Critical Reviews™ in Physical and Rehabilitation Medicine, 34(4):39–62 (2022)

Evaluation and Physiotherapy Management of Diaphragm Dysfunction in Patients Admitted to the Medical Critical Care Unit: A Review of the Literature

Hiranmayee Bagwe, Bela Agarwal,* & Rajani Mullerpatan

MGM School of Physiotherapy, MGM Institute of Health Sciences, Kamothe, Navi Mumbai-410209, Maharashtra, India

*Address all correspondence to: Bela M. Agarwal, Professor, MGM School of Physiotherapy, MGM Institute of Health Sciences, Kamothe, Navi Mumbai-410209, Maharashtra, India; Tel.: +919819000674, E-mail: bagarwal@mgmsopnm.edu.in

ABSTRACT: Difficulty in weaning from ventilators is a major challenge in rehabilitation of patients in the critical care unit (CCU). Diaphragm dysfunction is highly prevalent among patients admitted to the CCU and is associated with high mortality. Early identification of diaphragm dysfunction and its management is of prime importance to enable maximal clinical outcomes and early discharge from hospital. Hence, a review of literature was undertaken to explore evaluation methods used to identify diaphragm dysfunction and physiotherapy management strategies for prevention and early management of diaphragm dysfunction. A systematic literature search was performed using, PubMed, CINHAL, Cochrane Library and Google Scholar data bases. Keywords used were diaphragm dysfunction, physiotherapy, training, rehabilitation, intensive care unit, CCU. Twenty-two studies including systematic reviews, meta-analysis, narrative reviews, randomized controlled trials and cross-sectional studies were included in the review. Methods used to evaluate diaphragm dysfunction were diaphragm thickness fraction (ultrasonography and magnetic resonance imaging), electrical activity of diaphragm (surface EMG) and physical examination. Management strategies for strengthening diaphragm involved use of inspiratory muscle training (IMT), early physical activity, prone positioning, proprioceptive neuromuscular facilitation (PNF) of diaphragm and phrenic nerve stimulation. Strong evidence is available for efficacy of IMT and early mobilization as rehabilitation strategies. Lack of high level of evidence suggests the need for randomized controlled trials to evaluate efficacy of techniques such as prone positioning, respiratory PNF, abdominal and phrenic nerve stimulation on diaphragm dysfunction to enable inclusion of these techniques in existing treatment and weaning protocols in intensive-care units.

KEY WORDS: physiotherapy management, early diagnosis, respiratory function, physical function, critical care

ABBREVIATIONS: **CCU**, critical care unit; **DD**, diaphragm dysfunction; **EXdi**, diaphragm excursion; **ICU**, intensive care unit; **MV**, mechanical ventilation/ventilated; T_{di}, diaphragm thickness; **TFdi**, diaphragm thickening fraction; **SIDD**, sepsis-induced diaphragm dysfunction; **VIDD**, ventilator-induced diaphragmatic dysfunction

I. INTRODUCTION

Critical care unit (CCU)–acquired muscle weakness is strongly associated with increased physical functional impairments, short- and long-term morbidity, and

0896-2960/22/$35.00

mortality.[1] The number of mechanically ventilated (MV) patients in medical CCUs has increased dramatically over the past two decades. Currently in the United States, about 800,000 patients per year require MV with annual mortality exceeding 200,000.[2] Several studies have demonstrated that 60–80% of MV and intubated patients show clinically significant diaphragm dysfunction leading to prolonged MV and weaning failure and worsening of clinical outcomes.[3,4] Recent evidence suggests diaphragm dysfunction is twice as prevalent as limb weakness among critically ill patients.[3]

Causes of diaphragm dysfunction are multifactorial in nature.[5] Acute diaphragm injury and weakness may result from sepsis, trauma, systemic inflammation, or MV.[6] Ventilator-induced diaphragmatic dysfunction (VIDD) was previously defined as loss of diaphragmatic force-generating capacity specifically related to use of MVs. VIDD may typically be observed after variable periods of controlled MV.[7] The other potential causes of diaphragm weakness in mechanically ventilated patients is sepsis-induced diaphragm dysfunction (SIDD). Oxidative stress from infective pathologies damage mitochondrial electron transport chain subunits, contributing to reduction in muscle endurance, activation of proteolytic enzyme pathways leading to reduction in contractile proteins and consequent reduction in muscle strength.[3]

Diaphragmatic dysfunction is also a prevalent cause of mortality among patients with systemic neuromuscular disorders such as Guillain–Barré Syndrome, myasthenia gravis, amyotrophic lateral sclerosis or multiple sclerosis, in addition to critical illness polyneuropathy, critical illness myopathy, or critical illness neuromyopathy.[8]

Higher CCU mortality is known to correlate with diaphragm weakness. A study reported, 49% incidence of intensive care unit (ICU) death in patients with poor diaphragm muscle strength. In fact, it has been reported that diaphragm weakness is a more potent predictor of CCU mortality than the degree of organ failure, the severity of lung function abnormalities, or the comorbidity index among MV patients.[9]

Clinical signs suggestive of presence of diaphragm function abnormal were the earliest methods used for diagnosis of diaphragm dysfunction. Presence of abdominal paradox, a marked inward motion of abdomen during inspiration was considered as a cardinal sign of existence of severe diaphragm weakness or bilateral diaphragmatic paralysis.[9,10] Presence of diaphragm dysfunction was considered as a differential diagnosis for patients on MV with failed weaning trials despite clinical improvement in pulmonary infiltrates, lung examination, and several days of bronchodilator or antibiotic therapy to treat the underlying pulmonary disorder. High rapid shallow breathing index and observation of abnormality in chest radiograph suggests the possibility of diaphragm pathology.[3] Further, with development of instrumented diagnosis, methods such as invasive pulmonary function test (PFT), ultrasound and electromyography have been used for evaluation of structure and function of diaphragm.[11]

Moreover, rapid and detectable diaphragmatic atrophy in patients on controlled mandatory ventilation within 18–69 hours of treatment necessitates the need for early diagnosis of diaphragm dysfunction and treatment strategies for prevention. Muscle atrophy tends to be worse in patients ventilated with controlled modes compared to

spontaneous modes.[12,13] Inactivity-induced disuse muscle atrophy also results from decreased protein synthesis and increased protein degradation due to prolonged immobilization, effects of general anesthesia and disturbed redox signaling due to presence of infection.[12,13]

Existing systematic reviews reported medical management as mainstay of treatment for diaphragm dysfunction. Although, surgical techniques such as diaphragm pacing, plication of diaphragm and phrenic nerve stimulation are available, they require expertise and resources in additional to hemodynamic stability of the patient. Implementation of early physiotherapy techniques to improve lung hygiene and lung function is of substantial importance in early discharge from the CCU. Several studies have established the role of physiotherapy techniques in the CCU. Systematic reviews report improved respiratory muscle strength and endurance following inspiratory muscle training (IMT) in patients suffering from diaphragm dysfunction. Despite this emerging evidence, IMT is not a standard practice in most CCUs around the world.[13] Although respiratory muscle weakness is highly prevalent and manageable, standard treatment protocol for diaphragm dysfunction lacks definitive clinical evaluation methods that will aid in early diagnosis and management to improve diaphragm muscle strength. The present review aims to explore clinical evaluation methods and physiotherapy management techniques to prevent and treat diaphragm dysfunction. Early identification and timely intervention can potentially reduce associated morbidity and mortality in patients admitted in CCU.

II. MATERIALS AND METHODS

A. Database Source and Search

A systematic literature search was performed from January to June 2022 using the Cochrane Library, PubMed, Google Scholar, and CINAHL databases. Studies from the year of inception of the database until date were included in the review. Search using key words "diaphragm dysfunction," "physiotherapy," "intensive care unit," "rehabilitation, training," and "critical care unit" and Boolean operators "AND" and "OR" was undertaken. Titles and abstracts were screened based on the key words and relevant articles were further scrutinized for inclusion. Cross references from the identified articles were also included. PRISMA guidelines were followed for reporting findings of review as represented graphically in Fig. 1.

B. Inclusion Criteria

Articles published in English language from inception to 2022, including the keywords in title and abstract were screened for inclusion. Articles reporting diaphragm dysfunction in patients admitted to the CCU and articles discussing evaluation and physiotherapy techniques used for management of diaphragm dysfunction were included.

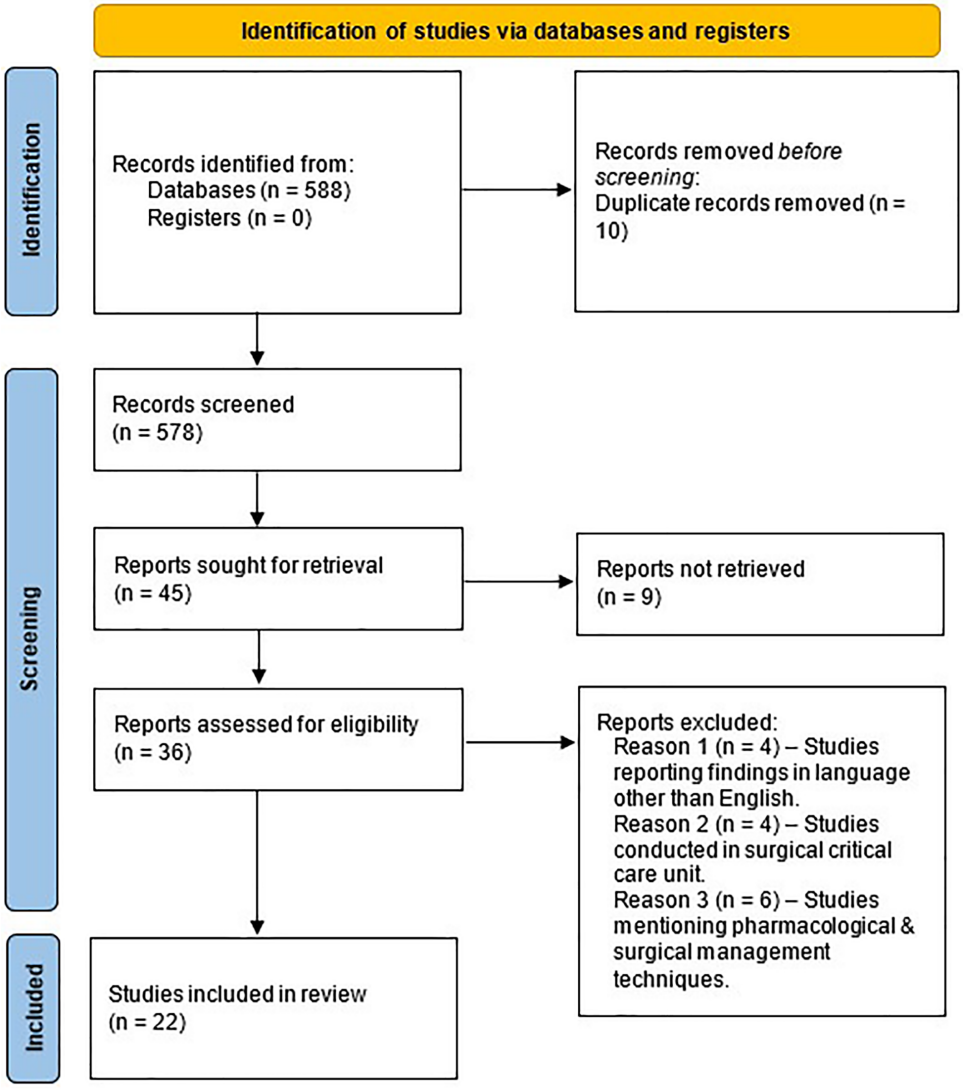


FIG. 1: PRISMA flowchart of methods used to identify studies from databases

C. Exclusion Criteria

Articles in languages other than English, articles discussing surgical management and studies not presenting the effect of physiotherapy management on diaphragm function were excluded. Level of evidence was assessed using PEDro scale for quality of evidence.

A total of 588 articles were identified on initial screening. After removal of duplicate articles, 578 article titles screened for inclusion. Forty-five articles were retrieved

further screening based on inclusion and exclusion criteria. Nine articles were not relevant to the review. From the 36 full text articles, 14 studies were excluded based on the exclusion criteria. Twenty-two relevant full text articles were included for the review.

III. RESULTS

All the studies included in the review were conducted on patients with diaphragm dysfunction admitted to the medical CCU. Out of the 22 articles included in current review, six studies were reviews and one a systematic review with meta-analysis presenting level I evidence; 15 were prospective studies, of which one study was randomized control trial (level II).

Among the 22 included studies, six articles were literature reviews. Of the remaining 16 articles, 14 articles were rated as fair quality and two articles were rated as poor quality on PEDro scale as presented in Table 1. Data reporting, patient characteristics, duration on mechanical ventilator, study setting, duration of ICU stay, methods used for evaluation of diaphragm and treatment techniques used are presented in Table 2.

In the current review, we observed the following methods of evaluation and physiotherapy management for early diagnosis and management of diaphragm dysfunction. Intubated as well as non-intubated patients on MV were studied. Average length of CCU stay was 15 days. Methods use to evaluate included physical examination, physiological and radiological evaluation. Physiotherapy treatment techniques observed were prone positioning, early mobilization, IMT and functional electrical stimulation (FES) in patients suffering from diaphragm dysfunction related to either ventilator, sepsis or neuromuscular pathology.

A. Evaluation

Detailed clinical evaluation is necessary to identify the etiology of diaphragm dysfunction, and to confirm the presence and severity of disease. Commonly used methods of evaluation were as follows.

B. Physical Examination

A single study with poor level of evidence suggested tests for evaluation of diaphragm function. Bordoni diaphragmatic test, a two-phased test, was performed with the patient standing with eyes closed. The patient was required to rhythmically raise one knee and then the other and, while flexing the thighs, an inhale deeply. The second phase of the test, included placing resistance on the knee each time the patient flexed the thigh. A wider inhalation movement was equated to a greater thickness of the diaphragm muscle, which was correlated with better respiratory function. The test was repeated, without deep breaths, in order to highlight the positive influence of the diaphragm. Reliability and validity of test was not reported.[14]

TABLE 1: Quality of evidence for studies included as per the PEDro scale

Author of article	Mercurio et al.	Saleem Khan et al.	Harlaar et al.	Jansen et al.	Krishnakumar et al.	Cammarota et al.	Trifi et al.	Samir et al.	Dong et al.	McCaughey et al.	Leite et al.	Zwolinski et al.
Eligibility criteria were specified	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Subjects were randomly allocated to groups	×	×	×	✓	×	×	×	✓	✓	✓	✓	✓
Allocation was concealed	×	×	×	×	×	×	×	×	×	×	×	×
The groups were similar at baseline regarding the most important prognostic indicators	✓	✓	✓	✓	×	×	×	×	✓	✓	×	×
There was blinding of all subjects	×	×	×	×	×	×	×	×	×	×	×	×
There was blinding of all therapists who administered the therapy	×	×	×	×	×	×	×	×	×	×	×	×
There was blinding of all assessors who measured at least one key outcome	×	×	×	×	×	×	×	×	×	×	×	×
Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
The results of between-group statistical comparisons are reported for at least one key outcome	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
The study provides both point measures and measures of variability for at least one key outcome	✓	✓	✓	✓	×	×	×	✓	✓	✓	✓	✓
Total score (level of evidence)	5 (fair)	5 (fair)	5 (fair)	6 (good)	6 (good)	3 (poor)	3 (poor)	5 (fair)	6 (good)	6 (good)	5 (fair)	5 (fair)

TABLE 2: Overview of articles included in the present review

Study	Design	Sample size	Patient population	Length of ICU stay (days)	Time of ventilator assistance (days)	Patient characteristics	Outcome measures and evaluation methods	Physiotherapy techniques used
Mercurio et al.	Experimental study	21	ARF requiring NIV treatment admitted to the emergency department	17	13	Respiratory rate ≥ 35 breaths per minute, PaO_2/FiO_2 < 200 with oxygen therapy through a Venturi mask or a High Flow Nasal Cannula, and active contraction of the accessory muscles of respiration or paradoxical abdominal motion during breathing	ratio between respiratory rate and DTF (respiratory rate/ DTF), Clinical outcomes - NIV weaning, ICU length of stay, respiratory rate and PaO_2	Not mentioned

TABLE 2: (*continued*)

Study	Design	Sample size	Patient population	Length of ICU stay (days)	Time of ventilator assistance (days)	Patient characteristics	Outcome measures and evaluation methods	Physiotherapy techniques used
Saleem et al.	Cohort study	8	Tracheostomies *in situ* and were fully liberated from the ventilator before having MRI scans		25	Patients requiring inspired fraction of oxygen (FiO_2) < 40% by a tracheostomy mask; patients on pressure support ventilation or continuous positive airway pressure for at least 24 hrs; no significant electrolyte or metabolic abnormalities, or fever	3.0 Tesla Philips Achieva MRI system, equipped with 32 RF receiver channels - sagittal and coronal dynamic MRI	Not mentioned
Harlaar et al.	Cross-sectional exploratory study	12	Confirmed diagnosis of either a myopathy (other than Pompe disease) or motor neuron disease			Signs of respiratory muscle weakness defined as a vital capacity < 80% of predicted using spirometry	3 Tesla Signa 750 MRI system - 2D and 3D MRI imaging	Not mentioned

TABLE 2: (*continued*)

Jansen et al.	Prospective cohort study	15	Adult ventilated patients	26	24		Neuromuscular efficiency index and electrical activity of diaphragm	Not mentioned
Krishnakumar et al.	Experimental study	8	Guillain–Barre syndrome (GBS) or myasthenia gravis		25	age > 18 years and patients who required MV for > 7 days	Electrical activity of diaphragm, diaphragm thickness fraction, diaphragm excursion, respiratory rate, $EtCO_2$	Not mentioned
Cammarota et al.	Randomized control trial	20	All adult patients, admitted to ICU with moderate-to severe COVID-19-related ARDS undergoing NIV combined to cycles of prone position			Laboratory confirmation for infection by severe acute respiratory syndrome coronavirus	Diaphragm ultrasound, Inspiratory thickness, Expiratory thickness, thickening fraction, lung ultrasound score	Awake prone positioning protocol

TABLE 2: (*continued*)

Study	Design	Sample size	Patient population	Length of ICU stay (days)	Time of ventilator assistance (days)	Patient characteristics	Outcome measures and evaluation methods	Physiotherapy techniques used
Trifi et al.	Randomized control trial	40	Adult intubated patients			Ventilator modes on assisted control volume with a low trigger flow	Ultrasonographic measurements: End inspiratory diameters, end expiratory diameter changes, diaphragm thickening fraction	60 mins of prone positioning
Samir et al.	Randomized control trial	60	COPD, stage III		2–5 days	Dyspnea, chronic cough and expectorations, with forced expiratory volume in one second (FEV1sec) < 70% of predicted value, tachypnea 22 to 28 breathes per minute, PaO_2 ranged from 29 to 73 mmHg and $PaCO_2$ ranged from 24 to 94 mmHg	Blood-Gas analyzer at the beginning of the session and after session for 5 consecutive days	Group A – Prone positioning; Group B – Diaphragm release technique

TABLE 2: (*continued*)

Dong et al.	Randomized control trial	39	Adult patients on prolonged MV			Prolonged MV (> 72 h); stable oxygen saturation, fraction of inspired oxygen ≤ 55%, and positive end expiratory pressure (PEEP) ≤ 8 cmH_2O; dose of dopamine < 10 μg/kg/min and dose of epinephrine < 0.4 μg/kg/min; mean arterial pressure > 75 mmHg and urine output > 1 mL/kg/h; good healing of the incision after surgery; normal cognitive function; and no history of chronic mental illness or chronic obstructive pulmonary disease	Diaphragm excursion, diaphragm thickening fraction	Rehabilitation therapy in six level of gradual mobilization

TABLE 2: (*continued*)

Study	Design	Sample size	Patient population	Length of ICU stay (days)	Time of ventilator assistance (days)	Patient characteristics	Outcome measures and evaluation methods	Physiotherapy techniques used
McCaughey et al.	Randomized control trial	20	Critically ill MV patients	11	7	≥ 18 years of age and dependent on MV due to critical illness	Respiratory function, clinical outcomes - ventilation duration, ICU length of stay	Stimulation was applied for 30 minutes, twice per day for 5 days a week over transversus abdominis, internal and external oblique muscles
Leite et al.	Randomized control trial	41	Critically ill MV patients	13	16	18 years or more and 24 hours or more of MV	Peripheral and respiratory muscle strength, FSS-ICU scale	Application of the neuromuscular electrical stimulation in the diaphragm was Aussie current, frequency of 30 Hz, 1 s pulse of muscle contraction period, 1 s pulse decrease period, and 20 s of disconnection period

TABLE 2: (*continued*)

Zwolinski et al.	Randomized control trial	27	Critically ill MV patients		8	Adults of both sexes, conscious and cooperative, MV in assisted ventilation mode, haemodynamically stable	Heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and percutaneous oxygen saturation (SpO_2)	Proprioceptive Neuromuscular Facilitation (PNF)

ARDS, acute respiratory distress syndrome; ARF, acute respiratory failure; FiO_2, inspired fraction of oxygen; PaO_2, Partial pressure of arterial oxygen; RF, respiratory failure.

In another study, an alternative method of inspiratory muscle strength assessment was used in ICU patients. In the Marini method, the patient exhaled for 25 s through a one-way valve to reach true residual volume before maximal inhalation. A maximum inspiratory pressure (MIP) score of < 30 cmH_2O was considered indicative of inspiratory muscle weakness which influence weaning from ventilator and functional recovery. Reliability and validity of Marini test is not reported. This necessitates need for exploring and evaluating physical examination tests using robust scientific techniques.[15]

C. Physiological Evaluation

1. PFT

Diaphragm contraction is an essential component responsible for maintaining pulmonary pressures within thorax. Direct invasive tests provide confirm diagnosis with staging of dysfunction. Multiple studies report the use of invasive pulmonary tests include esophageal pressure (Pes) and transdiaphragmatic pressure (Pdi) measurement by estimating the difference between Pes (intrathoracic pressure) and gastric pressure (Pga) (intra-abdominal pressure) [Pdi = Pes − Pga]. A Pdi of 0 is considered confirmatory of bilateral diaphragmatic paralysis. However, some researchers have established the cut-off point at < 10 mm Hg.[16] Pdi, reportedly predicts extubation duration better than MIP. Successful extubation is anticipated at Pdi values of –30 cmH_2O. A Pdi of > 10 cmH_2O with unilateral phrenic nerve stimulation or > 20 cmH_2O with bilateral phrenic nerve stimulation rules out diaphragmatic dysfunction.[17]

Four studies report the use of indirect PFTs such as determination of maximum static pressures during inspiration (MIP) and expiration [maximum expiratory pressure (MEP)] with airway closed for evaluation of respiratory muscle weakness.[16–19] It is considered a reasonable method for measuring the force generated jointly by the inspiratory and expiratory muscles. Normal MEP combined with low MIP suggests the existence of isolated weakness of the diaphragm. Concomitant reduction of MIP and MEP suggests that diaphragmatic involvement due to a generalized process, with simultaneous involvement of the inspiratory and expiratory muscles. In percentage values, MIP is around 60% of the predicted value in unilateral affectation vs. 40% in bilateral dysfunction. Nasal sniff maneuver to determine inspiratory pressures through the nose which involved performance of rapid voluntary inspiratory effort through the nasal passages. The test was considered useful for evaluating strength of the diaphragm in clinical practice due to its feasibility and portability. Pressure values < 70 mm Hg in men and 60 mm Hg in women were likely to be associated with significant inspiratory muscle weakness.[16,17]

2. Electrophysiological Tests

Five studies report the use of magnetic stimulation of the phrenic nerve as the gold standard method for the quantification of the mechanical function of the diaphragm which is measured by calculating the negative pressure generated by diaphragm contraction in

response to the stimulation of the phrenic nerve.[16,17,19] Transcutaneous electrical phrenic stimulation was performed at the level of the neck unilaterally or bilaterally. However, this technique caused patient reported discomfort and was technically difficult in obese patients. The magnetic stimulation of phrenic nerve was usually applied bilaterally at the level of the cervical spine. A Twitch Pdi < 10–20 cm H_2O is considered suggestive of diaphragmatic dysfunction.[16]

Some researchers have used the traditional method of electromyography activity of the diaphragm to measure phrenic nerve latencies and amplitudes of muscle compound action potentials. In some neuromuscular disorders such as demyelinating polyneuropathies, latencies are delayed due to slow phrenic nerve conduction (6–8 m/s in healthy adults). A lack of muscle action potential after phrenic stimulation is suggestive of diaphragmatic paralysis with a lesion near or at the neuromuscular junction.[16]

A randomized controlled trial reported a standard weaning protocol followed with spontaneous breathing trials. For measuring electrical activity of diaphragm (Edi) a catheter was inserted via nasogastric tube and connected via a cable to the neurally adjusted ventilatory assist module of a SERVO-i ventilator (MAQUET, Solna, Sweden). TFdi showed significant reduction by a magnitude of 2.98% every 30 min of weaning; but no change over number of days of weaning. A significant increase in diaphragm excursion were observed and leads to a successful breathing trial.[20,21] The neuromuscular efficiency index (NME) can be used to estimate inspiratory effort; however, its reliability has not been investigated yet. There was moderate correlation reported between Edi and NME ($r = -0.90$ to $r = 1.0$).[22]

D. Radiological Evaluation

1. Ultrasonography

Multiple studies report the use of Ultrasonographic evaluation of the diaphragm.[2–4,16–20] The technique is simple, non-invasive and readily available tool at the bedside. Studies report that static measurement of diaphragm thickness (Tdi), dynamic evaluation of inspiratory diaphragm thickening fraction (TFdi) and excursion (EXdi). Diaphragm thickening fraction correlates with pressure-generating capacity of diaphragm, work of breathing and respiratory effort (correlation coefficient reported 0.35). A literature review reported use of diaphragm thickening fraction to identify diaphragm dysfunction, monitor temporal changes and predict weaning outcomes in patients with invasive or non-invasive ventilation admitted in CCU. Diaphragm thickening fraction value < 20% and diaphragm thickness value < 2 mm was considered as a diagnostic marker for diaphragm paralysis. The normal lower limit accepted for diaphragm thickening fraction was 20%.[16] Higher diaphragm thickening fraction was reported in the first 96 hrs of post successful non-invasive ventilation (NIV) weaning compared with NIV failure and lower respiratory rate/Tdi.[22] Diaphragm excursion using curvilinear probe positioned over infra-hepatic region. Diaphragm excursion was reproducible and related to transdiaphragmatic pressure and weaning outcome in intubated patients.[19]

A meta-analysis reported that diaphragm excursion values between 7 and 27 mm predict weaning failures. The B-mode ultrasonography was useful in evaluating fiber morphometry in relaxation as well as in respiratory maneuvers whereas the M-mode quantified the direction and amplitude of the diaphragm excursion during inhalation.[17]

Recent ultrasonography method of two-dimensional speckle tracking imaging measures have been used to study contraction-associated longitudinal muscle shortening. Previous modes of ultrasonography employed techniques to measure diaphragm thickening which is poor indicator of dysfunction as compared to muscle shortening. Strain value of –30% indicates local muscle fiber shortening by 30%. The more negative the number, greater the deformation and greater the contraction.[20]

A literature review reported the use of ultrasound shear wave elastography imaging method that allows real-time quantification of tissue mechanical properties and relies on the estimation of the propagation velocity of shear waves generated inside tissues. Shear modulus (SMdi) of the diaphragm was reported to increase along with increase in airway pressures (Paw) with positive correlation between SMdi and mouth pressures ($r^2 = 0.99 \pm 0.01$).[20] Ultrasonography has a high sensitivity (93%) and specificity (100%) for diaphragmatic neuromuscular disease.[14]

2. Radiological Imaging

Six studies reported use of chest radiographs to detect diaphragm dysfunction.[2–4,16,17,19] Ricoy et al. reported sensitivity, specificity, and positive and negative predictive value for the diagnosis of unilateral diaphragmatic paralysis are 90%, 44%, 33%, and 93% respectively using radiographs.[16] An elevated hemidiaphragm was suggestive of unilateral phrenic nerve paralysis. However, it was difficult to detect diaphragm elevation in patients with bilateral paralysis.[16]

A study reports the use of static magnetic resonance imaging (MRI) to assess the shape, position, thickness and surface area of diaphragm. Advanced imaging technique of dynamic MRI was used to study the mechanisms responsible for the diaphragm's shape at functional residual capacity, diaphragm motion in different body postures and to quantify the volume displaced by the contraction of the diaphragm.[20]

E. Physiotherapy Management

1. Prone Positioning

Three studies report the use of prone positioning for improving lung ventilation.[23–25] In ventilated patients, prone position is reported to improve thoraco-pulmonary compliance resulting from the release of the posterior regions. The mean end inspiratory diameter decreased (2.8 mm [2.4–3.19] in supine position vs. 2.45 mm [2.24–2.95] in prone position). Maximum TFdi was showed with the posterior level (posterior: 45%, median: 31% and anterior: 38%).[23] Inspiratory diaphragmatic thickness and diaphragmatic thickening fraction increased moving from supine to prone position (inspiratory diaphragmatic

thickness; diaphragmatic thickening fraction). Application of awake prone positioning did not show any improvement in expiratory thickness of the diaphragm.[24]

2. Diaphragmatic Release Technique

One study reports the use of diaphragmatic release technique which involves application of a low load of myofascial stretch for long duration. With application of 6 treatments on non-consecutive days for 2 weeks of diaphragm release technique, residual volume decreased from 4.5 to 3.9 L, inspiratory capacity increased from 2.0 to 2.1 L and SpO_2 increased from 93% to 96% in patients admitted to ICU with chronic obstructive pulmonary disease (COPD) exacerbation. The manual diaphragm release technique improved diaphragmatic mobility, exercise capacity and inspiratory capacity in people with chronic obstructive pulmonary disease admitted to ICU.[25]

Level 1a evidence for IMT in diaphragm dysfunction, level 2a evidence on Sackett for physiotherapy management techniques of early activity, FES and prone positioning were included in this review.

3. IMT

Evidence suggests IMT improves respiratory muscle performance and weaning outcomes. Studies have reported the use of inspiratory resistance devices placed at the end of endotracheal or tracheal tubes to provide training stimulus. Inspiratory pressure generated across a resistive load is proportional to the inspiratory airflow. Whereas, threshold inspiratory devices provide pressure overload that is not dependent upon the inspiratory flow. Other approaches included flow resistive training, diaphragmatic breathing exercises, and biofeedback on respiratory patterns such as rapid shallow breathing and relaxed breathing patterns. They also describe effects of these training methods individually.[26]

A study reported improved maximal inspiratory pressure measured at the tracheal tube by approximately 71% of the inspiratory muscle strength after training for 2 weeks of high pressure, low repetition training program (four sets of six to 10 inspiratory efforts daily, 5 days/week at the maximal pressure tolerated). Control group's maximal inspiratory pressure increased 47% compared to study group. The differences in maximal inspiratory pressure and weaning outcome between the intervention and control groups were significant.[26,27] An intensity of minimum 50% of MIP was well-tolerated, although in practice this should be considered the minimum training threshold. With improvement in inspiratory muscle strength, the intensity should be increased incrementally in the magnitude of 1–2 cmH_2O every 1–2 days.[13,15]

4. Early Physical Activity

Prolonged immobilization and inactivity in addition to steroid induced myopathies lead to skeletal muscle as well as diaphragm atrophy. Studies have shown that skeletal

muscle fiber area decreases by 2–4% per day in the CCU, with atrophy occurring within days of onset of critical illness.[5,6,12] A recent randomized clinical trial showed that implementation of early physiotherapy resulted in improved physical function and a reduced duration of delirium in critically ill patients.[12] Early physical activity intervention was combined with daily sedation interruptions and protocol-driven breathing trials resulting in improved breathing without assistance.[12] Another randomized controlled trial reported a novel rehabilitation program for implementation of early physical activity in ICU patients. Rehabilitation therapy consisted of six levels: level 0: turning over once every 2 hours for unconscious patients with unstable vital signs where level 1–2 included maintaining joint range of motion to prevent muscle atrophy at least 20 min, three times a day, level 3 included sitting on the edge of the bed for patients who could perform upper-limb anti-gravity training, in level 4 patients who could perform lower-limb anti-gravity training performed standing up or sitting in a chair for at least 20 min a day and in level 5, patients actively moved from the bed and walked bedside.[28]

Level 1–5 exercises were observed to be suitable for conscious patients. Level 1–3 exercises were implemented for intubated patients, while level 3–5 exercises was implemented for patients with tracheotomy. The two groups were assessed for diaphragm excursion and TFdi using ultrasonography at 1 day and 4 days of MV. Before rehabilitation therapy, there was no significant difference in diaphragm excursion and diaphragm thickness fraction between both groups on first day of MV. At 4-day of MV, the rehabilitation group demonstrated significantly decreased TFdi compared to the control group (0.15 ± 0.06 g vs. 0.12 ± 0.05 g). These results reveal that early rehabilitation training can reduce diaphragm dysfunction caused by prolonged MV.[28]

5. Functional Electrical Stimulation (FES)

Two studies report the use of FES, the application of electrical pulses to a motor nerve, causing muscle contraction in the associated muscle.[29,30] A pilot study showed that FES of the rectus abdominis and pectoral muscles maintained respiratory muscle thickness to a greater degree than sham stimulation and shortened the length of ICU stay. Stimulation was applied for 30 min, twice per day, 5 days per week until discharge from the ICU via surface electrodes. Electrodes were placed postero-laterally over the abdominal wall to activate the transversus abdominis and internal and external oblique muscles. Stimulation was applied during exhalation using a commercially available abdominal FES device with automatic synchronization with the participant's breathing. Intervention group received abdominal FES at an intensity causing strong visible muscle contraction (median 60 mA [range 50–65 mA]), with a frequency of 30 Hz and a pulse width of 350 μs. Control (sham stimulation) group stimulation current was set at 10 mA with no visible abdominal muscle contraction, with a frequency of 10 Hz and a pulse-width of 350 μs. Ventilation duration (median 6.5 versus 34 days) and ICU length of stay (median 11 versus not estimable days) were shorter in the intervention group as compared to the control (sham stimulation) group.[29]

In another study, neuromuscular electrical stimulation of quadriceps muscle presented better results in compared MV duration, MIP, Barthel index, and functional status with diaphragm and control group. Although, recent studies have reported an increase in respiratory muscle strength with electrical stimulation of the diaphragm. However, the study was conducted in non-hospitalized patients.[30]

IV. DISCUSSION

The current review, reports evaluation and physiotherapy management techniques for diaphragm dysfunction in patients admitted to medical CCU. Timely identification of respiratory muscle weakness using robust, reproducible results can lead to early implementation of interventional strategies to decrease morbidity and mortality in artificially ventilated patients.

The review identifies paucity of literature on physical tests evaluating isolated diaphragm function. Bordoni test and Marini's test for clinical evaluation of diaphragm dysfunction are not well established and reliability and validity of these tests has not been reported. Thus, more robust studies exploring clinical evaluation methods for diagnosis of diaphragm dysfunction are needed.

PFTs and radiological imaging are the second most preferred modes of evaluation. Invasive methods of pressure assessment provide a direction and accurate clinical picture. Primary drawback of volitional clinical assessment such as PFT is the high level of dependency on cooperation and effort of the patient, which is difficult to achieve in patients admitted to ICU.[16]

Gold standard method of evaluation of diaphragm dysfunction is phrenic nerve stimulation that measures contractile capacity of diaphragm. However, this technique causes considerable patient discomfort and is technically more difficult in obese patients. Recent techniques of application of neurally adjusted ventilatory assist during a spontaneous breathing trial can aid in ventilation liberation model of ICU care and prevent diaphragm dysfunction due to prolonged MV.[21] The main advantage of monitoring diaphragm function by surface EMG is that it is continuous and noninvasive. However, electrical noise from the electrical conduction of heart, neighboring skeletal muscle activity and electromagnetic interferences from multiple machines operating make surface EMG difficult to implement in CCU. Edi values are difficult to interpret; as very limited data is currently available concerning normative values. Strong correlation has been reported between Electrical activity of diaphragm and Transdiaphragmatic pressure suggesting, NME ratio could be used to estimate inspiratory effort on breath-by-breath analysis. However, reliability of neuromechanical efficiency ratio has been questioned recently and requires further scientific exploration.[31]

Considerable evidence pertinent to evaluation and diagnosis of diaphragm dysfunction employing Ultrasonography as primary tool of evaluation is available. B-mode and M-mode ultrasound imaging were methods of choice for early diagnosis of diaphragm dysfunction. While M-mode is ideal in CCU patients with acute respiratory failure as it enables early goal-directed ultrasound examination, the technique is not applicable for

patients who are on MV. As excursion measured with M-mode (in centimeters) represents the composite score of diaphragmatic contraction plus pressure applied by mechanical ventilator. In such cases, B-mode ultrasound aids direct visualization of the diaphragm's thickness in its zone of apposition.[4]

Dynamic imaging methods of measuring inspiratory diaphragm thickening fraction (TFdi) and excursion (EXdi) are more sensitive and specific compared to previously reported outcome measure of static modes of US imaging such as diaphragm thickness.[16,19] Newer methods of two-dimensional speckle tracking and Shear wave elastography provide with an estimate of muscle contraction and tissue mechanical properties respectively. These methods aid in greater understanding of biomechanical pathophysiology of diaphragm dysfunction which were not offered using previous methods. Ultrasonography is conventionally considered a superior method of evaluation as compared to other methods for the prediction of diaphragm dysfunction. Factors contributing towards the success of this method are ability to provide serial, non-invasive data at the point of care (i.e., at the bedside of critically ill patients in CCU) and enabling the evaluation of diaphragmatic function over time. Limitations identified for accurate diagnosis of diaphragm dysfunction using ultrasonography are poor acoustic window (occurs in about 2–10% of cases), variability in diaphragm thickness at different levels of intercostal space, and variable reproducibility (18%) and repeatability (8%) in reporting of TFdi%. Although proven superior over older methods of ultrasonography imaging, these newer methods require expertise and special training.[4,15,17]

Chest radiographs are easy and most feasible tool of evaluation in CCU for detection of DD. Although, most widely available, chest radiographs provide nonspecific findings that are indicative of other pathologies like atelectasis, pneumonia, lobectomy and pulmonary fibrosis. However, chest radiographs pose difficulty in detecting bilateral diaphragm paralysis. MRI emerges as a better tool to detect asymmetrical and disproportional involvement of diaphragm. Limited downwards motion and increased diaphragmatic curvature in the thorax indicate diaphragmatic dysfunction, while limited anterior motion of thoracic wall indicates weakness of intercostal muscles.[32] Thereby, Dynamic MRI is reported effective alternative to overcome the shortcoming of radiological imaging in diaphragm dysfunction.[20] Moreover, MRI might be able to detect a decreased diaphragmatic function when PFTs are still in the normal range. However, the limited motion of the thoracic wall can also be caused by a decreased compliance increased stiffness. MRI is relatively expensive and time-consuming and necessitates maximum breathing performance of the patient within the MRI machine.[32,33]

Although several management techniques have been used in patients with diaphragm dysfunction, IMT was most commonly preferred mode of treatment. Prone position helps improving oxygenation, and improved mobility in posterior and lateral regions. Beneficial changes are reported after minimum 1 hour of prone position thereby, posing difficulty as it requires additional manual labor. It was also suggested in a study, motion was non-uniform in prone with motion mostly occurring in the dorsal i.e non-dependent regions. Proprioceptive Neuromuscular Techniques such as Diaphragm release although

reported benefits and improvement in diaphragm function, validity and reliability of the technique necessitates further exploration.[34]

IMT helped improving inspiratory muscle strength and quality of life post discharge.[13] IMT in general when applied in various patient populations shows beneficial effects on diaphragm function, functional exercise capacity, and fatigue.[35]

A study reported simple diaphragmatic breathing exercises with IMT can significantly increase the recruitment of the diaphragm as compared with simple IMT application. Concluding with questionable reliability in advantages of IMT strategy for diaphragm function.[35]

A randomized controlled trial reported no significant impact on weaning time or successful weaning rates when IMT was implemented in tracheostomized patients.[36,37] Through a scientific perspective, Shei et al. conclude that, despite decades of research and evidence on IMT, some studies showing clear benefit and others show no benefit. This demands for personalized, and tailored IMT training and not a generalized training protocol.[38,39]

Effects of physical activity on diaphragm has not been reported directly but as a part of inspiratory muscle group. Early activity reverses the effects of inactivity and immobilization on myofibrils of diaphragm, thereby improving muscle function.[28] A randomized controlled trial reported early mobilization can delay diaphragmatic atrophy and systolic dysfunction in patients who are MV.[40] Although beneficial, there are studies reporting no significant change in CCU discharge rate, reduction in CCU days of stay. These variations could be attributed to difference in study population and setting. However, it warrants further robust studies exploring direct effects of early mobilization and physical activity in patients admitted to CCU.[41]

Phrenic nerve stimulation is invasive technique that involves pacing of phrenic nerve and inducing diaphragm contraction. Evidence suggests it reduces the rate of diaphragm atrophy during MV and leads to an increase diaphragm thickness.[34] On the other hand, FES is a noninvasive technique applied at abdominal muscles can achieve desired effects on diaphragm function with much ease and comfort. Abdominal FES did not result in increased diaphragm thickness, but it did reduce CCU length of stay and ventilator dependence. We recommend further exploratory studies to be conducted to examine the effect of the same.[29]

In summary, diaphragm dysfunction is prevalent in about 60% of critically ill ventilated patients within 24 hours after CCU admission. The current review explores existing methods of evaluation and management of diaphragm dysfunction. Existing evidence suggests that robust evaluation methods comprising of ultrasonography, surface EMG and MRI are useful in identifying diaphragm dysfunction. However, these investigations place a considerable demand on resources. Poor level of evidence of physical examination tests warrants the dire need of developing bedside physical examination methods for early identification of diaphragm dysfunction. This will aid early diagnosis of diaphragm dysfunction independent from need of additional high-end diagnostic resources which may not be available across hospital settings with financial constraints.

Benefits of physiotherapy management in improving respiratory muscle strength and endurance in critically ill patients admitted to the ICUs is established with fair level of evidence. physiotherapy and other health-care professionals working in the ICUs can adopt these techniques for maximization of respiratory function and early weaning off artificial ventilation. However, more research is required in this area of rehabilitation to generate high quality evidence. The current review was limited to studies reported in English language and patients admitted to medical CCU. The effect of physiotherapy management techniques in patients with diaphragm dysfunction in presence of surgical conditions was not reviewed.

V. CONCLUSION

The review informs methods used to evaluate diaphragm dysfunction. Ultrasonography, magnetic resonance imaging, surface electromyography and physical examination were the most commonly used evaluation tools. Management strategies for strengthening diaphragm involved use of IMT, early physical activity, prone positioning, proprioceptive neuromuscular facilitation of diaphragm, and phrenic nerve stimulation. Strong evidence is available for efficacy of IMT and early mobilization in improving respiratory muscle strength and functional recovery of patients admitted in the CCU, suggesting the need to include these techniques in existing treatment and weaning protocols used in intensive-care units.

REFERENCES

1. Sommers J, Engelbert RH, Dettling-Ihnenfeldt D, Gosselink R, Spronk PE, Nollet F, van der Schaaf M. Physiotherapy in the intensive care unit: An evidence-based, expert driven, practical statement and rehabilitation recommendations. Clin Rehab. 2015;29(11):1051–63.
2. Supinski GS, Ann Callahan L. Diaphragm weakness in mechanically ventilated critically ill patients. Crit Care. 2013;17(3):R120.
3. Supinski GS, Morris PE, Dhar S, Callahan LA. Diaphragm dysfunction in critical illness. Chest. 2018;153(4):1040–51.
4. Vetrugno L, Guadagnin GM, Barbariol F, Langiano N, Zangrillo A, Bove T. Ultrasound imaging for diaphragm dysfunction: A narrative literature review. J Cardiothorac Vasc Anesth. 2019;33(9):2525–36.
5. Saccheri C, Morawiec E, Delemazure J, Mayaux J, Dubé BP, Similowski T, Demoule A, Dres M. ICU-acquired weakness, diaphragm dysfunction and long-term outcomes of critically ill patients. Ann Intensive Care. 2020;10(1):1.
6. Dres M, Goligher EC, Heunks L, Brochard LJ. Critical illness-associated diaphragm weakness. Intensive Care Med. 2017;43(10):1441–52.
7. Berger D, Bloechlinger S, von Haehling S, Doehner W, Takala J, Z'Graggen WJ, Schefold JC. Dysfunction of respiratory muscles in critically ill patients on the intensive care unit. J Cachexia Sarcopenia Muscle. 2016;7(4):403–12.
8. Vanhorebeek I, Latronico N, Van den Berghe G. ICU-acquired weakness. Intensive Care Med. 2020;46(4):637–53.
9. Tobin MJ, Laghi F, Jubran A. Ventilatory failure, ventilator support, and ventilator weaning. Compr Physiol. 2012;2(4):2871–921.
10. Laghi F, Tobin MJ. Disorders of the respiratory muscles. Am J Respir Crit Care Med. 2003;168(1):10–48.

11. Dres M, Demoule A. Diaphragm dysfunction during weaning from mechanical ventilation: An underestimated phenomenon with clinical implications. Crit Care. 2018;22(1):73.
12. Mendez-Tellez PA, Needham DM. Early physical rehabilitation in the ICU and ventilator liberation. Respir Care. 2012;57(10):1663–9.
13. Bissett B, Leditschke IA, Green M, Marzano V, Collins S, Van Haren F. Inspiratory muscle training for intensive care patients: A multidisciplinary practical guide for clinicians. Australian Crit Care. 2019;32(3):249–55.
14. Bruno B, Escher AR. Functional evaluation of the diaphragm with a noninvasive test. J Osteopath Med. 2021;121(11):835–42.
15. Bissett B, Gosselink R, Van Haren FM. Respiratory muscle rehabilitation in patients with prolonged mechanical ventilation: A targeted approach. Crit Care. 2020;24(1):103.
16. Ricoy J, Rodríguez-Núñez N, Álvarez-Dobaño JM, Toubes ME, Riveiro V, Valdés L. Diaphragmatic dysfunction. Pulmonology. 2019;25(4):223–35.
17. del Mar Sánchez Sánchez C, Molina-Peña ME, Rodriguez-Triviño CY. Comprehensive assessment of respiratory function, a step towards early weaning from the ventilator. Adv Respir Med. 2021;89(3):299–310.
18. Mercurio G, D'Arrigo S, Moroni R, Grieco DL, Menga LS, Romano A, Annetta MG, Bocci MG, Eleuteri D, Bello G, Montini L. Diaphragm thickening fraction predicts noninvasive ventilation outcome: A preliminary physiological study. Crit Care. 2021;25(1):219.
19. Dubé BP, Dres M. Diaphragm dysfunction: Diagnostic approaches and management strategies. J Clin Med. 2016;5(12):113.
20. Laghi FA, Saad M, Shaikh H. Ultrasound and non-ultrasound imaging techniques in the assessment of diaphragmatic dysfunction. BMC Pulm Med. 2021;21(1):85.
21. Krishnakumar M, Muthuchellappan R, Chakrabarti D. Diaphragm function assessment during spontaneous breathing trial in patients with neuromuscular diseases. Neurocrit Care. 2021;34(2):382–9.
22. Jansen D, Jonkman AH, Roesthuis L, Gadgil S, van der Hoeven JG, Scheffer GJ, Girbes A, Doorduin J, Sinderby CS, Heunks L. Estimation of the diaphragm neuromuscular efficiency index in mechanically ventilated critically ill patients. Crit Care. 2018;22(1):238.
23. Trifi A, Abdellatif S, Abdennebi C, Daly F, Touil Y, Ben Lakhal S. Ultrasound variations of diaphragm activity between prone position versus supine position in ventilated patients: A cross-sectional comparative study. J Ultrasound. 2021;24(4):447–55.
24. Cammarota G, Rossi E, Vitali L, Simonte R, Sannipoli T, Anniciello F, Vetrugno L, Bignami E, Becattini C, Tesoro S, Azzolina D. Effect of awake prone position on diaphragmatic thickening fraction in patients assisted by noninvasive ventilation for hypoxemic acute respiratory failure related to novel coronavirus disease. Crit Care. 2021;25(1):305.
25. Samir A, Isaac ZZ, Nassif NL, Youssef M. Effect of prone position versus diaphragmatic release in patients with COPD in ICU. Med J Cairo Univ. 2020;88(3):1279–85.
26. Vorona S, Sabatini U, Al-Maqbali S, Bertoni M, Dres M, Bissett B, Van Haren F, Martin AD, Urrea C, Brace D, Parotto M. Inspiratory muscle rehabilitation in critically ill adults. A systematic review and meta-analysis. Ann Am Thorac Soc. 2018;15(6):735–44.
27. Martin AD, Smith BK, Gabrielli A. Mechanical ventilation, diaphragm weakness and weaning: A rehabilitation perspective. Respir Physiol Neurobiol. 2013;189(2):377–83.
28. Dong Z, Liu Y, Gai Y, Meng P, Lin H, Zhao Y, Xing J. Early rehabilitation relieves diaphragm dysfunction induced by prolonged mechanical ventilation: A randomized control study. BMC Pulm Med. 2021;21(1):106.
29. McCaughey EJ, Jonkman AH, Boswell-Ruys CL, McBain RA, Bye EA, Hudson AL, Collins DW, Heunks L, McLachlan AJ, Gandevia SC, Butler JE. Abdominal functional electrical stimulation to assist ventilator weaning in critical illness: A double-blinded, randomised, sham-controlled pilot study. Crit Care. 2019;23(1):261.
30. Leite MA, Osaku EF, Albert J, Costa CR, Garcia AM, Czapiesvski FD, Ogasawara SM, Bertolini GR,

Jorge AC, Duarte PA. Effects of neuromuscular electrical stimulation of the quadriceps and diaphragm in critically ill patients: A pilot study. Crit Care Res Pract. 2018;2018:4298583.
31. Dres M, Demoule A. Monitoring diaphragm function in the ICU. Curr Opin Crit Care. 2020;26(1):18–25.
32. Harlaar L, Ciet P, van Tulder G, Brusse E, Timmermans RG, Janssen WG, de Bruijne M, van der Ploeg AT, Tiddens HA, van Doorn PA, van der Beek NA. Diaphragmatic dysfunction in neuromuscular disease, an MRI study. Neuromusc Disord. 2022;32(1):15–24.
33. Saleem Khan K, Meaney J, Martin-Loeches I, Collins DV. MRI assessment of global and regional diaphragmatic motion in critically ill patients following prolonged ventilator weaning. Med Sci. 2019;7(5):66. doi: 10.3390/medsci7050066. PMID: 31121866; PMCID: PMC6571928.
34. Dong Z, Liu Y, Gai Y, Meng P, Lin H, Zhao Y, Xing J. Early rehabilitation relieves diaphragm dysfunction induced by prolonged mechanical ventilation: A randomized control study. BMC Pulm Med. 2021;21(1):106.
35. Wang LY, Yang PY, Chen YJ, Wu HD, Huang YH, Hsieh CH. Inspiratory muscle training attenuates irradiation-induced diaphragm dysfunction. Am J Transl Res. 2019;11(9):5599–610.
36. Ramsook AH, Koo R, Molgat-Seon Y, Dominelli PB, Syed N, Ryerson CJ, Sheel AW, Guenette JA. Diaphragm recruitment increases during a bout of targeted inspiratory muscle training. Med Sci Sports Exerc. 2016;48(6):1179–86.
37. Zwoliński T, Wujtewicz M, Szamotulska J, Sinoracki T, Wąż P, Hansdorfer-Korzon R, Basiński A, Gosselink R. Feasibility of chest wall and diaphragm proprioceptive neuromuscular facilitation (PNF) techniques in mechanically ventilated patients. Int J Environ Res Public Health. 2022;19(2):960. doi: 10.3390/ijerph19020960. PMID: 35055783; PMCID: PMC8776000.
38. Roceto Ratti LDS, Marques Tonella R, Castilho de Figueir do L, Bredda Saad IA, Eiras Falcão AL, Martins de Oliveira PP. Inspiratory muscle training strategies in tracheostomized critically ill individuals. Respir Care. 2022;67(8):939–48.
39. Shei RJ, Paris HL, Sogard AS, Mickleborough TD. Time to move beyond a "one-size fits all" approach to inspiratory muscle training. Front Physiol. 2022;12:766346.
40. Yang S, Liu J, Yang W, Yuan J, Meng S, Liang M, Shi Q. Effect of early mobilization on diaphragmatic function in patients with mechanical ventilation: A prospective randomized controlled study. Zhonghua Wei Zhong Bing Ji Jiu Yi Xue. 2018;30(2):112–6 (in Chinese).
41. Schreiber A, Bertoni M, Goligher EC. Avoiding respiratory and peripheral muscle injury during mechanical ventilation: Diaphragm-protective ventilation and early mobilization. Crit Care Clin. 2018;34(3):357–81.

Pilot implementation of rural rehabilitation services, India

Rajani Mullerpatan,[a] Prasad Waingankar,[b] Shrutika Parab,[a] Bela Agarwal,[a] Omeshree Nagrale[a] & Shashank Dalvi[b]

Objective To implement rehabilitation services in a rural area of Raigad district, Maharashtra, India.

Methods We piloted a rehabilitation service delivery model through the Mahatma Gandhi Mission Institute of Health Sciences, in five villages. The institute performed participatory rural appraisal and focus group discussions with stakeholders to identify general issues in village life that could affect delivery. To integrate rehabilitation service delivery into the existing primary care system, a team from the institute developed a strategic plan through multidisciplinary clinical meetings. A rehabilitation team conducted a door-to-door survey and referred people needing rehabilitation services to the outreach visits the team was making to the primary health centre twice a week. If needed, patients could be referred to a university teaching hospital for tertiary-level care.

Findings The rural appraisal identified lack of awareness, inadequate workforce and infrastructure as key issues for rehabilitation services delivery. In response, we conducted awareness campaigns and formed a rehabilitation team consisting of personnel and students from the institute. Between 2018 and 2021, the team provided care to 1800 patients, of which half (900 patients) had musculoskeletal disorders. After rehabilitation, 360 (40%) of these 900 patients performed daily-living activities and continued to work with reduced pain within 2–3 days after rehabilitation. The team provided antenatal care to 1629 pregnant women with musculoskeletal pain or stress urinary incontinence.

Conclusion Provision of rehabilitation services built awareness about physiotherapy, developed a rehabilitation care pathway and established a need for regular services. Using existing resources of the institute and involving students rendered the model sustainable.

Abstracts in عربي, 中文, Français, Русский and Español at the end of each article.

Introduction

To achieve universal health coverage, rehabilitation needs to be integrated as an essential health service for people across their entire life-course. Although rehabilitation enhances quality of life and contributes to several sustainable development goals, rehabilitation services are under-prioritized within health-care systems in most parts of world, particularly in low- and middle-income countries.[1]

In middle-income countries, integrating rehabilitation services within health-care systems poses huge challenges because such services require multilevel and complex delivery models. For example, India's large population, of which the majority reside in rural settings, stark diversity in socioeconomic conditions and inadequate resources challenge the authorities to deliver appropriate services. The pace and extent of integration of rehabilitation services into the health-care system do not meet the rising need for rehabilitation services due to lack of skilled workforce, infrastructure and resources.[2,3] This gap exists despite the fact that India's 2017 National Health Policy focuses on preventive and promotive health care and universal access to good quality health-care services with attention to disability and rehabilitation services.[4]

In the Raigad district, a rural area in Maharashtra state, the Mahatma Gandhi Mission Institute of Health Sciences – a higher education institute with an affiliated university teaching hospital – has provided community health-care services since 2008. Studies conducted by the institute between 2015 and 2018 showed poor knowledge of immunization; noncompliance with treatment of hypertension and diabetes; lack of trained workforce for newborn care; and elderly people experiencing poor health-related quality of life.[5–8] These observations prompted integration of rehabilitation experts within the community medicine team to deliver comprehensive multidisciplinary rehabilitation services. Here we describe how a service delivery model for rehabilitation was implemented in the rural areas of Raigad district, using a community-based participatory approach.

Methods

Local setting

Raigad is the second largest district in Konkan region of Maharashtra state in India with a population of 2 634 200 (2011 census), of which 63% (1 659 546 people) live in rural areas.[9] The district faces common rural health challenges, such as high prevalence of communicable diseases, malnutrition in children and elderly people and urinary incontinence in women.[10]

The public health system consists of one primary health centre at Nere village and a subcentre at Dhamani village. The health-care team at the primary health centre includes a medical officer, a resident auxiliary nurse, a midwife and a multipurpose worker. The Mahatma Gandhi Mission Institute of Health Sciences community medicine team consists of preventive-community medicine doctors and a medical social worker. This team is assisted by mobile community health workers (CHWs), including one accredited social health activist worker and *anganwadi* workers (that is, rural childcare workers). Before the implementation, the primary health centre and subcentre had no employed rehabilitation personnel.

For this pilot implementation, the Mahatma Gandhi Mission Institute of Health Sciences included a cluster of five villages with a total population of 4571 (Dhamani, Dhodani, Dehrang, Tawar Wadi and Waghachi Wadi) including its satellite habitats encompassing the entire Maldung *gram panchayat*

[a] Mahatma Gandhi Mission School of Physiotherapy, Mahatma Gandhi Mission Institute of Health Sciences, Sector 1, Kamothe, Navi Mumbai-410209, Maharashtra, India.
[b] Department of Community Medicine, Mahatma Gandhi Mission Institute of Health Sciences, Navi Mumbai, India.
Correspondence to Rajani Mullerpatan (email: rajani.kanade@gmail.com).
(Submitted: 28 February 2022 – Revised version received: 16 May 2022 – Accepted: 18 May 2022 – Published online: 19 September 2022)

of Panvel Tehsil. We selected these villages because the institute participated in the *Unnat Bharat Abhiyan* flagship scheme of the Indian government Ministry of Human Resource Development and adopted these villages through the Mahatma Gandhi Mission Community Health-Care Project.

Participatory rural appraisal

In 2018, the community medicine department of the institute performed essential participatory rural appraisal in the villages. To identify general issues in village life, including health problems and other challenges, the community medicine team adopted a community need assessment approach. Villagers, including people living with disabilities, and accredited social health activist workers participated in informal discussions with the team during transect walks, and village mapping was conducted in all five villages. Transect walks were organized to follow the geographical map of each village. Village mapping was organized in an open space outside the *anganwadi* (rural childcare centre). One *anganwadi* worker, one youth volunteer and a few villagers participated in village mapping. The youth volunteer drew a rough sketch of the village map on the ground soil with a stick and ash. Thereafter, the detailed sketch was drawn on chart paper with a pencil, and coloured pens were used to mark critical landmarks in the village such as the *anganwadi*, *samaj mandir* (community hall), Dhamani subcentre and schools.

Additionally, the community medicine team and a medical social worker held focus group discussions with pertinent stakeholders, namely: district officers, *gram panchayat* (council for a group of villages), a medical officer and a resident auxiliary nurse from the primary health centre, local leaders, primary school teachers and CHWs. Topics of discussion included health issues such as prevention of infectious diseases, noncommunicable diseases, breastfeeding, supplementary nutrition and anaemia.

Service delivery model

To integrate rehabilitation service delivery into the existing primary care system, a team from Mahatma Gandhi Mission Institute of Health Sciences (including physiotherapists, preventive-community medicine doctors, nurses and medical social workers, along with members from obstetrics–gynaecology, paediatrics, medicine, otorhinolaryngology, ophthalmology, dermatology and orthopaedics departments) developed a strategic plan based on findings of the participatory rural appraisal. This team held monthly integrated multidisciplinary clinical meetings at the institute to discuss implementation of the strategies developed. During these meetings the following activities were undertaken: (i) designing of a comprehensive multidisciplinary rehabilitation framework; (ii) scheduling of monthly visits to the primary health centre and subcentre; (iii) identifying members from involved health disciplines who should be included in the upcoming outreach visits; (iv) optimizing the use of the institute's resources; (v) reviewing the patient referral protocol; and (vi) brainstorming on feasible preventive care measures.

The multidisciplinary rehabilitation team from the institute included two community medicine doctors, two gynaecologists, two paediatricians, one general physician, one orthopaedic surgeon, and one resident each from otorhinolaryngology, ophthalmology and dermatology departments. The multidisciplinary team also included a physiotherapy team comprised of one faculty member, one master's student, one PhD student and five bachelor's students from Mahatma Gandhi Mission School of Physiotherapy. The team's task was to visit the primary health centre, subcentre and villages twice per week to address the health and rehabilitation needs of the population.

The institute also organized a multidisciplinary programme to address the identified health-pertinent issues during the rural appraisal. The programme consisted of: (i) health camps delivered by the multidisciplinary team including the physiotherapy team, who clinically evaluated pregnant women and managed identified health concerns; and (ii) community health education programmes.

This service delivery model used qualified workforce and resources available at Mahatma Gandhi Mission Institute of Health Sciences to strengthen existing government efforts (Fig. 1). The institute developed this model in alignment with the recent updates in national health-care policy,[4] which attempts to address the growing burden of noncommunicable diseases; reduce unsustainable health expenditure; fill gaps in infrastructure in health-care facilities; and address scarcity of CHWs and community rehabilitation personnel, especially in rural areas.[11] Gaps in implementation of existent policies, especially in the area of health promotion, prevention and management of commonly reported health conditions, led to the development of the service delivery model.

Implementation

In 2018, the physiotherapy team conducted door-to-door surveys in households and screened all the present villagers for major health conditions, such as musculoskeletal pain, neurological conditions, cardiorespiratory conditions, and women's health issues such as stress urinary incontinence and urogenital prolapse. Following the survey, patients requiring rehabilitation were referred to the primary health centre for physiotherapy. The referral protocol instructed the physiotherapy team to refer patients with a medical history indicating a risk of having a serious disorder, such as infection, cancer or fracture,[12] to Mahatma Gandhi Mission University Teaching Hospital, Kamothe for tertiary-level multidisciplinary care.

Household members identified with rehabilitation needs received information about the outreach visits. CHWs reminded the patients about these visits a day before the planned visits through public announcements on a loudspeaker.

The multidisciplinary team made day-long (8 hours) outreach visits to the primary health centre and Dhamani subcentre twice a week for the delivery of rehabilitation services for patients identified during the survey. On the first visit to the primary health centre, patients were attended to on a first-come first-served basis. The services were free of charge to all patients. Patients with identified health conditions were given a follow-up appointment at the next outreach visit. CHWs reminded patients about follow-up visits through public announcements on a loudspeaker. We used existing resources of the institute to deliver rehabilitation services, and the institute supported the costs for the travel of the team and for portable equipment.

For the health camps, the multidisciplinary team used the *Surakshit Matritva Din* platform offered by *Pradhan Mantri Surakshit Matritva Abhiyan* to deliver antenatal care to pregnant

women at the primary health centre once a month. This scheme is funded by the government to ensure comprehensive and quality antenatal care, free of cost across the nation on the ninth day of every month.[13] The team prescribed medicines and nutritional supplements and provided physiotherapy. CHWs helped with dissemination of information about the camp and assisted with the registration and crowd management. Before the camps, the team obtained medicine and consumable supplies from the university teaching hospital. The institute supported the transportation of supplies.

To discuss the logistics of creating awareness, review the activities conducted and strategies to garner community support, regular meetings were held every 6 months. These meetings included members of the *gram panchayat*, a public health nurse and a medical social worker of the community medicine team, and university teaching hospital administrators, and took place at the Maldung *gram panchayat* office or the university teaching hospital.

To build awareness regarding the role of physiotherapy in women's health, we adopted strategies to reach women and children in need of rehabilitation by approaching them during antenatal health check-up and immunization campaigns at the primary health centre. Simultaneously, community health education programmes delivered by resident doctors and physiotherapy master's students built awareness regarding the need for rehabilitation among villagers and CHWs. The team used various strategies such as health talks, awareness rallies, poster exhibitions and street plays, as well as the distribution of informative pictorial brochures, the display of educational charts, and the provision of exercises, yoga, ergonomic advice and home-based self-care strategies to empower patients through self-rehabilitation.

Results

Findings of the participatory rural appraisal and focus group discussions revealed lack of awareness, lack of health facilities at village level and in hamlets, lack of CHWs in one village, lack of medical doctors at the subcentre and lack of rehabilitation personnel in all five villages. The rural participatory appraisal also revealed health-pertinent issues such as infectious diseases, noncommunicable diseases and anaemia (Table 1).

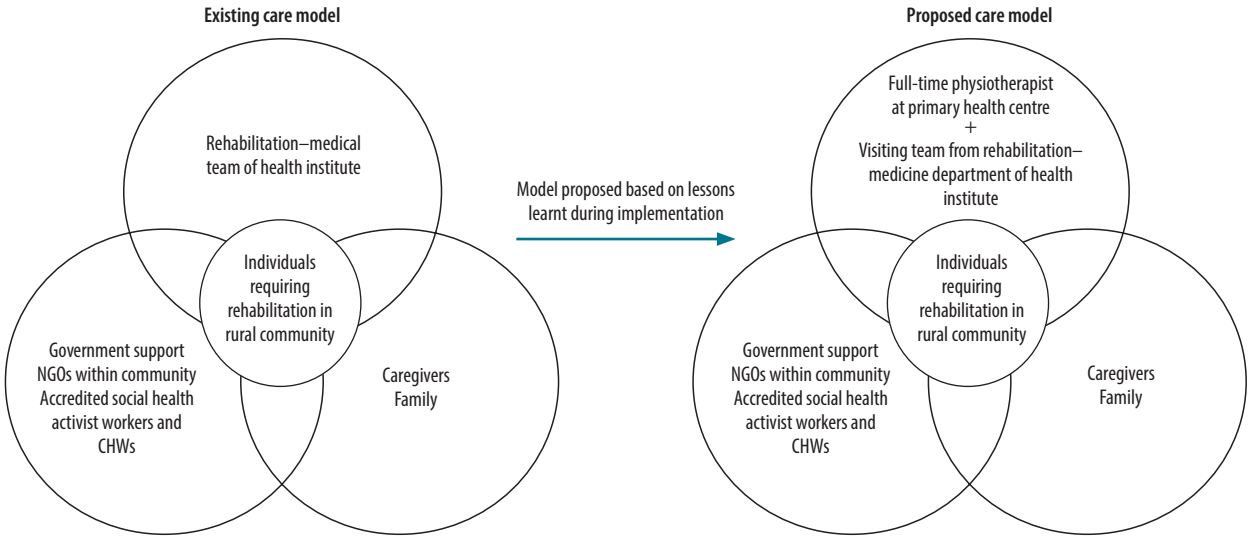
During the door-to-door survey, we questioned 2073 people about spine care. The point prevalence of low back pain was 4.9% (101 respondents) and neck pain was 2.9% (61 respondents). Among the 250 tribal people surveyed, 10% (25 respondents) had low back pain and 3.6% (9 respondents) had neck pain.[14] Additionally, screening for developmental disorders revealed lack of knowledge among 500 new mothers about age-appropriate, neurodevelopmental milestones and need for postnatal exercises for new mothers.

To address the rehabilitation needs identified through the screening, the physiotherapy team offered physiotherapy care through the outreach visits. During the implementation, an average of 50 patients (range: 35–55) attended the outreach visits per month. In total, the physiotherapy team provided care for 1800 patients, of which 50% (900) of patients, including elderly people, presented with musculoskeletal disorders, such as knee pain and spine pain; 10% (180) with neurological disorders; and 40% (720) were women who received postnatal care during immunization campaigns.

Between 2018 and 2021, 40 health camps were conducted, and the physiotherapy team delivered antenatal care to 1629 pregnant women with musculoskeletal pain or stress urinary incontinence. On the *Surakshit Matritva Din* platform, the team educated pregnant women about antenatal physiotherapy care, offered antenatal physiotherapy care, and then followed them up during consecutive outreach visits.

The multidisciplinary team offered rehabilitation services to all patients who reported disability due to musculoskeletal, neurological, cardiorespiratory or geriatric health problems or women requiring antenatal or postnatal care at primary care level. None of the patients required referral for tertiary care at the university teaching hospital. Of the 900

Fig. 1. **Existing and proposed model of care adopted at Mahatma Gandhi Mission Institute of Health Sciences to integrate rehabilitation into primary care, India, 2018–2021**



CHW: community health worker; NGO: nongovernmental organization.

patients with musculoskeletal disorders who underwent rehabilitation, 360 (40%) performed daily-living activities and continued to work with reduced pain within 2–3 days after rehabilitation.

In parallel, the pilot implementation of the service delivery model helped to sensitize and train 945 bachelor's students and 67 master's students of physiotherapy in service delivery at primary care level through a real-life problem-solving learning approach.

The estimated cost for delivery of rehabilitation services per year was computed by accounting for the cost of human resources, capital resources including rental of the primary health centre building, medicine, transport, equipment, furniture, stationery and printing. Total in-house cost of delivery of rehabilitation care was 876 277 Indian rupees (about 11 033 United States dollars) per year. However, projected cost for rehabilitation service delivery in primary care by an external dedicated rehabilitation service agency is likely to be higher, as the current model was embedded within the resources of a multidisciplinary health institute.

Discussion

Our experience of providing rehabilitation services in a rural part of India taught us several lessons (Box 1). The model of service delivery resulted

Table 1. **Key problems identified and lesson learnt during integration of rehabilitation services into primary care in a rural setting, India, 2018–2021**

Key problems identified[a]	Processes identified	Key findings	Lessons learnt
Lack of awareness regarding need for rehabilitation and available health-care solutions	• Villagers were introduced to the health-care team during survey, camps, health check-up, antenatal check-up and immunization drive conducted at primary health centre • Awareness talks by physiotherapists on specific health conditions • Distribution of informative pictorial brochures to patients and caregivers • Use of informative charts and street plays to highlight benefits offered by rehabilitation • Door-to-door screening for need assessment	• Increase in awareness regarding the need for rehabilitation in the management of various health conditions such as spine pain, knee pain, antenatal care, postnatal care, developmental disorders and stroke among people in the local setting • The screening survey identified the need for rehabilitation over the implementation period • 900 adults with musculoskeletal disorders • 180 infants, children and adults living with various neurological disorders • 1629 antenatal women with musculoskeletal pain and/or stress incontinence	• A specific in-depth need assessment for rehabilitation services is essential to plan required resources for uninterrupted care • This rehabilitation service delivery model can be used to initiate improvement in attitudes, correct beliefs about various noncommunicable diseases, maternal and child health, and developmental disorders, increase awareness regarding rehabilitation options and encourage people to seek care early on to minimize disability and optimize functioning
Inadequate qualified multidisciplinary rehabilitation workforce and lack of access to care	• Strengthened workforce in the community through using resources of the university teaching hospital, namely experts in community medicine, physiotherapy, orthopaedics, gynaecology and other disciplines, faculty members, postgraduate students, interns and residents • Use of university transport to reach distant locations of rural villages to offer rehabilitation services	• The model is sustainable as the workforce resources of the health institute are available consistently • All specialty services provided by the multidisciplinary rehabilitation team exist at the health institute • Faculty members are experienced in evidenced-informed care • A large taskforce of postgraduate students and interns are involved in delivery of care enabling a greater reach-out • Students can connect with local problems faced by the community and are exposed to real-life situations which instil critical thinking for problem solving • Students feel a sense of societal contribution • Patients do not need to travel long distances to access health care, therefore the model is economically viable for patients	• Workforce reconfiguration with inclusion of dedicated and qualified multidisciplinary rehabilitation team members and offering services within the community to increase the use of rehabilitation services
Lack of infrastructure and resources at primary health centre and subcentre	• We encouraged use of tools available in local setting, e.g. use of mud packs for local heat application in patients with knee pain	• Use of portable resources of university teaching hospital to offer rehabilitation services in primary care	• Resources of the university teaching hospital can be used to initiate care at primary level. • Infrastructure needs can be met by engaging in research-driven activities, engaging the local governments and developing industry partnership

[a] We identified the problems during a participatory rural appraisal and a door-to-door survey of villagers.

Box 1. **Summary of main lessons learnt**

- Rehabilitation service delivery offered by health institutes needs to be complemented by the rehabilitation workforce including full-time physiotherapist and visiting speech therapist, occupational therapist, prosthetist and orthotist at primary care facilities.
- The multidisciplinary rehabilitation workforce needs to be strengthened by partnerships with industry and nongovernmental organizations.
- To improve detection, rehabilitation and monitoring, new technology needs to be integrated into the service delivery model.

in changes for various stakeholders, including patients and caregivers, the health institute, community volunteers and policy-makers. This approach helped to build knowledge and awareness about rehabilitation needs, leading to increased demand for physiotherapy services. The approach also helped to improve attitudes and beliefs of patients and caregivers, through first-hand experience of substantial improvement in functional status and well-being.

Raising awareness among policy-makers – such as the *gram panchayat*, government officers and local leaders – through focused group discussions and meetings, facilitated delivery of rehabilitation services. The experience gained during the implementation of the service delivery model helped to organize basic infrastructure for a full-time physiotherapist at the primary health centre using human resources and portable equipment from the institute.

The service delivery model informed the institute's strategic research planning framework. This framework guides the institute to design and conduct implementation research that identifies evidence-informed, culturally acceptable models of rehabilitation service delivery. Linking the model to student training at the institute made the model sustainable, both economically and workforce wise. The model was also used for engaging students in the communities and in social responsibility, by conducting community-based participatory research. Training students in real-life problem-solving learning approaches is pivotal in creating a future trained and sensitized rehabilitation workforce.

The service delivery model faced various challenges at the beginning of implementation such as community acceptability due to lack of knowledge about rehabilitation, the team's access to remote areas and transport for the workforce. We gained community acceptability by adopting a participatory approach, wherein CHWs were engaged along with community leaders in sensitization of people (Table 1).

We anticipate that the magnitude of rehabilitation need in the district is higher because we were unable to survey the entire population of the five villages, as a few houses were closed at the time of the survey, some people were at work or migrated to other areas.[14] Therefore, further need assessment is essential for precise planning of necessary resources for rehabilitation services. Alongside this, the service delivery model created a need for development of a central database spanning across district, state and national levels to monitor rehabilitation outcomes.

The service delivery implementation model faced disruptions caused by emergencies such as the coronavirus disease 2019 pandemic and heavy monsoon. The climatic conditions made access to the primary health centre and villages difficult. Other challenges causing disruptions were limited transport facility and time constraints caused by academic engagements of faculty members and students.

Therefore, we recommend making provision for a full-time dedicated physiotherapist at primary health centres supported by visiting rehabilitation personnel (Fig. 1). Furthermore, strengthening the model through partnerships with industry and nongovernmental organizations (NGOs), sharing similar ideologies, is essential to augment government resources. We are currently attempting to partner with NGOs working in this field and are seeking funding from the industry through corporate social responsibility initiatives.

In addition to the need for training caregivers and CHWs, formal engagement of people with disabilities into the planning and implementation of the rehabilitation service delivery model is imperative for the outcomes.

To reach more people, integrating technology into service delivery is warranted. We are in the process of developing mobile-based applications to strengthen existing capacities for detection, rehabilitation and monitoring.

By involving the large network of government and private health institutes in India, the service delivery model presented here can be scaled up, leading to more people with rehabilitation needs improving their functional health. Subsequently, this improvement will contribute to the overall sustainable development of the rural health sector. ■

Acknowledgements

We thank the Mahatma Gandhi Mission Institute of Health Sciences for supporting the rural physiotherapy services and Ashlesha Tawde, coordinator of the Mahatma Gandhi Mission Institute of Health Sciences for the *Unnat Bharat Abhiyan* flagship scheme of the Ministry of Human Resource and Development, Government of India.

Competing interests: None declared.

ملخص

التنفيذ التجريبي لخدمات إعادة التأهيل الريفي، الهند

الغرض تنفيذ خدمات إعادة التأهيل في منطقة ريفية في منطقة رايجاد، ماهاراشترا، بالهند.

الطريقة قمنا بتجريب نموذج تقديم خدمة إعادة التأهيل من خلال معهد مهاتما غاندي لبعثة العلوم الصحية في خمس قرى. أجرى المعهد تقييمًا ريفيًا مشتركًا، ومناقشات جماعية مركزة مع أصحاب المصلحة لتحديد القضايا العامة في حياة القرية، والتي بإمكانها أن تؤثر على تقديم الخدمة. لدمج تقديم خدمة إعادة التأهيل في نظام الرعاية الأولية القائم، قام فريق من المعهد بوضع خطة إستراتيجية من خلال اجتماعات تحليلية متعددة التخصصات. قام فريق إعادة التأهيل بإجراء استطلاع للرأي من خلال الزيارات المنزلية، وإحالة الأشخاص الذين يحتاجون إلى خدمات إعادة التأهيل إلى زيارات التوعية التي كان يقوم بها الفريق إلى مركز الصحة الأولية مرتين في

الأسبوع. وإذا لزم الأمر، يمكن إحالة المرضى إلى مستشفى تعليمي جامعي للحصول على رعاية من المستوى الثالث.
النتائج أشار التقييم الريفي للنقص في الوعي، وعدم ملاءمة قوى العمل، وضعف البنية التحتية، باعتبارها قضايا رئيسية لتقديم خدمات إعادة التأهيل. وكاستجابة لذلك، قمنا بحملات توعية وشكلنا فريقًا لإعادة التأهيل يتكون من موظفين وطلاب من المعهد. قام الفريق بين عامي 2018 و2021، بتقديم الرعاية لعدد 1800 مريض، يعاني نصفهم (900 مريض) من اضطرابات عضلية هيكلية. بعد إعادة التأهيل، قام 360 (40%) من هؤلاء المرضى البالغ عددهم 900 بأداء أنشطة الحياة اليومية، واستمروا في العمل مع تخفيف الألم في غضون 2 إلى 3 أيام بعد إعادة التأهيل. قدم الفريق رعاية ما قبل الولادة لعدد 1629 امرأة حامل يعانين من آلام عضلية هيكلية، أو سلس البول الإجهادي.
الاستنتاج أدى تقديم خدمات إعادة التأهيل إلى بناء الوعي بالعلاج الطبيعي، ووضع مسار لرعاية إعادة التأهيل، وإنشاء الحاجة إلى الخدمات المنتظمة. أدى استخدام الموارد الحالية للمعهد وإشراك الطلاب إلى جعل النموذج مستدامًا.

摘要

印度：农村地区开展康复服务试点
目的 在印度马哈拉施特拉邦莱加德农村地区提供康复服务。
方法 我们通过圣雄甘地医学健康科学研究所，在五个村庄开展康复服务试点。该研究所与利益攸关方进行了参与式农村评估和专题小组讨论，确定了农村生活中可能影响康复服务的一般问题。为了将康复服务整合到现有的初级医疗保健体系中，由研究所人员组成的小组在临床应用多学科会议上制定了一项战略计划。我们的一个康复小组进行了挨家挨户的调查，将需要康复治疗的患者转介到外展服务中心，该小组每周前往初级卫生保健中心进行两次会诊。如需要，会将患者转介到医学院的附属医院进行三级护理。
结果 农村评估发现，缺乏康复宣传、康复服务人员以及基础设施建设，这是提供康复服务面临的关键问题。因此，我们开展了宣传活动，并组建了一个由研究所人员和学生组成的康复小组。2018 年至 2021 年间，小组为 1800 名患者提供了护理服务，其中半数患者（900 名患者）患有肌肉骨骼疾病。康复治疗后，这 900 名患者中的 360 (40%) 名患者可以进行日常活动，并在康复后 2-3 天内疼痛减轻，继续开始工作。小组为 1,629 名患有肌肉骨骼疼痛或压力性尿失禁的孕妇提供了产前护理。
结论 康复服务的提供促进了人们对物理治疗的认识，制定了康复护理方案并满足了人们对常规服务的需求。利用研究所的现有资源，并让学生参与，可以有效促进该模型的可持续性。

Résumé

Mise en œuvre expérimentale de services de réadaptation en milieu rural en Inde
Objectif Proposer des services de réadaptation dans une région rurale du district de Raigad, dans le Maharashtra, en Inde.
Méthodes Nous avons déployé un modèle de prestation de services de réadaptation dans cinq villages par l'intermédiaire du Mahatma Gandhi Mission Institute of Health Sciences. L'institut a procédé à une évaluation rurale participative et organisé des discussions au sein de groupes de réflexion impliquant différentes parties prenantes, afin de repérer les principaux problèmes rencontrés dans les villages et susceptibles d'affecter les prestations. En vue d'intégrer les services de réadaptation dans le système de soins primaires existant, une équipe de l'institut a élaboré un plan stratégique lors de réunions cliniques multidisciplinaires. De son côté, une équipe de réadaptation a effectué une enquête en porte-à-porte et proposé aux personnes nécessitant de tels services de se rendre dans le centre de soins de santé primaires, à l'occasion des visites de proximité qu'elle réalise deux fois par semaine. Si besoin, les patients pouvaient être transférés vers un hôpital universitaire pour des soins de niveau tertiaire.
Résultats L'évaluation rurale a permis d'identifier les obstacles majeurs à la prestation de services de réadaptation: un manque de sensibilisation, ainsi que l'absence d'infrastructures et de personnel qualifié. Pour y remédier, nous avons mené des campagnes de sensibilisation et formé une équipe de réadaptation, composée d'employés et d'étudiants de l'institut. Entre 2018 et 2021, cette équipe a pris en charge 1800 patients; la moitié (900 patients) souffraient de troubles musculosquelettiques. À l'issue de leur réadaptation, 360 (40%) de ces 900 patients étaient capables d'accomplir les tâches du quotidien et ont repris le travail 2 à 3 jours plus tard avec une douleur moins vive. L'équipe a également prodigué des soins prénatals à 1629 femmes enceintes présentant des douleurs musculosquelettiques ou une incontinence urinaire à l'effort.
Conclusion Les prestations de réadaptation ont permis de faire connaître la kinésithérapie, de développer un parcours de soins en la matière et d'exprimer la nécessité d'une régularité des services. L'utilisation des ressources de l'institut et l'implication des étudiants ont assuré la viabilité du modèle.

Резюме

Пилотное внедрение реабилитационных услуг в сельской местности, Индия
Цель Внедрение реабилитационных услуг в сельской местности района Райгад, штат Махараштра, Индия.
Методы При содействии Института медицинских наук имени Махатмы Ганди в пяти деревнях была экспериментально запущена модель предоставления реабилитационных услуг. Институт провел в сельской местности совместную оценку и обсуждения в фокус-группах с заинтересованными сторонами с целью выявления общих проблем в жизни деревни, которые могут повлиять на предоставление услуг. Чтобы интегрировать предоставление реабилитационных услуг в существующую систему первичной медико-санитарной помощи, командой института был разработан стратегический план в рамках междисциплинарных клинических

совещаний. Группа по реабилитации провела подомовой опрос и направила людей, нуждающихся в реабилитационных услугах, на консультации в центр первичной медико-санитарной помощи, которые проводились два раза в неделю. При необходимости пациенты могли быть направлены в клиническую больницу при институте для получения специализированного медицинского обслуживания.

Результаты По результатам оценки, проведенной в сельской местности, ключевыми проблемами для предоставления реабилитационных услуг были признаны недостаточная осведомленность, нехватка рабочей силы и инфраструктуры. В ответ были проведены информационно-просветительские кампании и сформирована группа по реабилитации, состоящая из сотрудников и студентов института. В период с 2018 по 2021 год группа оказала помощь 1800 пациентам, из которых у половины (900 пациентов) наблюдались заболевания опорно-двигательного аппарата. После реабилитации 360 (40%) из этих 900 пациентов выполняли повседневную деятельность и продолжали работать с уменьшением боли в течение 2–3 дней после реабилитации. Группа предоставила дородовое наблюдение 1629 беременным женщинам с мышечно-скелетной болью или стрессовым недержанием мочи.

Вывод Предоставление реабилитационных услуг способствовало повышению осведомленности о физиотерапии, разработке плана реабилитации пациентов и формированию потребности в получении регулярных услуг. Использование существующих ресурсов института и привлечение студентов привели к устойчивости модели.

Resumen

Aplicación piloto de los servicios de rehabilitación rural en la India

Objetivo Establecer servicios de rehabilitación en una zona rural del distrito de Raigad, Maharashtra, en la India.

Métodos Se puso a prueba un modelo de prestación de servicios de rehabilitación a través de Mahatma Gandhi Mission Institute of Health Sciences en cinco pueblos. El instituto llevó a cabo una evaluación rural participativa y debates en grupos de discusión con las partes interesadas para identificar los problemas generales en la vivencia del pueblo que podrían afectar a la prestación. Para integrar la prestación de servicios de rehabilitación en el sistema de atención primaria existente, un equipo del instituto elaboró un plan estratégico mediante reuniones clínicas multidisciplinares. Un equipo de rehabilitación realizó una encuesta puerta a puerta y remitió a las personas que necesitaban servicios de rehabilitación a las visitas de promoción que el equipo realizaba al centro sanitario primario dos veces por semana. En caso necesario, se podía derivar a los pacientes a un hospital universitario para que recibieran atención de nivel terciario.

Resultados La evaluación rural identificó la falta de concienciación, la falta de personal y los problemas de infraestructura como problemas clave para la prestación de servicios de rehabilitación. En respuesta, se organizaron campañas de concienciación y se formó un equipo de rehabilitación compuesto por personal y estudiantes del instituto. Entre 2018 y 2021, el equipo prestó atención a 1800 pacientes, de los que la mitad (900 pacientes) tenían trastornos osteomusculares. Después de la rehabilitación, 360 (40 %) de estos 900 pacientes realizaron actividades de la vida diaria y siguieron trabajando con un dolor reducido en los 2 a 3 días posteriores a la rehabilitación. El equipo prestó asistencia prenatal a 1629 mujeres embarazadas con dolor osteomuscular o incontinencia urinaria de esfuerzo.

Conclusión La prestación de servicios de rehabilitación permitió concienciar sobre la fisioterapia, desarrollar una vía de atención a la rehabilitación y establecer la necesidad de servicios regulares. La utilización de los recursos existentes en el instituto y la participación de los estudiantes hicieron que el modelo fuera sostenible.

References

1. Magnussen L, Ehir i J, Jolly P. Comprehensive versus selective primary health care: lessons for global health policy. Health Aff (Millwood). 2004 May-Jun;23(3):167–76. doi: http://dx.doi.org/10.1377/hlthaff.23.3.167 PMID: 15160814
2. Kumar SG, Roy G, Kar SS. Disability and rehabilitation services in India: issues and challenges. J Family Med Prim Care. 2012 Jan;1(1):69–73. doi: http://dx.doi.org/10.4103/2249-4863.94458 PMID: 24479007
3. Kamenov K, Mills JA, Chatterji S, Cieza A. Needs and unmet needs for rehabilitation services: a scoping review. Disabil Rehabil. 2019 May;41(10):1227–37. doi: http://dx.doi.org/10.1080/09638288.2017.1422036 PMID: 29303004
4. National Health Policy-2017. New Delhi: Ministry of Health & Family Welfare, Government of India; 2017: p. 3. Available from: https://www.nhp.gov.in/nhpfiles/national_health_policy_2017.pdf [cited 2022 Feb 26].
5. Sanjeev S, Waingankar P, Anjenaya S, Lohare BS. A study of reasons for nonimmunization among children attending the services of a rural hospital in Raigad district, Maharashtra. MGM J Med Sci. 2016;3(2):57–61. doi: http://dx.doi.org/10.5005/jp-journals-10036-1090
6. Kakumani KV, Waingankar P. Assessment of compliance to treatment of diabetes and hypertension amongst previously diagnosed patients from rural community of Raigad district of Maharashtra. J Assoc Physicians India. 2016 Dec;64(12):36–40. PMID: 28405986
7. Bhakare SS, Mohanty N, Gopalkrishnan S. Effect of planned teaching on practices of skilled birth attendants on 'facility based newborn care' at health care facilities in Raigad district, Maharashtra. Int J Health Sci Res. 2017;7(5):232–42. Available from: https://www.ijhsr.org/IJHSR_Vol.7_Issue.5_May2017/37.pdf [cited 2022 Sep 15].
8. Amonkar P, Mankar MJ, Thatkar P, Sawardekar P, Goel R, Anjenaya S. A comparative study of health status and quality of life of elderly people living in old age homes and within family setup in Raigad District, Maharashtra. Indian J Community Med. 2018 Jan-Mar;43(1):10–3. doi: http://dx.doi.org/10.4103/ijcm.IJCM_301_16 PMID: 29531431
9. District census handbook. Raigad: Directorate of Census Operations Maharashtra; 2011.
10. Abhijit B. Health and nutritional status of tribal children in Raigad district of Maharashtra. IJDTSW. 2015 Jun;3(1):31–65. Available from: http://www.ticijournals.org/health-and-nutritional-status-of-tribal-children-in-raigad-district-of-maharashtra/ [cited 2022 Feb 27].
11. Pati MK, Swaroop N, Kar A, Aggarwal P, Jayanna K, Van Damme W. A narrative review of gaps in the provision of integrated care for noncommunicable diseases in India. Public Health Rev. 2020 May 13;41(1):8. doi: http://dx.doi.org/10.1186/s40985-020-00128-3 PMID: 32435518
12. Finucane LM, Downie A, Mercer C, Greenhalgh SM, Boissonnault WG, Pool-Goudzwaard AL, et al. International framework for red flags for potential serious spinal pathologies. J Orthop Sports Phys Ther. 2020 Jul;50(7):350–72. doi: http://dx.doi.org/10.2519/jospt.2020.9971 PMID: 32438853
13. Abhiyan PMSM. New Delhi: Government of India, Ministry of Health & Family Welfare; 2016. http://www.nrhmhp.gov.in/sites/default/files/files/PMSMA-Guidelines.pdf [cited 2022 Sep 15].
14. Mullerpatan R, Nahar S, Singh Y, Cote P, Nordin M. Burden of spine pain among rural and tribal populations in Raigad District of Maharashtra State of India. Eur Spine J. 2021 Apr;30(4):1004–10. doi: http://dx.doi.org/10.1007/s00586-020-06585-3 PMID: 32914232

Journal of Hand Therapy xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Hand Therapy

journal homepage: www.elsevier.com/locate/jht

Determinants of hand function in children and adolescent with Down Syndrome-A scoping review

Neha Padia, MPT Scholar[a], Meruna Bose, PhD, MPTh (Neurophysiotherapy)[a,b], Shrutika Parab, MPT (Neurophysiotherapy)[a,*]

[a] MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, Maharashtra, India
[b] College of Health Sciences, Gulf Medical University, United Arab Emirates (UAE)

ARTICLE INFO

Article history:
Received 14 August 2021
Revised 4 July 2022
Accepted 5 July 2022
Available online xxx

Keywords:
Down syndrome
Upper extremity
Grip and pinch strength
Hand function
Fine motor function
Manual dexterity

ABSTRACT

Background: Down Syndrome (DS) is a genetic condition. Physical characteristics like short stature, hypotonia, small, and thick hands result in decreased grip and pinch strength and quality of fine motor tasks.

Purpose: The purpose of this review is to summarize the evidence of upper extremity physical characteristics and its influence on hand function in DS population.

Study Design: A scoping review.

Methodology: A comprehensive electronic literature search was conducted through PubMed, CINAHL, Cochrane Library. The search was limited to articles written in English and published between 2010 to 2021. Additionally, books were referred for a better understanding of the hand function in DS. The Preferred Reporting Items for Systematic Review and Meta-Analysis extension for scoping reviews (PRISMA-ScR) was adopted to develop the protocol.

Results: Following a detailed review of 28 articles meeting the inclusion criteria, fetuses with a diagnosis of DS are reported to have shortening of humerus on sonographic markers wherein 9% of fetuses had below 5th percentile shortening. Additionally, literature reports that during reaching there was increased trunk rotation (effect size = 0.88). DS population had 60% less grip strength, 33% less palmar pinch strength ,20% less key pinch strength and poor manual dexterity (CI = 4.5-5.5).

Conclusion: Findings of this review concludes that physical characteristics of the upper extremity have an influence on hand function performance in children and adolescents with DS.However, only arm length and hand span have been quantified and correlated with grip strength. Further work must focus on correlation of upper extremity anthropometry and overall hand function in children and adolscents with DS.

Introduction

Down Syndrome (DS), was first described by Dr John Langdon Down in 1866 as a genetic mental disability.[1] However, DS is an autosomal chromosomal genetic disorder that occurs due to overexpression of a gene on human chromosome 21.[2]

Individuals with DS exhibit deficiencies within multiple domains like physical and motor function. Body composition and muscle strength are vital parameters for children's gross motor, fine motor (such as tying a shoelace, printing or stringing beads),[31] and functional performance.[1] Physical characteristic exhibited by DS is short stature, small and broad hands with Simian crease, clinodactyly, low tone.[3] Motor performance in DS is addressed to be poor with weaker grip strength such that it affects functional domain and performance associated with daily activities.[4]

The children with DS often show 2 years of delays in their functional development, specifically in eye-hand coordination, bimanual tasks, gross and fine motor tasks. Features of ligamentous laxity, absence of some carpal bones, smaller hands, deflected fifth

Abbreviations: DS, Down Syndrome; TD, Typically Developing; ID, Intellectual disability; M-ABC, Movement assessment battery for children; CoP, Centre of pressure; RTG, Reach to grasp; BOT2, Bruininks- Oseretsky Test of Motor Proficicency -2; GMFM, Gross motor function measure; NMT, Neuromuscular tapping; T21, Trisomy 21.

Conflict of interest: We declare that there is no conflicting interest, guiding this research.

* Corresponding author: Shrutika Parab, MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, Maharashtra, India. Telephone no: +91-9969402471

E-mail address: shrutikaparab.mgmsop@gmail.com (S. Parab).

0894-1130/$ – see front matter © 2022 Elsevier Inc. All rights reserved.
https://doi.org/10.1016/j.jht.2022.07.010

Please cite this article as: N. Padia, M. Bose and S. Parab, Determinants of hand function in children and adolescent with Down Syndrome-A scoping review, Journal of Hand Therapy, https://doi.org/10.1016/j.jht.2022.07.010

finger are important predictors of multidomain deficiencies in individuals with DS.[5]

While summoning back to embryological development, DS individuals have delayed appearance of the primary center of ossification of digit 5, in comparison with premature fusion and thus explaining brachymesophalangia of digit 5 (wider and shorter middle phalanx of digit 5). Radiological studies infer the presence of pseudo-epiphysis of a base of the second metacarpal.[6,7]

Upper extremity function is usually associated with motor coordination, manual dexterity, muscle strength, and sensibility. Manual dexterity provides precision, speed and coordination of upper extremity movements to a task; grip and pinch strength provide quantitative measurement of upper extremity integrity.[8] Individuals with DS are restrained and sensitive from exploring different possibilities that require time to experience movement, to attain and refine fine motor skills.[9]

The quality of hand function often exhibits longer reaction time, high incidence of muscle coactivation, hypotonicity, ligamentous laxity. This alters the movement patterns in DS, inferred as "clumsy."[10] Proximal coordination of trunk and arm segment is a limiting factor for reach-to-grasp control in children with DS; also, slow and atypical movement contribute to late-onset of preparatory grip closure that limits manipulative skills and contributes to poor dexterity. Low muscle tone impairs recruitment and sequencing of muscle activation, resulting in compensation for instability and delayed interaction between the trunk and arm movements. Therefore, arm movements are poorly differentiated in DS, which prompts for atypical and immature grasps characteristics and orientation of hand to an object[11]

The International Classification of Functioning, Disability and Health in Children and Youth (ICF-CY) is referred to understand the pathway of a particular disease. Determinants of health play a vital role in assisting us in designing an assessment rehabilitation.[12] Amongst which, behavioral determinants of health consist of genetic conditions (such as DS, Klinefelter syndrome, etc.) as higher classification levels. This aids to connect us to different domains of ICF-CY.[13]

All these helps and guide us in understanding pathway of the physical, social and behavioral contribution of a population towards different aspects of ADLs and IADLs.

The various forms of studies performed to evaluate hand function in this population had insufficient results due to smaller sample size, incomplete tests and age appropriateness. Also, the systematic review published consisted of one component of hand function, whereas hand function is a broad term and has various sub-functions which needs to be roofed. The cross-sectional studies performed often had incomplete test results when compared with other populations (Typically developed [TD], other intellectual disabilities [ID]) and so results were inadequate and incomplete tests score were not involved in results. Physical characteristics studied are more restricted to hand span evaluation, which tells us about susceptibility towards hand injury and power grasp function.

Thus, in this scoping review, we aimed at exploring the comprehensive hand function of children and adolescents in DS. We also look for these altered comprehensive hand functions' effect on activities of daily living and instrumental activities of daily living.

Methodology

Searches

The methods of study analysis were ascertained. PRISMA-ScR guidelines were adopted for structuring this study. Data collection was done first by reading the title and abstract, second by preparing documents of selected studies obtained by applying search strategies in the database. It was discussed with reviewers and studies that had closed access, contact to correspondence author was established for same.

Data source information was obtained from studies listed in PICO format, studies including children and adolescents; focusing on hand function, grip strength, pinch strength, manual dexterity and fine motor function in the DS population.

Further data sources were obtained through textbooks, reference books, and cross-references on embryological development, musculoskeletal development, hand function and fine motor development in children with and without DS.

A total of 41,884 articles were listed on application of keywords to searching of the database, articles were selected on basis of inclusion criteria, out of which duplicate articles were removed

Screening

a) Human studies, b) studies presented in PICO format, c) studies exploring hand function in children and adolescents with DS with or without comparison with typically developed, d) age between 4 months to 25 years e) any study design (systematic reviews, RCTs, non-RCTs, cross-sectional, observational studies, pilot RCTs) f) Studies on hand function, upper limb function, reach, grasp, manipulation; manual dexterity, fine motor control, and coordination, precision grasping skills, g) studies in English language

Results

The survey comprised 41,884 scientific papers published nationally and internationally. Out of which 84 full-text articles were selected for review, among these 55 full-text articles were excluded. Out of the total, 6 articles were not accessible. Amongst all these, a total of 28 articles were included and studied in this review based on inclusion criteria.

a. Embryological studies: The studies relating to embryological abnormalities in DS was reflected in our search strategy as review articles and chapter from the textbook. Jonathan et al, in his review, stated shortening of humerus in sonographic markers in the first trimester (9% of fetuses had below 5th percentile shortening)[14]
b. Biomechanical constraints: Lopes et al, in their review stated that few studies performed the kinematic evaluation of upper limb in DS. They further added up stating that overall peak force and velocity in DS is lower and reaching tasks affects the dynamics of postural control. Also, this function was more feedback dependent.
c. Grip and pinch strength: Matute et al, examined the correlation of hand span on grip strength in DS and found that optimal grip span had a higher correlation in dominant ($r = 0.66$, $p > 0.05$) than nondominant hand ($r = 0.408$, $p < 0.05$). Jover et al, tested for grasping characteristics in DS and with TD; stated DS used fewer fingers to grip coin (effect size = 6), placing pegs (effect size = 0.5), picking up blocks (effect size = 0.92). Priosti et al, evaluated grip strength and manual dexterity in DS, and found no linear relation between dominant grip strength and manual dexterity ($r = 0.31$) and mean grip strength in DS were lower than TD ($p = 0.0$) and dominants' mean manual dexterity were lower in DS ($p = 0.00$). de Campos et al, (2010) study tested for reach and grasp in infants with DS, and found increase frequency of reach ($u(1) = 6.5$, $p = 0.01$) and decreased grasping frequency ($U(1) = 3.9$, $p = 0.04$). de Campos et al (2014), found DS infants used less unimanual grasping ($p = 0.03$) than bimanual grasping ($p = 0.009$) for smaller objects. Valvano et al, find-

ings during reach to grasp analysis in DS were increased in endpoint trunk rotation (effect size = 0.88), preparatory phase had poor anticipatory adjustment (effect size = 1.11 for gripping the aperture). Mullerpatan et al, findings stated that the DS population showed 60% less grip strength, 33% less palmar pinch strength and 20% less key pinch strength.de Campos et al (2014) studied the effect of object size on grasping in infants with DS and stated that DS infants touched larger objects with higher velocity ($p = 0.02$); in another study (2013) they found that DS infants reached frequently for large rough balls ($p = 0.004$) and large softballs ($p = 0.02$).

d. Manual dexterity and fine motor function: Vimercati et al, tested for fine motor function in DS through a drawing test, stating no significant difference was found in overall drawing performance but had increased velocity. Zareian et al, in their intervention study, stated improved reaction time in DS intervention post-intervention ($F = 75.5$, $p = 0.6$). dexterity improved ($F = 7.8$ for card sorting, $F = 23.0$ for arranging beads). Schott et al, in a cross-sectional study, stated the results of M-ABC, highest effect size found in "Forming letters using pen or pencil" ($r = 0.88$), "uses scissors to cut paper" ($r = 0.84$), "Fastens buttons" ($r = 0.78$). Marchal et al, in a longitudinal study, found manual dexterity is poor and testswere incomplete (CI = 4.5-5.5, SD = 5.0). Masumoto et al, found DS adolescents showed larger force generation and thus significant error in performing finger-tapping tasks.

e. Palmar arches and creases: There is lacunae in literature whilst addressing this sub-component of hand function, specifically concerning the DS population. However, their development and delayed are often expressed by a few authors but that was traced back four to five decades ago.

f. Dermatoglyphics: Lakshmi Prabha in her short review has given a highlight on dermatoglyphics in DS. Although a new term holds an important aspect when describing dental health in normal as well as DS population

Discussion

The results in Table 1 highlight the relationships and different aspects of hand function across life spans in children and adolescents with DS.

The acquisition of reaching and grasping represents an important milestone and contributing factor for functional independence during the growth period. Motor skills are distilled by repetitive and rhythmic task performance; also known as the repetitive perception-action-perception cycle, in children with DS this characteristic is refrain, and they have limitations while exploring their possibilities consequently requiring more time for acquiring and refining motor skills.[10]

In infancy reaching and grasping skills in the DS population are being influenced by various intrinsic factors, and there is a correlation between intrinsic (age, biomechanical factors, posture, etc.) and extrinsic (environment, object properties, and experience) factors. This results in the adoption of different strategies for reaching in infants with DS.[10] Intrinsic properties influence the accuracy and speed of reaching and grasping in infants with DS.[25] Pregrasping behaviors in infants with DS seemed to be less efficient in generating action-relevant information, and postgrasping behaviors required greater perceptual-motor demands and difficulty.[16] DS infant characteristics of grasping rely on object configuration rather than object properties. These infants require a longer time to adjust to uni and bimanual strategies which may be a functional limitation since early ages.[15]

Interest in an object often speaks about a child's engagement in an activity and development of language. In children with DS novel actions and objects might be repeated but a carry-over in their language and communication was reduced.[30] Reaching tasks in infants with DS leads to an exploration of environment and object, helping an infant with motor, and cognitive function.[34]

The birth performance-based measures and teachers' report reflects the bottom-up approach of current motor skills performance and long-term impression (top-down) in both DS and TD. Both the combined methods help in the evaluation of individually performed skills and thereby aid in tailored-made rehabilitation for each child.[11]

Children with DS demonstrated a moderate rate of grip and pinch strength reduction when compared to typically developed children. Also, weight, height, forearm length, hand length, and breadth were factors that influenced upper extremity strength differences.[26]

Hand strength and manual dexterity were similar in both genders; a correlation was also seen between age and hand function. Sound knowledge of manual skills is important for planning various aspects of developmental activities. Hand dynamometer is the gold standard tool for the evaluation of hand strength in healthy population and is used frequently. The same method can be used in DS population for evaluation of hand strength. It will help us to gain a sound knowledge about their hand strength.[22]

The three-dimensional analysis of kinematics for the evaluation of upper limb movements is necessary in children with DS to understand the velocity, speed and accuracy of movements. However, due to the dearth of standardizing protocol for evaluation of upper limb kinematics properties, there are often deviated protocols. Thus, a three-dimensional upper limb movement analysis should be developed for understanding the patterns of movements adopted during gripping and other hand function activities.[23]

Mental assessment at the age of 2 years, gender, and presence of infantile spasms can aid to some extent in predicting adaptive and motor skills by the end of school age in children with DS.[35] Understanding perceptual-motor development in children with T21, with an emphasis on atypical grasping features; and correlation of perceptual-motor functioning and grasping behaviors.[21]

The population with T21 often scores poorly in fine motor skills tasks because of specific brain and body characteristics. This lessens their effective dexterity skills and often contributes to their clumsiness and reduced participation in life situations represented in ICF (C-Y).[17]

The fine motor task in children with and without DS shows differences concerning developmental milestones, sensory, motor, cognitive and perceptual domain. These domains are often impaired in the DS population and many times inadequately addressed while testing fine motor tasks.[19] The adolescent with DS showed higher peak force-velocity and systematic delay on the onset of finger tapping movement. It may be due to differences in motor unit recruitment patterns.[18]

Significant limitations were found in RTG (reach-to-grasp) which contributes to more upper limb movement limitations and poor manual dexterity performance in school-aged children with DS.[29]

The postural sway (defined as small oscillatory motion made in body segments by an healthy individual to control and maintain an upright posture) in DS population is more with increased velocity in center of pressure (CoP). The CoP displacement was greater in medial/lateral directions. The motor skills performance such as standing, walking, running/jumping were inadequately achieved as per the results on gross motor functional measure (GMFM) and Bruininks-Oseretsky test of motor proficiency (BOT-2).[36]

Please cite this article as: N. Padia, M. Bose and S. Parab, Determinants of hand function in children and adolescent with Down Syndrome-A scoping review, Journal of Hand Therapy, https://doi.org/10.1016/j.jht.2022.07.010

Table 1
Data charting and synthesis of results highlight the relationships and different aspects of hand function across life spans in children and adolescents with DS.

Sr no	Title	Study population age & gender	Level of evidence/ study design	Outcome measure	Method
1	Priosti et al,[24]	Down Syndrome 7-9 y/ both	II cross-sectional	Jamar dynamometer assessed grip strength using American Society of Hand Therapy guideline of measurement, Box and Blocks test assessed manual dexterity	Grip strength and manual dexterity were assessed for both hands. Each evaluation lasted for 15 min
2	Matute-Llorente et al, 2017[22]	Down Syndrome 15-18 y/ Both	II Cross-sectional	Hand span measured and Digital Dynamometer	Hand span was measured with hand widely opened, references from tip of thumb to the tip of the little finger; digital dynamometer was used for measuring grip strength with subject attaining standard bipedal position arm in abduction, elbow incomplete extension and forearm pronation. Subjects were recruited in two sections; one 27 subjects were tested and after a few weeks, 15 subjects were further recruited to determine optimal grip strength and reduce the risk of bias.
3	Zareian & Delavarian, 2014[5]	Down Syndrome 7-12 y/ both	II Experimental study	Bruininks-Oseretsky test to assess fine motor skills, Briggs-Nebes Handedness Inventory was used to establish laterality	Pre and post-test evaluations were performed. Hand laterality was established using Briggs-Nebes Handedness inventory. Subjects performed individual and group exercise of sport stacking in two sessions per week for 30 min. At first, edutainment video was set for patterning and speed, techniques were the point of emphasis
4	de Campos et al, 2010[10]	Down Syndrome and Typically developed 4-6 mo/ both	II Cross-sectional study	Alberta Infant Motor scale	Infants were placed on baby chairs reclined 50 degrees from horizontal. Pearl-like spherical markers were affixed to infants' wrists. An attractive spherical object was presented at infants' midline, shoulder height and arm's length for 1 min or until infant performed seven reaches. Reaching movements were recorded by using a three-camera (60 Hz) motion capture system 1 camera was positioned above and behind the chair and the other two were positioned in front of the diagonally to chair on right and left sides.
5	Lopes et al, 2018[23]	Down Syndrome and Typically developed	I Systematic review	PRISMA, PICO criteria, Crowe Critical Appraisal Tool (CCAT)for quantification of methodological quality of studies	The title and abstract were retrieved by researchers individually using a systematic strategy based on inclusion criteria. A total of 344 articles were retrieved and five full texts were included in this review.
6	Vimercati et al, 2015[19]	Down Syndrome and Typically developed 14-19 y/ both	II Clinical measurement	IQ assessment and SMART-D BTS (optoelectronic system) 200Hz frequency camera and integrated video system	The children were seated comfortably on an adjustable chair and in front of the desk. They were given a paper sheet with a printed figure (a circle, an equilateral cross, a square) and were asked to copy the illustrated figure with their dominant hand. Children were given modified ink pen with markers on the cap that allowed reconstruction of the trace drawn.
7	Camargo Oliveira & Cavalcante Neto, 2016[3]	Down Syndrome	I Systematic review	PRISMA	Exploratory and descriptive literature review, realized by digital media by recommendations of Cochrane Handbook for Systematic Reviews. Databases comprised LILACS, Medline, PubMed, Scielo, IBECS, Scopus. MeSH was selected for searching keywords, a medical classification system based on English language articles indexed in the area of research. Out of 38 articles, eight were selected on basis of common agreement amongst judges.

(*continued on next page*)

Table 1 (*continued*)

Sr no	Title	Study population age & gender	Level of evidence/ study design	Outcome measure	Method
8	Jover et al, 2010[21]	Down Syndrome and typically developed v 4-18 y/ both	II Cross-sectional	Movement Assessment Battery for Children (M-ABC)	Children were asked to write their name or their signature on a sheet of paper and to show which hand they preferred to brush their teeth or comb their hair; to determine preferred and non-preferred hand (PH) and (NPH) respectively. Then the children were asked to perform three manual tasks: a) posting coins, b) placing pegs, c) picking up blocks.
9	Memisevic & Macak, 2014[33]	One group (Down syndrome, Fragile X syndrome, Williams Syndrome, Prader Willi Syndrome) and a second group (unknown etiology of intellectual disability) 7-15 y/ both	II Comparative study	Purdue Pegboard test,	The test consists of four tasks to be performed by the children. The first three tasks required the children to place as many pegs in a peg-hole in a period of 30 s. The final task involves making as many assemblies as possible within one group
10	Chen et al, 2014[4]	Down syndrome Young male	II Interventional study	Hydraulic Dynamometer, treadmill, PAR-Q, Peabody picture vocabulary test	It is a pre-and post-evaluation study evaluating effectiveness of bout exercises on grip force in individuals with DS. The participants performed treadmill walking for 20 min following multistage protocol.
11	de Campos et al, 2011[25]	Down Syndrome and Typically developed 4-6 mo/ both	II Exploratory study	Apgar score, Cytogenic analysis	Infants were placed on baby chairs reclined 50 degrees from horizontal. Pearl-like spherical markers were affixed to infants' wrists. Four attractive spherical balls of different textures (two soft and two rigid) were presented at infants' midline, shoulder height and arm's length for 1 min or until infant performed seven reaches. Reaching movements were recorded by using a three-camera (60 Hz) motion capture system 1 camera was positioned above and behind the chair and the other two were positioned in front of the diagonally to chair on right and left sides. Kinematics characteristics of reaching were additionally performed by calculating deceleration time and maximum time by calculating maximum velocities value as a result of the difference of two minimum velocities.
12	de Campos et al, 2013[16]	Down Syndrome and Typically developed 4-6 mo/ both	II Observational study	Apgar score, Cytogenic analysis	Infants were placed on baby chairs reclined 50 degrees from horizontal. Pearl-like spherical markers were affixed to infants' wrists. Four attractive spherical balls of different textures (two soft and two rigid) were presented at infants' midline, shoulder height and arm's length for 1 min or until infant performed seven reaches. Reaching movements were recorded by using a three-camera (60 Hz) motion capture system 1 camera was positioned above and behind the chair and the other two were positioned in front of the diagonally to chair on right and left sides. Grasping behaviors were studied in four stages: pregrasping behavior, grasping, post grasping and post grasping exploration behaviors and frequencies of reaches were studied.

(*continued on next page*)

Please cite this article as: N. Padia, M. Bose and S. Parab, Determinants of hand function in children and adolescent with Down Syndrome-A scoping review, Journal of Hand Therapy, https://doi.org/10.1016/j.jht.2022.07.010

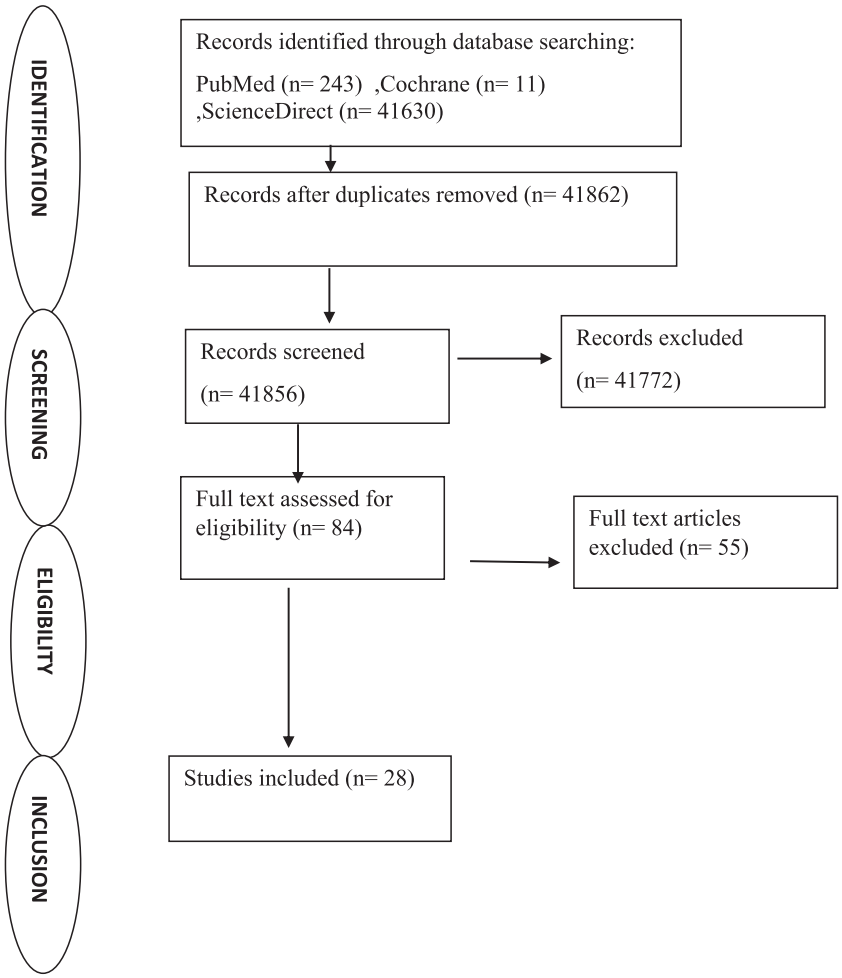
Table 1 (*continued*)

Sr no	Title	Study population age & gender	Level of evidence/ study design	Outcome measure	Method
13	de Campos et al, 2014[15]	Down Syndrome and Typically developed 4-8 mo/ both	II Exploratory study	Apgar score,	Infants were placed on a reclined chair with truncal support. Four spherical objects (two large and soft and two soft and small) were placed in infant's midline at shoulder height in the line of arm. The object was presented for seven trials on both sides. Three cameras were used to record the reaching performance.
14	Fidler et al, 2014[30]	Down Syndrome and Typically developed Both	II Observational study	Leiter-Scale of performance, child development and family history, oral and written language scales, generativity performance	Different objects such as pipe cleaners, wooden beads, plastic coins, rubbery bracelets, paper cups for baking, straws, miniature pompoms, colored popsicles stick, foam sheets with holes punched around perimeter and lanyard strings. These objects created ambiguous plays. Participants' engagement was coded using Nodulus Observer XT coding software on following criteria: type of engagement and novel use of an object.
15	Holzapfel et al, 2015[27]	Intellectual disabilities 17-20 y/ both	II Interventional study	Modified Snellen chart, audiometer, Peabody Picture Vocabulary test 4th edition,	Participants completed cycling sessions using modified motorized stationary recumbent bicycling for 30 min three times per week for 8 weeks.
16	Jover et al, 2014[17]	Down Syndrome and Typically developed 5-20 y/ both	II Observational study	Movement Assessment Battery for Children (M-ABC)	The participants were recorded whilst they performed two tasks selected from M-ABC with both the hands preferred and non-preferred in sitting posture in front of a table
17	Latash et al, 2002[20]	Down Syndrome and age-matched typically developed 19-21 y/ both	II Cross-sectional Study	Experimental setup using sensor and piezoelectric effect tapping systems for recording a maximum voluntary contraction	All the participants performed trials of maximum voluntary contraction test using each finger separately and all four fingers together of the dominant hand. A ramp test was done with 12 trails with zero force for 5 sec projecting contraction and then a 30 percent increase in force for 2 s and repeat.
18	Lobo et al, 2015[34]	Down Syndrome, typically developed and high-risk infants 0-6 mo/ both	III Exploratory study	Observation of various grasping behaviours	Through various observations, the authors have described typical and atypical characteristics of the grasping behavior of infants. They have also highlighted stages of grasping and emphasized shifting of grasping behavior from general exploration to typical infant grasping and how it differs in infants with DS
19	Marchal et al, 2016[35]	Down Syndrome 6 months-10.7 y/ both	I Randomized Controlled Trial	Bayley Scale of Infant Development, Snijders-Oomen Nonverbal Intelligence test, Vineland Adaptive Behavior, M-ABC 2,	The participants were recruited right from their birth and a regular follow up every 2 mo were made. Their demographic data were recorded and different scales were used at different age intervals to score for various activities, such as early mental and motor development, intelligence at age of 10.7 y, adaptive functioning at age of 10.7 y, motor skills at age of 10.7 y.

(*continued on next page*)

Table 1 (*continued*)

Sr no	Title	Study population age & gender	Level of evidence/ study design	Outcome measure	Method
20	Masumoto et al, 2012[18]	Down Syndrome 15-17 y/ male	II Cross-sectional	Edinburgh Handedness Inventory scale	The apparatus consisted of two load cells used for finger tapping were amplified with a strain amplifier and displayed on an oscilloscope. Participants were seated facing load cells and were instructed to perform uni and bi-manual tapping movements at a target force of 2N.
21	Rigoldi et al, 2015[28]	Down Syndrome 21-25 y/ both	IV Pilot experimental study	IQ	The NMT was applied over cervical spine bilaterally, over the shoulder and extensors of the hand and fingers of the same dominant hand. The optoelectric system was used for graphic picture tracing like squares, circles and triangles.
22	Schott et al, 2014[11]	Down Syndrome and Typically developed 7-11/ both	II Cross-sectional study	Test of gross motor development, M-ABC,	Data was collected from gym of schools where the children wore proper sports dresses and running shoes and had not been attending any motor activity prior
23	Valvano et al, 2017[29]	Down Syndrome and Typically developed 6-13 y/ both	II Exploratory study	Three-dimensional kinematic evaluation of RTG (reach-to-grasp)	Participants began the trial by sitting on a chair and no back support, arm on table. The object was placed at the end of reach point measuring full arm length. First was a kaleidoscope, that was kept and the participants had to reach and grasp it then bring it towards the eye for viewing. second was a small box to measure trunk and upper limb coordination.
24	Wang et al, 2012[36]	Down Syndrome and age-matched typically developed 14-17 y/ both	II Cross-sectional study	Force plate, GMFM, BOT-2	Participants were supposed to stand on force plates with eyes open and closed for measuring postural control for 15 s, then they had to concentrate on the visual signal that was the cue for throwing a ball, GMFM and BOT-2 4 subtests for further evaluation.
25	Herrero et al, 2017[37]	Down syndromev 3-5 mo/ both	II Exploratory study	Prechtl method of global and detailed general movement assessment	Within GenGM 5 min video recording of the infant's mobility was recorded during the period of wakefulness, feeding, supine lying.
26	John et al, 2016[26]	Down Syndrome and age-matched typically developed 9-16 y	II Cross-sectional study	Jamar hydraulic dynamometer, B&L gauge pinch dynamometer, anthropometric measurement of arm using semi-flexible tape	The students were recruited from two special schools and grip and pinch strength was measured using a standardized protocol for three trials and the best out three scores were taken as the final score.
27	Girish et al, 2013[32]	Down syndrome, Left-handedness, hypothyroidism	I Review	Fingerprints	I



PRISMA. flow diagram.

Children with DS present motor impairments pertinent for continued studies on this population, mainly based on appropriate motor interventions and construction of standardized scales for populations with DS. An opportunity for sports evaluation and intervention especially in the DS population will aid in enhancing the skills of hand-eye coordination and perceptual-motor activities. It will also allow the medical team for providing better guidance towards an evaluation of manual skills concerning reaction time. Focus on evaluation of fine motor skills and training them efficiently will help to improve quality of life in the DS population.[3,5]

A lower extremity rhythmical activity such as walking, stimulates peripheral sensory inputs, that reach the motor cortex, which in turn leads to improvement of grip strength in the DS population.[44] Finger coordination through repeated finger tapping tasks improves fine motor activities, and helps children to have a carryover effect in their ADLs and perform them with ease. The NMT (neuromuscular taping) aids by stimulating skin receptors and thus, creates sensory efference copy.[20] This intervention reduces dependency on external stimuli for functional tasks performance.[28]

Conclusion

Thus, from this review, we conclude that physical characteristics of upper limb (such as anthropometric measurements of arm, forearm and hand) have an influence on hand function performance (like grip and pinch strength, fine motor functions, manual dexterity) in the DS population. Further, a comprehensive evaluation of upper limb anthropometric measurements and hand function is required. A correlational study of the upper limb measurements and hand function will help us design tailored-made rehabilitation in DS population (PRISMA 1).

Acknowledgments

The authors would like to thank the MGM Institute of Health Sciences (MGMIHS) for providing the facility of the Central Library to access databases and journals to complete this study. We also thank the Library Team, Dr Ram Prakash Dixit University Librarian, MGMIHS & Mr R Pradeep Ram Phadke, Assistant Librarian, MGM-SOP.

References

1. Beqaj Samire, Tërshnjaku Esmira, Qorolli Merita, Zivkovic Vujica. Contribution of physical and motor characteristics to functional performance in children and adolescents with down syndrome: a preliminary study. *Med Sci Monit Basic Res.* 2018;24:159–167. doi:10.12659/MSMBR.910448.
2. Sandra G. Bellamy and Eunice Yu Chiu Shen. Genetic Feedback- A Paediatric Perspective. Sixth Edition. Mosby/Elesiver 3251 Riverport Lane St. Louis, Missouri 63043; 2017.
3. Oliveira Cristina, Cavalcante Neto Jorge. Manual dexterity of children and adolescents with down syndrome: systematic review of the literature. *J Genet Syndr & Gene Ther.* 2016;7. doi:10.4172/2157-7412.1000305.
4. Chen Chih-Chia, Ringenbach DRS, Snow M. Treadmill walking effects on grip strength in young men with down syndrome. *Res Dev Disabil.* 2013;35:288–293. doi:10.1016/j.ridd.2013.10.032.

Please cite this article as: N. Padia, M. Bose and S. Parab, Determinants of hand function in children and adolescent with Down Syndrome-A scoping review, Journal of Hand Therapy, https://doi.org/10.1016/j.jht.2022.07.010

5. Zareian E, Delavarian F. Effect of sport stacking on fine motor proficiency of children with Down syndrome. *Int j sport stud*. 2014;4:1010–1016.
6. Cunningham C, Schester L, Black S, Liversidge H, Christie A. Developmental Juvenile Osteology. 2nd ed. Elesiver; 2016 London, UK.
7. James A, Merz Timothy, Janower Murray, Dorst John. Radiological features of the most common autosomal disorders: Trisomy 21–22 (Mongolism or Down syndrome), trisomy 18, trisomy 13–15, and the cri du chat syndrome. *Clin Radiol*. 1971;22:417–433. doi:10.1016/S0009-9260(71)80108-3.
8. Young Choi. *Comparison of grip and pinch strength in adults with dexterity limitations to normative values* Procedia Manuf; 2015:5326–5333.
9. Henderson, Pehoski. Hand Functions in the Child: Foundations for Remediation. 2nd edition. Elesiver; 2006 USA.
10. Campos Ana, Rocha Nelci, Savelsbergh Geert. Development of reaching and grasping skills in infants with Down syndrome. *Res Dev Disabil*. 2010;31:70–80. doi:10.1016/j.ridd.2009.07.015.
11. Schott Nadja, Holfelder Benjamin, Mousouli Ourania. Motor skill assessment in children with Down Syndrome: relationship between performance-based and teacher-report measures. *Res Dev Disabil*. 2014;35:3299–3312. doi:10.1016/j.ridd.2014.08.001.
12. ICF-An overview. PT6 Working paper (cdc.gov)
13. P ublic health classifications project – determinants of health; phase two: final report. classifications-project.pdf (nsw.gov.au)
14. LaCombe JM, Roper RJ. Skeletal dynamics of Down syndrome: a developing perspective. *Bone*. 2020;133:115215. doi:10.1016/j.bone.2019.115215.
15. Campos Ana, Cerra Larissa, Silva Fernanda, Rocha Nelci. Bimanual coordination in typical and atypical infants: movement initiation, object touching and grasping. *Res Dev Disabil*. 2014;35:2416–2422. doi:10.1016/j.ridd.2014.05.023.
16. Campos Ana, Costa Carolina, Savelsbergh Geert, Rocha Nelci. Infants with Down syndrome and their interactions with objects: development of exploratory actions after reaching onset. *Res Dev Disabil*. 2013;34:1906–1916. doi:10.1016/j.ridd.2013.03.001.
17. Jover Marianne, Ayoun Catherine, Berton Catherine, Carlier M. Development of motor planning for dexterity tasks in Trisomy 21. *Res Dev Disabil*. 2014;35:1562–1570. doi:10.1016/j.ridd.2014.03.042.
18. Masumoto Junya, Abe Takafumi, Inui Nobuyuki. Adolescents with down syndrome exhibit greater force and delay in onset of tapping movements. *Perceptual and motor skills*. 2012;114:826–836 10.2466%2F15.10.25.PMS.114.3.826-836.
19. Vimercati Sara, Galli Manuela, Stella G, Caiazzo G, Anci Andrea, Albertini Giorgio. Clumsiness in fine motor tasks: evidence from the quantitative drawing evaluation of children with Down Syndrome. *J Intellect Disabil Res*. 2014;59. doi:10.1111/jir.12132.
20. Latash Mark, Kang Ning, Patterson David. Finger coordination in persons with Down syndrome: atypical patterns of coordination and the effects of practice. *Exp brain res. Experimentelle Hirnforschung. Expérimentation cérébrale*.. 2002;146:345–355. doi:10.1007/s00221-002-1189-3.
21. Jover Marianne, Ayoun Catherine, Berton Catherine, Carlier M. Specific grasp characteristics of children with Trisomy 21. *Dev Psychobiol*. 2010;52:782–793. doi:10.1002/dev.20474.
22. Casajus José, Vicente-Rodríguez Germán, González-Agüero Alejandro, Matute-Llorente Ángel. Hand span influences optimal grip span in adolescents with Down syndrome. *Nutr Hosp*. 2017;34:626. doi:10.20960/nh.612.
23. Palma Lopes Jamile, Moura Renata, Lazzari Roberta, Duarte Natália, Dumont Arislander, Oliveira Claudia. Evaluation of upper limb movements in children with Down syndrome: a systematic review. *Infant Behav Dev*. 2018;51:45–51. doi:10.1016/j.infbeh.2018.03.001.
24. Priosti Paula, Blascovi-Assis Silvana, Cymrot Raquel, Vianna Denise, Caromano Fátima. Grip strength and manual dexterity in Down Syndrome children. *Fisioter. Pesqui*.. 2013;20:278–285. doi:10.1590/S1809-29502013000300013.
25. Campos, Ana, Francisco, Kelly, Savelsbergh, Geert & Rocha, Nelci. How do object size and rigidity affect reaching and grasping in infants with Down syndrome?*Res Dev Disabil*. 201; 32:246-52. doi: 10.1016/j.ridd.2010.09.023
26. Rebecca John, Dhanve Ankita, Rajani Mullerpatan. Grip and pinch strength in children with Down syndrome. *Hand Therapy*. 2016;21:85–89 10.1177%2F1758998316649102..
27. Holzapfel SD, Ringenbach SD, Mulvey GM, et al. Improvements in manual dexterity relate to improvements in cognitive planning after assisted cycling therapy (ACT) in adolescents with down syndrome. *Res Dev Disabils*. 2015;45-46:261–270. doi:10.1016/j.ridd.2015.08.003.
28. Rigoldi C, Galli M, Celletti C, Blow D, Camerota F, Albertini G. Does neuromuscular taping influence hand kinesiology? A pilot study on Down Syndrome. *La Clin Ter*. 2015;166(4):e257–e263. doi:10.7417/T.2015.1870.
29. Valvano Joanne, Hogy Sara, Worster Kate, et al. Analysis of reach-to-grasp by school-aged children with down syndrome elucidates limitations in upper extremity motor control. *Phys. Occup. Ther. Pediatr*.. 2017;37:1–15. doi:10.1080/01942638.2016.1261979.
30. Fidler Deborah, Will Elizabeth, Daunhauer Lisa, Tomaszewski Brianne, Visootsak Jeannie. Object-related generativity in children with Down syndrome. *Res Dev Disabil*. 2014;35:3379–3385. doi:10.1016/j.ridd.2014.07.024.
31. Maryanne Bruni. Fine motor skills for children with Down Syndrome: a guide for parents and professionals. 2nd edition. 2006
32. Jeevanandham, Lakshmi Prabha. (2021). A short review on Dermatoglyphics.
33. Memisevic Haris, Macak Amra. Fine motor skills in children with Down syndrome. *Spec. Edukac. Rehabil*.. 2014;13:365–377. doi:10.5937/specedreh13-7465.
34. Lobo Michele, Galloway James, Heathcock Jill. Characterization and intervention for upper extremity exploration & reaching behaviors in infancy. *J Hand Ther*. 2014;28. doi:10.1016/j.jht.2014.12.003.
35. Marchal Jan, Maurice-Stam Heleen, Houtzager Bregje, et al. Growing up with Down syndrome: development from 6 months to 10.7 years. *Res Dev Disabil*. 2016;59:437–450. doi:10.1016/j.ridd.2016.09.019.
36. Wang Hui-Yi, Long I-Man, Liu Mei-Fang. Relationships between task-oriented postural control and motor ability in children and adolescents with Down syndrome. *Res Dev Disabil*. 2012;33:1792–1798. doi:10.1016/j.ridd.2012.05.002.
37. Herrero D, Einspieler C, Panvequio Aizawa CY, et al. The motor repertoire in 3- to 5month old infants with Down syndrome. *Res Dev Disabil*. 2017;67:1–8. doi:10.1016/j.ridd.2017.05.006.

Please cite this article as: N. Padia, M. Bose and S. Parab, Determinants of hand function in children and adolescent with Down Syndrome-A scoping review, Journal of Hand Therapy, https://doi.org/10.1016/j.jht.2022.07.010

AB No: 46: Effect of Low Intensity Transcutaneous Electrical Nerve Stimulation (TENS) on Vastus Medialis Obliques Muscle Activation for Reduction in Pain and Improvement in Function in Patients with Chronic Osteoarthritis of Knee Joint

Author: Mamta Shetty and Rucha Pradhan
Affiliation: MGM School of Physiotherapy Navi Mumbai

DOI: 10.4103/2456-7787.361098

Purpose: Knee osteoarthritis is a leading cause of disability resulting in significant reduction of knee function and quadriceps strength with increase in pain. This study focuses on effects of low intensity TENS with exercises on Vastus medialis obliques muscle activation for osteoarthritis knee versus conventional exercises.
Relevance: TENS is known to be an effective modality used to alleviate pain, improve muscle strength, and function.
Participants: Study comprised of 38 participants with osteoarthritis knee (19 in each group) between 50–70 years age group as per ACR diagnostic criteria, selected by purposive random sampling.

Methodology: Group A received conventional exercises. Group B received TENS on Vastus Medialis Obliques muscle additionally. They were assessed pre intervention, 6th week and 12th week of study using NRS, Modified WOMAC, Bergs Balance Scale and 30 Second Chair Stand Test

Analysis: Data was analyzed using SPSS software (Version 24; USA, 2019) and Shapiro- Wilk test was used to assess normality.

Results: Intra group analysis reported reduction in pain (p=0.00) level (on NRS- 63.6% in group A and 39.6% in group B; on WOMAC- 72.4% in group A and 36.6% in group B), increase in function by 56.4% in group A and 33% in group B (p=0.00), and improvement in strength by 35% in group A and 0.2% in group B (p=0.00). No significant improvement was noted on inter group comparison in pain (p= 0.086), function (p= 0.066) and strength (p=0.190) post 12 weeks of intervention.

Conclusion: Findings from present study report application of Low Intensity TENS for Vastus Medialis Obliques muscle activation along with exercise versus conventional exercises demonstrated no significant difference on chronic osteoarthritis knee patients for pain, function and strength.

Implications: TENS would act as an adjunct to conventional treatment of osteoarthritis in not only chronic stage but also in early stages. It could also be implied to any age group having osteoarthritis

Keywords: Osteoarthritis Knee, Pain, Function, Strength, Low intensity TENS, Exercise

Review Article

A review of the physiological effects of Suryanamaskar in children

Abhijeet K. Kanojia, Hiranmayee S. Bagwe, Bela M. Agarwal

MGM School of Physiotherapy, MGM Institute of Health Sciences (Deemed to be University), Kamothe, Navi Mumbai, Maharashtra, India

Abstract

Increasing physical inactivity in children necessitates the exploration of physical activities that can confer health benefits. The purpose of this study was to review the literature regarding the physiological benefits of Suryanamaskar, a composite yogasana on physical fitness in children. Primary source articles in English, published between 1980 and 2020, in peer-reviewed journals were included. A literature review was carried out using PubMed, Cochrane-Library, Science Direct, and Google Scholar databases. Keywords used were "Suryanamaskar," "physical fitness," "sun-salutation," "physiological effects," "physical activity," "health promotion," "yoga," and "children." The methodological quality of the studies was assessed using the Physiotherapy Evidence Database scale. The effect of Suryanamaskar training on physical fitness components, namely flexibility, muscle strength, cardiorespiratory endurance, and cognition, was reviewed. Seven studies matched the inclusion criteria. All seven studies were randomized controlled trials. The level of evidence was of fair quality with a high risk of bias. Following Suryanamaskar intervention, improvement in musculoskeletal function—muscle strength and endurance, and the flexibility of hip joint, wrist joint, hamstrings, and dorso-lumbar fascia were reported. Improvements in cardiorespiratory variables such as peak expiratory flow rate forced vital capacity, forced expiratory volume, vital capacity, and reduction in blood pressure and heart rate are reported in children. Improvements in cognition were also observed following Suryanamaskar's intervention. Suryanamaskar training confers health benefits and improves physical fitness components such as muscle strength, flexibility, cardiorespiratory endurance, and cognition. Suryanamaskar can emerge as a useful tool to increase physical fitness, deter physical inactivity, and promote healthy behavior (sanskar) in school-going children. High-quality longitudinal randomized control trials need to be undertaken to confirm the same.

Keywords: Health promotion, physical activity, physical fitness, physiological effects, Sun salutation, Suryanamaskar, yoga

Address for correspondence: Dr. Bela M. Agarwal, MGM School of Physiotherapy, MGM Institute of Health Sciences (Deemed to be University), Kamothe, Navi Mumbai 410209, Maharashtra, India.
E-mail: bagarwal@mgmsopnm.edu.in

Received: 11-07-2022
Accepted: 03-08-2022
Published: 29-09-2022

Access this article online	
Quick Response Code:	Website: www.mgmjms.com
	DOI: 10.4103/mgmj.mgmj_106_22

INTRODUCTION

The World Health Organization (WHO) estimates that over 170 million children, less than 18 years of age, in

How to cite this article: Kanojia AK, Bagwe HS, Agarwal BM. A review of the physiological effects of Suryanamaskar in children. MGM J Med Sci 2022;9:410-8.

developing countries are physically inactive.[1] WHO recommendations for daily physical activity for children aged 5–17 years include engaging in 60 min of moderate-to-vigorous activity. According to the Centers for Disease Control and Prevention, only 17%–39% of children in the United States are involved in organized physical activity for at least 60 min per day.[1,2] Similar observations are reported from European and Asian countries.[3-5]

In developing countries, like India, a decline in moderate-to-vigorous physical activity is observed among urban school children.[1,6] Children engage in physical activity either during physical education classes during school hours or recreational playtime over weekends. Physical training in Indian educational institutes is restricted to less than 30–60 min of physical education activity period once or twice a week, which is inadequate and unstructured.

Further, it is well known that the practice of regular physical activity promotes fitness and enables a person to perform daily activities without fatigue. The modification of a sedentary lifestyle can contribute to an active and healthy life beyond childhood and adolescence.[7,8] Industrialization has brought about changes in lifestyle with greater engagement of children in sedentary activities.[6] Reduced physical fitness in children is associated with an elevated risk of presenting an increase in body mass index, elevated lipoproteins and cholesterol level, and developing obesity and insulin-resistance juvenile diabetes mellitus in school-aged children.[2,9-11]

General recommendations for promoting physical activity in children include engagement in structured play, games, sports, planned exercise or physical education activity, and yoga.[1,12,13] Yoga has been practiced for over 5000 years and is an ancient form of physical activity that encompasses breathing techniques, postures, strengthening exercises, and meditation. The practice of yoga originated in India and has slowly gained popularity all over the world.[14]

Suryanamaskar is one of the ancient yogic practices, which means "to worship the Sun." In Suryanamaskar, "*Surya*" denotes the Sun, and "*namaskar*" denotes salutation; therefore this yogic practice is discerned as "salutation to the Sun."[15]

Suryanamaskar is a set of six asanas or postures performed in a cyclic reversal, which include *Pranamasana* (prayer pose) as the first and 12th pose, *Hasta uttanasana* (raised arms pose) as the second and 11th pose, *Hastapadasana* (hand to foot) as the third and 10th pose, *Ashwa sanchalanasana* (equestrian pose) as the fourth and ninth pose, *Parvatasana* (mountain pose) as the fifth and eighth pose, *Ashtanga namaskar* (salutation with eight parts) as the sixth and ninth pose, and *Bhujangasana* (Cobra pose) as the seventh pose performed preferably in the morning facing the rising Sun[16,17] [Figure 2].

The benefits of Suryanamaskar on the musculoskeletal, cardiovascular, neurological, gastrointestinal, and endocrinal systems have been studied predominantly in adults.[18] Suryanamaskar confers great benefits on health, stamina, mental stability, physical strength, and mental calmness and is believed to revitalize cellular function.[10]

Regular practice of Suryanamaskar has been reported to improve blood circulation, to maintain health, to increase strength, flexibility, and the general feeling of well-being in adults. Physiological benefits include increased blood circulation to the brain and spinal mobility due to the various 12 positions achieved in Suryanamaskar. It also helps improve the peristaltic movement of the gut and cardiac myocardial contractility.[16]

Simultaneously, Suryanamaskar develops neuromuscular awareness (i.e., coordination and movement control), maintains healthy body weight, prevents chronic illnesses such as cancer, type 2 diabetes, and cardiovascular diseases, maintains good mental health, improves sleep, and lowers stress.[14] However, the physiological effects of Suryanamaskar have not been reviewed in children.

Therefore, there is an urgent need to review the physiological effects of Suryanamaskar and the benefits conferred on various body systems by performing Suryanamaskar intervention in children. Thus, a systematic review was undertaken to inform existing evidence of physiological effects of Suryanamaskar for health promotion in children.

MATERIALS AND METHODS

The study was commenced following ethical approval from the Institution Ethical Review Committee. A systematic review was carried out to review existing knowledge regarding the physiological effects of Suryanamaskar in children to enable the prescription of Suryanamaskar as a healthy lifestyle measure. A review of the literature was performed using the Preferred Reporting Items for Systematic Review and Meta-Analyses guidelines. PubMed, Cochrane Library, Science Direct, and Google Scholar databases were searched using keywords "Suryanamaskar" AND "Children" AND "Physical fitness" OR "Yoga" OR "Sun salutation" [Figure 1].

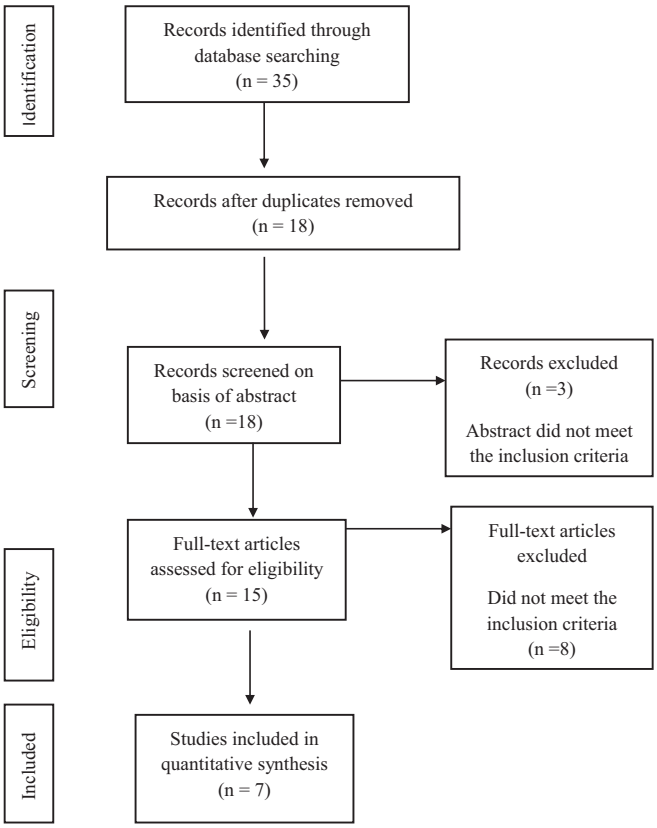


Figure 1: Flow diagram of the study selection process

Studies that included Suryanamaskar intervention in healthy children, in the age group of 9–15 years, published in the English language, in peer-reviewed journals were considered for inclusion. Studies with yoga interventions other than Suryanamaskar were not included. Studies included in the review were then screened in three stages: title screening, abstract screening, and screening for full-text articles. Titles that did not meet eligibility criteria were excluded. Further, abstracts of eligible studies were screened for content. The full texts of relevant articles were included in the review.

Each eligible article was reviewed for the objective of the study, age of the population included in the study, study design, outcome variables (physiological parameters, flexibility, vital capacity, musculoskeletal strength and endurance, and coordination), assessment tools, and primary observations. The internal validity of each article was independently assessed by using Physiotherapy Evidence Database (PEDro) score for randomized control trial (RCT) studies. The tool assesses the ability of each study to conclude the link between eligibility criteria and the physical parameters of the study. Flaws in the design and methodology of the study can increase the risk of bias and decrease the internal validity of the article. Two reviewers (AK and HB) scored each of the 11 items of the quality assessment tool as "YES" (√) and "NO" (×). To compare the risk of bias across studies, the answers weighted as "YES" were assigned a score of 1 and "NO" was assigned a score of 0. The total score for each study was used to classify the quality of the study and the risk of bias. Score < 4 was considered "poor," 4–5 were considered "fair," 6–8 were considered "good," and 9–10 were considered "excellent."[19,20] In case of conflict between the assessors, a third reviewer (BA) assessed the methodological quality of the study [Tables 1 and 2].

RESULTS

Thirty-five studies were identified using the keywords. Seventeen titles were identified as duplicates and were excluded. Abstracts of 18 articles were screened. Three studies did not meet the eligibility criteria and were excluded from the review process. The full text of the remaining 15 articles was reviewed. Eight full-text articles were excluded as they did not meet the eligibility criteria. Seven RCTs meeting the inclusion criteria were included in this review.

Quality assessment interpretation

As per the PEDro scale, all studies were of fair quality with clearly defined eligibility criteria, objectives, inclusion–exclusion criteria, and variables. Participants were randomized to Suryanamaskar or a control condition. However, a high risk of bias was observed as none of the studies included blinding of participants or researchers. Individual characteristics of the study group, gender classification, duration of intervention, type of Suryanamaskar, and clinical variables studied are described in the further sections. The level of evidence based on Sackett is 2a (limited), at least one "fair" quality RCT (PEDro scale score = 4–5).

Characteristics of the study group

Most studies included school-going children in the age group 9–15 years. Both male and female children were included in three studies (n = 221), whereas four studies included only male children (n = 126). The gender distribution of the total number of samples was 53% boys and 47% girls. The duration of Suryanamaskar intervention ranged between 8 and 12 weeks.

Types of Suryanamaskar

The various studies included some variations in the types of Suryanamaskar studied. The forms used were slow Suryanamaskar, fast Suryanamaskar, Hatha Suryanamaskar, Vinyasa Sun salutation, mantra chanting with Suryanamaskar, and breathing control with Suryanamaskar.

In slow Suryanamaskar, participants performed all 12 poses slowly and rhythmically in which all 12 postures were held

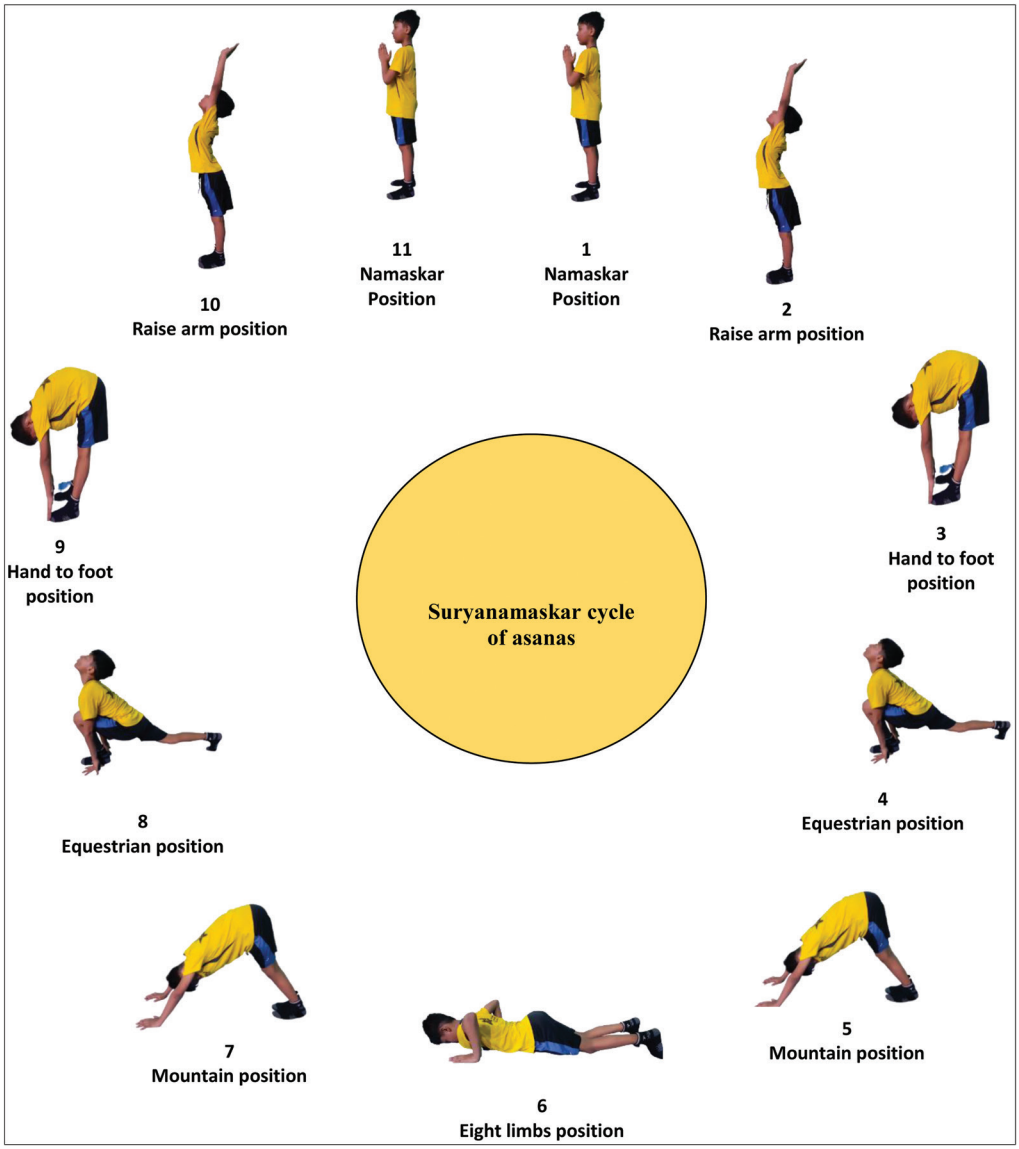


Figure 2: Suryanamaskar poses

Table 1: PEDro score quality assessment scale (PEDro scale)

	Bhavanani *et al*., 2011[21]	Sharma and Acharya[22]	Sasi Kumar *et al*., 2011[23]	Javadekar and Manjunath 2012[24]	Pal 2014[2]	Pal 2014[25]	Pal 2014[26]
Eligibility criteria	√	√	√	√	×	×	×
Randomized allocation	×	√	√	√	√	√	√
Concealed allocation	×	×	×	×	×	×	×
Comparable at baseline	√	√	√	√	√	√	√
Blinded subjects	×	×	×	×	×	×	×
Blinded therapist	×	×	×	×	×	×	×
Blinded assessors	×	×	×	×	×	×	×
Adequate follow-up	×	×	×	×	×	×	×
Intention to treat analysis	×	×	×	×	×	×	×
Between-group comparisons	√	√	×	√	√	√	√
Point estimate and variability	√	√	√	√	√	√	√
Total score	4/10 Fair quality	5/10 Fair quality	4/10 Fair quality	5/10 Fair quality	4/10 Fair quality	4/10 Fair quality	4/10 Fair quality

for 30 s. In fast Suryanamaskar, participants were instructed to perform all 12 postures rapidly without any holds. Vinyasa Sun salutation focused on dynamic connecting posture that created a link between Suryanamaskar poses and breathing. These postures are performed at a quicker pace than other forms of Suryanamaskar. In one study,

Table 2: Study selection process

Authors	Study type and sample size	Population	Intervention	Primary outcome	Outcome measures
1. Bhavanani *et al*., 2011[21]	Interventional study *n* = 42 Two groups with 21 children in each group	School children, 12–16 years of age	Group 1–Fast Suryanamaskar was performed in such a way that all 12 postures were completed in 2 min, and to complete 15 rounds of Suryanamaskar, took 30–40 min	Slow Suryanamaskar reduced diastolic pressure, whereas fast Suryanamaskar increased systolic pressure	Isometric handgrip, respiratory pressure such as MIP, and MEP measured by mercury manometer Pulmonary function test, PEFR, FVC, and FEV were measured by computerized spirometer
	Group 1 performed fast Suryanamaskar Group 2 performed slow Suryanamaskar		Group 2–Slow Suryanamaskar was performed such that each of the 12 postures was held for 30 s. Each round was completed in 6 min, five rounds were performed in 30–40 min. Duration of intervention is 6 months	Both types increased isometric handgrip strength and endurance, increased MIP, and peak flow rate	Cardiovascular parameter–blood pressure (BP)–was measured using semi-automatic BP monitor
2. Javadekar and Manjunath 2012[24]	Interventional study *n* = 64 32 in each group	School children, 12–14 years	The experimental group underwent Suryanamaskar practice	Suryanamaskar group showed a 16.7% improvement	DLST visual scanning, mental flexibility, sustained attention, psychomotor speed of information processing
			The control group underwent routine physical exercises for 30 days	The physical exercise group showed 13.2% improvement in DLST. No difference was observed between the two activities	
3. Sasi Kumar *et al*., 2011[23]	Interventional study *n* = 115	School children, 10–14 years of age	Suryanamaskar was performed for 45 days Cardiorespiratory parameters–BP, heart rate, RR, FVC, and PEFR–were measured pre- and postintervention	An increase in FVC and PEFR was observed Reduction in heart rate, diastolic pressure, and RR was reported after the practice of Suryanamaskar	FVC was measured by a spirometer, PEFR by using mini-Wright peak flow meter, BP using a sphygmomanometer, and RR by manual method
4. Pal 2014[25]	Interventional study *n* = 30 15 in each group The experimental group performed a Vinyasa Sun salutation The control group was given no intervention	School children, 14–16 years	The experimental group performed Vinyasa training for 45 min in the morning, 3 days a week for 8 weeks The control group continued routine daily activities	Participants who followed Vinyasa Sun salutation training improved their hip joint flexibility higher than participants in the control group	Hip joint flexibility was measured using goniometry
5. Pal 2014[26]	Interventional study *n* = 30 15 in each group The experimental group performed Vinyasa Sun salutation The control group was given no training protocol	14–16 years student	The experimental group performed Vinyasa training for 45 min in the morning 5 days a week for 8 weeks The control group continued routine daily activities	An increase in vital capacity (VC) was observed following Vinyasa training	VC was measured by a dry spirometer and recorded in liters
6. Pal 2014[2]	Interventional study *n* = 30 15 in each group	School children, 14–16 years	The experimental group performed Vinyasa training for 45 min in the morning, 3 times a week for 8 weeks. The control group continued a basic daily routine	A significant difference was seen in the experimental group who followed Vinyasa Sun salutation poses, which improved wrist joint flexibility among school-going children	Flexibility for the wrist joint was measured using a goniometer in degrees

Table 2: Continued

Authors	Study type and sample size	Population	Intervention	Primary outcome	Outcome measures
	The experimental group performed Vinyasa Sun salutation The control group was given no training protocol				
7. Sharma and Acharya[22]	School children, 13–15 years of age	Group 1 performed Suryanamaskar with mantra chanting Group 2 performed Suryanamaskar with a fixed breathing pattern Group 3 performed general Suryanamaskar For 45–50 min for 5 days a week for 6 weeks	No difference was observed on the DLST between the mantras and breathing group and breathing and control group following the intervention	DLST involves visual scanning, mental flexibility, sustained attention, psychomotor speed of information processing	

FVC = forced vital capacity

one group of children performed mantra chanting and another group performed breathing control with 12 Suryanamaskar poses.[9,25,27] Hatha Suryanamaskar consisted of 12 spinal poses performed with emphasis on breathing patterns and was the commonest form practiced. Poses included were *Pranamasana*, *Hasta uttanasana*, *Hastapadasana*, *Ashwa sanchalanasana*, *Parvatasana*, *Ashtanga namaskar*, and *Bhujangasana* performed in a cyclic manner.[16,17]

Effect of Suryanamaskar on physiological variables

Cardiorespiratory variables

Three studies observed a significant improvement in the cardiorespiratory variables post-Suryanamaskar intervention. Significant improvement was observed in systolic blood pressure and diastolic blood pressure with Suryanamaskar training. Resting cardiovascular variables such as heart rate and diastolic blood pressure decreased significantly following Suryanamaskar training for 6 months.[23,25,26]

Studies reported a significant improvement in peak expiratory flow rate (PEFR), forced vital capacity (FVC), and a decrease in respiratory rate (RR) after Suryanamaskar practice.[23,25,26] PEFR and FVC were measured using spirometer.[28] Change in lung volumes was observed following both slow and fast Suryanamaskar. Similarly, pulmonary functions such as PEFR, FVC, and forced expiratory volume (FEV) increased following both fast Suryanamaskar and slow Suryanamaskar. Additionally, an increase in respiratory muscle strength evaluated using maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) was observed following the Suryanamaskar intervention. A greater increase in MIP was reported following fast Suryanamaskar compared with slow Suryanamaskar, whereas a greater increase in MEP was observed in the slow Suryanamaskar group compared with the fast Suryanamaskar group. These values were measured using a mercury manometer.[25]

Muscle strength and endurance

Studies have reported an improvement in muscle strength and endurance following Suryanamaskar. Isometric handgrip strength endurance and time for 33% of isometric handgrip, i.e., handgrip endurance, improved in children performing fast and slow Suryanamaskar, with a greater increase in the fast Suryanamaskar group. Handgrip strength was measured with the dominant hand gripping the inflated cuff of mercury and sustaining the gripped cuff measured the handgrip endurance.[13,15,29]

Flexibility

A significant improvement in the flexibility of children is reported following Suryanamaskar intervention.[2] The flexibility of hip and wrist joints was observed to increase after 8 weeks of Vinyasa Suryanamaskar training. Flexibility was assessed by recording joint range of motion using a standard goniometer.[2]

Cognition

Two studies report a significant improvement in the cognition and reaction time in children after Suryanamaskar intervention.[23,30] Significant difference in the performance of the digit letter substitution test (DLST) was reported between children performing Suryanamaskar with mantra chanting for 6 weeks compared with the control group children who did not perform any intervention.[24,28]

DISCUSSION

This systematic review was undertaken to identify the physiological effects of Suryanamaskar and the benefits to include this style of yogic practice (Suryanamaskar) in routine physical activity for health promotion in children. Based on a literature review inclusive of seven studies, the benefits of Suryanamaskar on physical fitness and mental health are discussed further.

Most of the reviewed studies included school-going children in the age group 9–15 years. Children younger than 9 years were not included in any of the reviewed studies. All interventions were carried out during school hours, indicating that the inclusion of Suryanamaskar into the physical education curriculum is a feasible option for the health promotion of children within the school environment. Children of both genders were included in the studies reflecting on the application of common physiological benefits to both genders.

First, an improvement in the cardiorespiratory function is reported after Suryanamaskar training.[25-27] Resting cardiovascular variables such as heart rate decrease with increased training of Suryanamaskar. Systolic blood pressure was observed to increase, and diastolic blood pressure decreased significantly with increased Suryanamaskar training. Suryanamaskar is a dynamic aerobic activity that activates large muscles of the trunk and lower extremity, thus placing a volume overload on the heart. The dynamic muscle contractions help increase venous return and cardiac output during exercise. Long-duration training leads to the conditioning of the skeletal muscles with enhanced mitochondrial oxygen extraction and aerobic enzymatic activity, thus reducing the O2 demand following training.[21,25]

A significant improvement is reported in PEFR, FVC along with a reduction in RR.[31] Also respiratory pressures such as MIP and MEP show a significant improvement that increases the endurance and strength of respiratory and expiratory muscles. In pulmonary functions, FVC and FEV increased significantly.[29] VO2max value was also hypothesized to have a significant improvement after practicing Suryanamaskar with physical activity exercise.[1] Suryanamaskar asana such as *Hasta uttanasana, Bhujangasana,* and *Ashtangasana* stretch the respiratory and intercostal muscles, thus facilitating respiratory muscle contraction. This concept can be related to the Frank Starlings law, which suggests that greater stretch of the muscle leads to forceful muscular contraction.[32] Similarly, compression of the abdominal contents with a consequent diaphragm stretch during *Ashwa sanchalanasana* can increase tidal breathing and subsequently the vital capacity following long-duration training. Further, breathing coordination with exhalation during trunk flexion and inspiration during trunk extension along with mantra chanting improve total lung capacity as it improves the strength of respiratory muscles, which leads to adequate inflation and deflation of the lungs as the respiratory muscles work to their maximal extent.[17,33]

Second, muscle strength and endurance were reported to improve following Suryanamaskar intervention in children. Performing the 12 asanas included in Suryanamaskar demands isotonic muscle activation, whereas the maintenance of the postures requires isometric contraction during the steady state of different postures in Suryanamaskar as shown in Figure 2. Suryanamaskar is a well-sequenced composite asana designed in such a way that soft tissues such as the fascia muscles are stretched and joints undergo a varying degree of flexion and extension movements. While performing asanas such as *Hasta uttanasana, Hasta padasana, Ashwa sanchalanasana, Ashtangasana, Parvatasana,* and *Bhujangasana*, major muscle activity is observed in erector spinae, latissimus dorsi, lower trapezius, gastrocnemius gluteus maximus, vastus lateralis, and rectus abdominis. The activation of these postural muscles improves the posture of the body.[16,31] The regular performance of Sun salutation training thus strengthens the muscles of the lower extremity and trunk and improves muscle strength and general body endurance.[1,3,30]

Further, in comparison between fast and slow Suryanamaskar, studies indicate a greater increase in muscle strength following fast Suryanamaskar.[25] During physical activity, motor units are recruited in order of size during voluntary contraction concerning the increase in force and effort. During fast Suryanamaskar, the high-intensity exercise leads to increased recruitment of large motor units that produce greater muscle contraction and confers greater gains in muscle strength.[32]

Third, Suryanamaskar involves 12 asanas that demand alternate flexion and extension postures of the spine and extremities. These alternate postures improve

the stretchability of muscles of the lower limb, back, thorax, gluteal group of muscle, and length of the fascial structures such as the dorso-lumbar fascia.[10] Asanas such as the *Hasta padasana* stretches the hamstring and calve muscles while bringing about a complete flexion of the spine and hips, whereas *Bhujangasana* brings about the complete extension of the spine and hips.[10,17] It has also been shown to increase the flexibility of the hip joint, knee joint, ankle joint, and wrist joint.[2,25,29] Studies indicate that Suryanamaskar moves the joints of the spine and lower extremity through a large range of motion, which can result in the overall improvement in body flexibility observed following the regular practice of Suryanamaskar.[34]

Lastly, cognition was observed to be improved significantly following Suryanamaskar training, in the parameters such as DLST. Mantra chanting during the practice of Suryanamaskar improves sustained attention, visual scanning, mental flexibility, sustained attention, and psychomotor speed of information processing, leading to enhanced performance on DLST.[25,28,35]

This review summarizes the benefits offered by Suryanamaskar in children in the age group of 9–15 years on health-related physical fitness domains such as muscular strength and endurance, flexibility, cardiovascular and respiratory endurance cognition, and reaction time.[35] Existing studies were methodological of fair quality. Thus, better quality RCTs with a low level of bias need to be undertaken to establish the role of Yoga and Suryanamaskar as a lifestyle practice and health promotion strategy in school-going children.

The current review identified a lacuna in information regarding the benefits of Suryanamaskar on performance measures such as balance, speed, and agility. Further research is required in this area to study the comprehensive health benefits of Suryanamaskar in children. Most studies have been undertaken to include healthy children; therefore, the benefits of Suryanamaskar can be explored in children with attention disorders and children with developmental disorders.

CONCLUSION

Based on the current review, it can be concluded that Suryanamaskar training improves muscle strength and endurance, flexibility, cardiorespiratory function, cognition, and reaction time in children. The inclusion of Suryanamaskar into the regular physical education curriculum at school emerges as a feasible plan to increase physical fitness, deter physical inactivity, and promote healthy behavior (sanskar) in school-going children.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Shimpi A, Shetye J, Mehta A. Comparison between the effect of equal intensity training with Suryanamaskar or physical education activity or combination of both on physical fitness in adolescent urban school children—A randomized control trial: A hypothesis. J Med Thesis 2014;2:35-8.
2. Pal D. Effect of Vinyasa Sun salutation on wrist joint flexibility in school-going children. J Educ Chron 2014;5:98-100.
3. Peltzer K, Pengpid S. Leisure time physical inactivity and sedentary behaviour and lifestyle correlates among students aged 13-15 in the association of Southeast Asian Nations (ASEAN) member states, 2007-2013. Int J Environ Res Public Health 2016; 13:217.
4. Santaliestra-Pasías AM, Mouratidou T, Verbestel V, Bammann K, Molnar D, Sieri S, *et al*.; IDEFICS Consortium. Physical activity and sedentary behaviour in European children: The IDEFICS study. Public Health Nutr 2014;17:2295-306.
5. Riddoch CJ, Bo Andersen L, Wedderkopp N, Harro M, Klasson-Heggebø L, Sardinha LB, *et al*. Physical activity levels and patterns of 9- and 15-year-old European children. Med Sci Sports Exerc 2004;36:86-92.
6. Karkera A, Swaminathan N, Pais SM, Vishal K, Rai B S. Physical fitness and activity levels among urban school children and their rural counterparts. Indian J Pediatr 2014;81:356-61.
7. Malina RM, Katzmarzyk PT. Physical activity and fitness in an international growth standard for preadolescent and adolescent children. Food Nutr Bull 2006;27:S295-313.
8. Hussey J, Bell C, Bennett K, O'Dwyer J, Gormley J. Relationship between the intensity of physical activity, inactivity, cardiorespiratory fitness and body composition in 7-10-year-old Dublin children. Br J Sports Med 2007;41:311-6.
9. Kumar G, Monga G, Gothi N. Measuring impact of Surya Namaskar and Pranayama for management of child obesity in India. Int J Contemp Pediatr 2019;6:352.
10. Meena G, Venkatesan R. Effects of resistance, Suryanamaskar and combined training with almond supplementation on selected serum electrolytes among obese school children. Int J Health Phy Educ Comput Sci Sports 2018;29:55-9.
11. Raj M, Sundaram KR, Paul M, Deepa AS, Kumar RK. Obesity in Indian children: Time trends and relationship with hypertension. Natl Med J India 2007;20:288-93.
12. Sharma B, Chavez RC, Nam EW. Prevalence and correlates of insufficient physical activity in school adolescents in Peru. Rev Saude Publica 2018;52:51.
13. Strong WB, Malina RM, Blimkie CJ, Daniels SR, Dishman RK, Gutin B, *et al*. Evidence based physical activity for school-age youth. J Pediatr 2005;146:732-7.
14. Li AW, Goldsmith CA. The effects of yoga on anxiety and stress. Altern Med Rev 2012;17:21-35.
15. Bryant EF. The Yoga Sutras of Patanjali: A New Edition, Translation, and Commentary with Insights from the Traditional Commentators. New York: North Point Press; 2009. p. 598.

16. Nikam VM. A role of "Surya Namaskara" for good health. Aayushi Int Interdiscip Res J 2020;7:2349-638.
17. Vaibhav A, Shukla S, Singh OP. Surya Namaskar (Sun salutation): A path to good health. Int J Pharmaceut Res 2016;6:44.
18. Saraswati S. Surya Namaskar: A Technique of Solar Vitalization. Munger, Bihar: Yoga Publication Trust, Ganga Darshan; 1983. p. 97.
19. Joseph S. Effect of yoga practices, Suryanamaskar, and meditation on the psychological well-being of female school basketball players. In: Suresh Kumar M, editor. Modern Perspectives of Sports Science and Yoga for the Enhancement of Sports Performance, 3rd March 2018, Proceedings. Pudukkottai, Tamil Nadu: Research Department of Physical Education, Ganesar College of Arts and Science; 2018. p. 13-6.
20. de Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: A demographic study. Aust J Physiother 2009;55:129-33.
21. Bhavanani AB, Udupa K, Madanmohan, Ravindra P. A comparative study of slow and fast suryanamaskar on physiological function. Int J Yoga 2011;4:71-6.
22. Sharma VK, Acharya J. Effect of 6-weeks training of mantras and breathing in Surya Namaskar on performance of digit-letter substitution task by school children. Int J Hum Mov Sports Sci 2017;2:33-7.
23. Sasi Kumar A, Sivapriya DV, Thirumeni S. Effects of Suryanamaskar on cardiovascular and respiratory parameters in school students. Recent Res Sci Technol 2011;3:19-24.
24. Javadekar P, Manjunath NK. Effect of Surya namaskar on sustained attention in school children. J Yoga Phys Ther 2012;2:1-4.
25. Pal D. Effect of Vinyasa Sun salutation on flexibility among school children. Int J Phy Educ Health Social Sci 2014;3:1-3.
26. Pal D. Effect of Vinyasa Sun salutation on vital capacity among school-going children. J Educ Chron 2014;5:100-2.
27. Bhutkar MV, Bhutkar PM, Taware GB, Surdi AD. How effective is Sun salutation in improving muscle strength, general body endurance and body composition? Asian J Sports Med 2011;2:259-66.
28. Cashin AG, McAuley JH. Clinimetrics: Physiotherapy Evidence Database (PEDro) scale. J Physiother 2020;66:59.
29. Mohanty S, Venkata Ramana Murty P, Pradhan B, Hankey A. Yoga practice increases minimum muscular fitness in children with visual impairment. J Caring Sci 2015;4:253-63.
30. Vigneshwaran G. Influence of Suryanamaskar practices on back strength among male college students. Int J Adv Res Innov Ideas Educ 2016;2:1808-10.
31. Sinha B, Ray US, Pathak A, Selvamurthy W. Energy cost and cardiorespiratory changes during the practice of Surya namaskar. Indian J Physiol Pharmacol 2004;48:184-90.
32. Sale DG. Influence of exercise and training on motor unit activation. Exerc Sport Sci Rev 1987;15:95-151.
33. Chandrasekhar M, Ambareesha K, Nikhil C. Effect of Pranayama and Suryanamaskar on pulmonary functions in medical students. J Clin Diag Res 2014;8:BC04.
34. Mullerpatan RP, Agarwal BM, Shetty T, Nehete GR, Narasipura OS. Kinematics of suryanamaskar using three-dimensional motion capture. Int J Yoga 2019;12:124-31.
35. Drenowatz C, Greier K, Ruedl G, Kopp M. Association between club sports participation and physical fitness across 6 to 14-year-old Austrian youth. Int J Environ Res Public Health 2019;16:3392.

European Spine Journal (2022) 31:1333–1342
https://doi.org/10.1007/s00586-022-07194-y

REVIEW ARTICLE

SPINE20 recommendations 2021: spine care for people's health and prosperity

Giuseppe Costanzo[1] · Bernardo Misaggi[2] · Luca Ricciardi[1] · Sami I. AlEissa[3] · Koji Tamai[4] · Fahad Alhelal[5] · Yahya Alqahtani[6] · Hana I. Alsobayel[7] · Markus Arand[8] · Massimo Balsano[9] · Thomas R. Blattert[10] · Marco Brayda-Bruno[11] · Jamiu O. Busari[12] · Marco Campello[13] · Harvinder S. Chhabra[14] · Francesco Ciro Tamburrelli[15] · Pierre Côté[16] · Bambang Darwono[17] · Frank Kandziora[18] · Giovanni A. La Maida[19] · Eric J. Muehlbauer[20] · Raghava D. Mulukutla[21] · Paulo Pereira[22] · Shanmuganathan Rajasekaran[23] · Dominique A. Rothenfluh[24] · William J. Sullivan[25] · Eeric Truumees[26] · Edward J. Dohring[27] · Tim Pigott[28] · Ajoy P. Shetty[23] · Marco G. A. Teli[29] · Jeffrey C. Wang[30] · Christopher Ames[31] · Johannes R. Anema[32] · Anand Bang[33] · Kenneth M. C. Cheung[34] · Douglas P. Gross[35] · Scott Haldeman[36] · Salvatore Minisola[37] · Rajani Mullerpatan[38] · Stefano Negrini[39,40] · Louis-Rachid Salmi[41] · M. Silvia Spinelli[42] · Adriaan Vlok[43] · Kwadwo P. Yankey[44] · Fabio Zaina[45] · Ahmed Alturkistany[46] · Jörg Franke[47] · Ulf R. Liljenqvist[48] · Michael Piccirillo[20] · Margareta Nordin[49]

Received: 18 December 2021 / Revised: 18 December 2021 / Accepted: 19 March 2022 / Published online: 7 April 2022

Abstract

Purpose The focus of SPINE20 is to develop evidence-based policy recommendations for the G20 countries to work with governments to reduce the burden of spine disease, and disability.

Methods On September 17–18, 2021, SPINE20 held its annual meeting in Rome, Italy. Prior to the meeting, the SPINE20 created six proposed recommendations. These recommendations were uploaded to the SPINE20 website 10 days before the meeting and opened to the public for comments. The recommendations were discussed at the meeting allowing the participants to object and provide comments.

Results In total, 27 societies endorsed the following recommendations. SPINE20 calls upon the G20 countries: (1) to expand telehealth for the access to spine care, especially in light of the current situation with COVID-19. (2) To adopt value-based interprofessional spine care as an approach to improve patient outcomes and reduce disability. (3) To facilitate access and invest in the development of a competent rehabilitation workforce to reduce the burden of disability related to spine disorders. (4) To adopt a strategy to promote daily physical activity and exercises among the elderly population to maintain an active and independent life with a healthy spine, particularly after COVID-19 pandemic. (5) To engage in capacity building with emerging countries and underserved communities for the benefit of spine patients. (6) To promote strategies to transfer evidence-based advances into patient benefit through effective implementation processes.

Conclusions SPINE20's initiatives will make governments and decision makers aware of efforts to reduce needless suffering from disabling spine pain through education that can be instituted across the globe.

Keywords SPINE20 · G20 · Recommendation · Spine · Advocacy group

Introduction of SPINE20

Global demographic and health changes have led to a rapid increase in the number of people experiencing disability due to non-communicable diseases (NCDs) [1–3]. Musculoskeletal disorders are both predominant and the leading cause of disability within the NCDs group; this translates to 1.71 billion people affected, equating to 149 million years lived with disability [3]. Among all musculoskeletal disorders, spine pain is the leading cause of disability with more than half a billion individuals0 worldwide experiencing disability due to low back pain [1]. In 2017, the World Health Organization (WHO) launched the

✉ Koji Tamai
koji.tamai.707@gmail.com

Extended author information available on the last page of the article

Rehabilitation 2030 initiative to mobilize the global community and reduce the burden of disability [4].

Recently in 2019, four large spine care and research non-governmental organizations (EUROSPINE, the North American Spine Society, the German Spine Society, and the Saudi Spine Society) formed SPINE20, an advocacy group to bring global attention to spine disorders (Table 1). In 2020, the Italian Spine Society (SICV and GIS), the Indonesian Spine Society (ISS), and the Association of Spine Surgeons of India (ASSI) joined, which were the dominant societies of future G20 host countries. The main focus of SPINE20 is to develop evidence-based policy recommendations for the G20 countries to work with governments to reduce the burden of spine disease, disability, and injuries.

How can SPINE20 inform G20 nations?

The report from the May 21, 2021, G20 Global Health Summit summarized its support of these efforts in its statement: "We, the leaders of G20 and other states, in the presence of the heads of international and regional organizations meeting at the Global Health Summit in Rome, May 21, 2021, having shared our experience of the ongoing global COVID-19 pandemic, and welcoming relevant work in this regard." The G20 Global Health Summit provided 16 recommendations related to the COVID pandemic and recognized the very damaging impact of the pandemic on progress toward achieving the Sustainable Development Goals (SDG). In this document, the G20 group reaffirmed their commitment to achieving the goals to strengthen efforts to build back better (as in UNGA resolution, September 11, 2020) [5], and to the International Health Regulations 2005, which together will improve resilience and global health outcomes. [6]

As a newly formed advocacy group, SPINE20 is committed to working to facilitate the implementation of these recommendations. Specifically, SPINE20 recognizes the COVID-19 pandemic has led to a reduction in the availability and access of non-COVID-related surgical and rehabilitation care. Moreover, SPINE20 recognize that the burden of spine disorders in general, and low back pain in particular, will likely increase due to unmet rehabilitation needs and the growing number of people with "Long-COVID."[7] This is particularly important because spine problems are the greatest contributor to disability and health expenditures globally. [8] Furthermore, low back pain affects most severely female, elderly, and low-income populations. [9] The SPINE20 recommendations to the G20 group are meant to highlight deficiencies in prevention, education, access to spine care, and mitigate disability from spinal disorders in an effort to reduce the wave of disability that may follow the COVID-19 pandemic.

The recommendations are intended to benefit individuals with spine and low back ailments, thereby benefitting the community and ultimately the country adopting the recommendations. The world has different needs depending on the geographical location and socioeconomic status. One recommendation will not fit all. The potential solutions and strategic plans must be developed by the local health ministry with support from spine societies, public health officials, the communities, and the available care systems. The recommendations must be adapted and accepted by the cultural environment, have a positive human and economic impact, and finally must show progress over time.

SPINE20 domain concept

The concept indicates that all recommendations should be based on the specific domain that SPINE20 considered as critical for global improvement in spine health. In 2020, SPINE20's first recommendations were created based on 11 domains including "Spinal disability," "Prevention," "Value-based care," "Patient's safety," "Access to care," "Education," "Research and innovation," "Pediatric," "Aging spine," "Spinal cord injury," and "Low back pain." In 2021, the Publication and Recommendation Committee decided to retain 5 domains from 2020 to 2021 including "Spinal disability," "Value-based care," "Access to care," "Research and innovation," and "Aging spine." Additionally, this year the committee has decided to add two critical domains: "Implementation and outcomes" and "Building capacity." There is a need to implement global outcomes to measure progress and to create and monitor benchmarks to improving spine care for governments. Building capacity means to create a sustainable environment to reduce disability and enhance spine health.

Recommendations and rationale proposed for SPINE20 2021

On September 17 and 18, 2021, SPINE20 held its second annual meeting in Rome, Italy, with the theme "Spine Care for People's Health and Prosperity." Before the meeting,

Table 1 The SPINE20 suggested multi-dimensional initiatives

Establish high educational standards for spine care providers that ensure quality care throughout the world
Invest in spine research that increases our knowledge to improve spine care globally
Adopt spine disability prevention strategies that lead to healthier populations
Improve the ability to address issues relative to the aging population with spine disorders through government policies and recommendations

the SPINE20 Scientific Committee and Publication and Recommendation Committee created six proposed Recommendations including their rationale. These recommendations were uploaded to the SPINE20 website (https://spine20.org/event/) 10 days before the second annual meeting and opened to the public for comments. Subsequently, the recommendations were discussed at the hybrid annual meeting September 18, 2021, allowing the participants to object and provide comments. Finally, 188 participants from 34 societies have approved with no objection the proposed SPINE20 recommendation statement for 2021. The recommendation paper, which are listed below with their respective rationale, was again reviewed and endorsed by 27 societies (Table 2). Recommendations acted upon by SPINE20 participating societies will be tracked and presented at the upcoming SPINE20 meeting in Bali, Indonesia, (August 4–5, 2022) where the next G20 summit will take place. The following recommendations from the SPINE20 gathering in 2021were endorsed (Fig. 1).

Table 2 The list of societies endorsed the SPINE20 2021 recommendations (December 19, 2021)

Society	Nations	SPINE20 recommendations
Asian spinal cord network	India	Under reviewing
Asociación Mexicana de Cirujanos de Columna	Mexico	Under reviewing
Association of spinal surgeons of Russia	Russia	Reviewed and endorsed
Association of spine surgeons of India	India	Reviewed and endorsed
Associazione dei Cavalieri Italiani del Sovrano Militare Ordine di Malta	Italy	Reviewed but not endorsed
Australian pain society	Australia	Reviewed and endorsed
Brazil spine society	Brazil	Reviewed and endorsed
Egyptian spine association	Egypt	Reviewed and endorsed
Egyptian spine study group	Egypt	Reviewed and endorsed
EUROSPINE	International	Reviewed and endorsed
Foundation of orthopedics and complex spine	Ghana	Under reviewing
German spine society	Germany	Reviewed and endorsed
Hellenic society spine surgeons	Greece	Reviewed and endorsed
Indonesia spine society	Indonesia	Reviewed and endorsed
International society on scoliosis orthopedic and rehabilitation treatment	International	Reviewed and endorsed
Inter-state council secretariat	India	Reviewed and endorsed
Italian society of physical and rehabilitation medicine	Italy	Under reviewing
Italian spine society (SICV and GIS)	Italy	Reviewed and endorsed
Japanese society for spine surgery and related research	Japan	Reviewed and endorsed
Middle East spine society	International	Reviewed and endorsed
North America spine society	USA	Reviewed and endorsed
Order of Malta	Italy	Under reviewing
Saudi association of neurological surgery	Saudi Arabia	Reviewed and endorsed
Saudi physical therapy association	Saudi Arabia	Reviewed and endorsed
Saudi spine society	Saudi Arabia	Reviewed and endorsed
Sociedad Iberolatinoamericana de Columna	International	Reviewed and endorsed
Società Italiana di Ortopedia e Traumatologia	Italy	Reviewed and endorsed
Society for education, action and research in community health	India	Reviewed and endorsed
Society indian physiotherpy	India	Reviewed and endorsed
South african spine society	South Africa	Reviewed and endorsed
Spinal cord society	India	Reviewed and endorsed
Ukrainian spine society	Ukraine	Under reviewing
World federation of chiropractic	International	Reviewed and endorsed
World spine care	International	Reviewed and endorsed

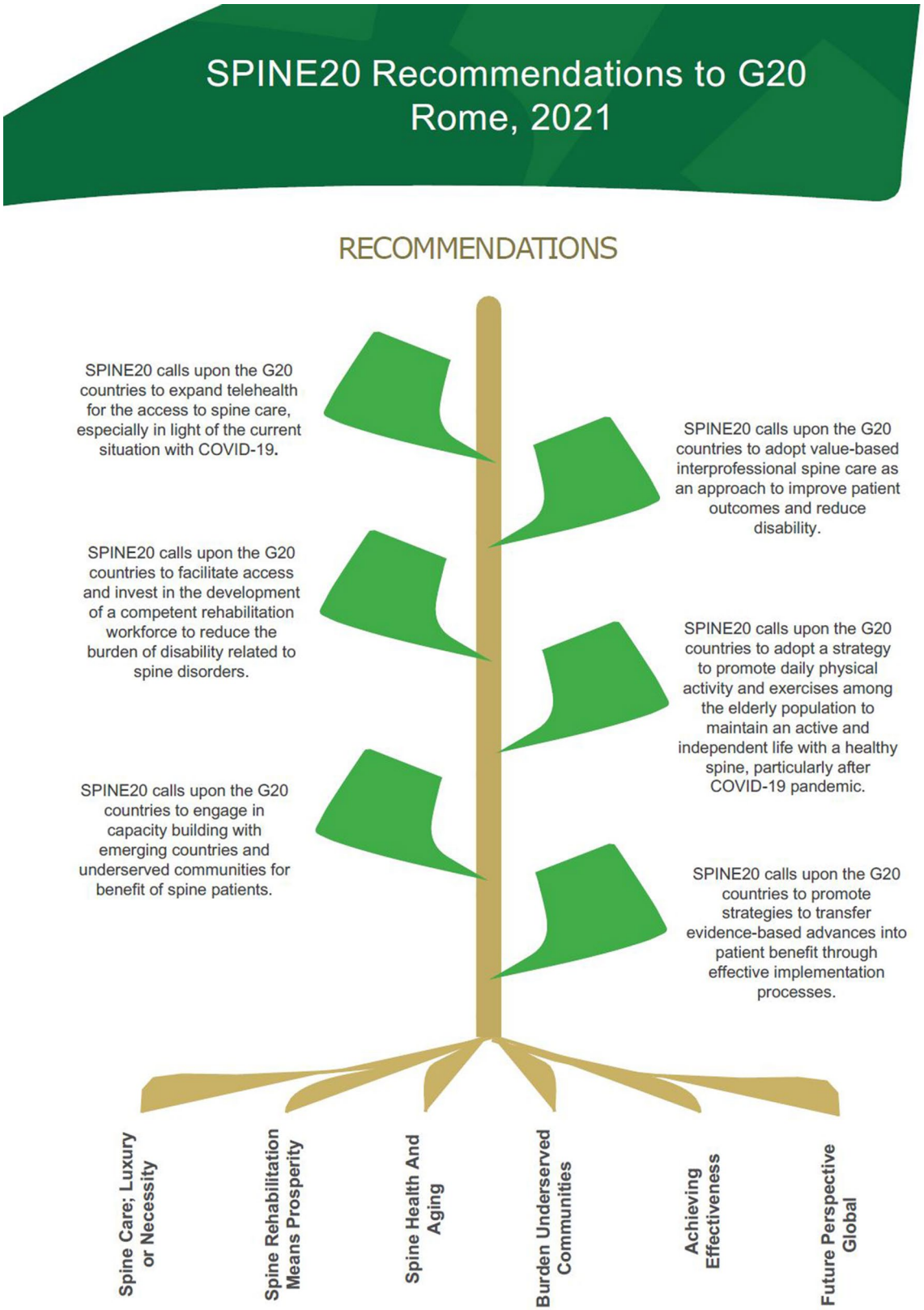


Fig. 1 SPINE20 Recommendations to G20 countries, 2021

Recommendation: research and innovation, access to care

SPINE20 calls upon the G20 countries to expand telehealth for the access to spine care, especially in light of the current situation with COVID-19

Background

The COVID-19 pandemic has greatly affected life, health, and society worldwide [10]. Though the emergent countermeasures, including home confinement and lockdowns, were effective to some extent in preventing the spread of COVID-19 in the community, the prolongation of these countermeasures is also negatively affecting many aspects of people's lives, such as overall decreasing physical activity and daily exercise [11]. In addition, due to the pandemic, patients with spinal disorders are experiencing delays in timely access to needed care.

Problem

Many patients with spinal disease have lost access to care, especially during the COVID-19 pandemic.

Potential solutions

SPINE20 calls upon the G20 countries to expand telehealth for spine care, especially due to the current ongoing situation with COVID-19 [12]. By taking this measure, patients with spinal diseases can obtain timely advice toward alleviating pain and recognizing critical symptoms that need urgent care, and thus obtaining treatment in a timely manner [13]. Telehealth has not been widely adopted in the diagnosis and treatment of spine disease. This might reflect the inherent limitations of telehealth visits for performing physical examinations and demonstrating rehabilitation instructions, but also reflects the previous restrictions on billing for application of electronic health and mobile health, telehealth visits, and the need for technical troubleshooting during telehealth visits [14, 15]. Although before COVID there was a lack of any strong impetus to change our approach to patient care, there is now a critical ongoing need to provide alternative means of evaluating and treating patients affected by the pandemic. Hence, SPINE20 recommend that each G20 country urgently develop a system to support telehealth in this COVID-19 era in order to ensure access to care for patients with spinal diseases. We believe that economic evaluations of telehealth, including the resulting increased productivity of workers worldwide, will validate the benefits of telehealth spine care [16].

Recommendation: value-based care

SPINE20 calls upon the G20 countries to adopt value-based interprofessional spine care as an approach to improve patient outcomes and reduce disability

Background

Lower back pain affects 80–90% of the adult population in both industrialized and emerging countries. Evidence suggests that 30% of affected individuals experience some disability and loss of function [3]. Prolonged pain leads to loss of function, loss of ability to work, poverty, and the loss of the ability to provide for oneself, one's family, and the community, and is often a primary cause for loss of quality-of-life, ability to function, and independent activity of daily living [17].

Problem

Due to its high prevalence and chronicity, spinal disease remains a leading cause of disability.

Potential solutions

SPINE20 calls upon the G20 countries to understand that effectiveness in spine care occurs when different specialists work together, i.e., interprofessional care, using evidence-based methods to prescribe the most effective and efficient care for any given patient. By utilizing the varied education and experience of professionals from different specialties, patients are the ultimate benefactors [18]. Spine Care providers include primary care physicians, surgeons, physiatrists, physical therapists, occupational physicians/therapists/nurses, chiropractors, pain management specialists, psychologists, psychiatrists, social workers, orthotists, assistive technologists, vocational counselors, peer counselors, and others who can all contribute key insights that will optimize comprehensive care for patients [19]. Governments should encourage interprofessional care by providing incentives or fair payment paradigms that bring multiple perspectives to bear on any given patient.

Recommendation: spinal disability, access to care

SPINE20 calls upon the G20 countries to facilitate access and invest in the development of a competent rehabilitation workforce to reduce the burden of disability related to spine disorders

Background

The COVID-19 pandemic has led to an unprecedented increase in unmet rehabilitation needs. Moreover, the prevalence of chronic spine pain and disability is likely to increase because of the growth in the number of individuals with "Long COVID" in which spine and bodily pain are frequently reported symptoms. Even if COVID is resolved, low back and neck pain will continue to be the main causes of disability globally and this puts a great burden on the health care systems and economic welfare of our societies [8]. However, most people who would benefit from rehabilitation for their back and neck pain cannot access these services because they are not available, are not affordable, or because of a shortage of health care providers in their community [3].

Problem

Despite significant health expenditures, the global burden of disability related to spine pain continues to grow and the COVID-19 pandemic has amplified this problem [20].

Potential solutions

SPINE20 calls upon the G20 countries to facilitate and invest in the development of a competent rehabilitation workforce to reduce the burden of disability related to spine ailments. The health, well-being, and productivity of the population will benefit from: (1) Developing a rehabilitation workforce that can deliver high quality and value-based rehabilitation for people with spine pain; (2) Promoting the delivery of high quality and value-based rehabilitation for people with spine pain; and (3) Facilitating easy access to high quality and value-based rehabilitation aimed at returning injured workers to a productive life. The government efforts should target the timely delivery of quality rehabilitation to these individuals to promote population prosperity. The delivery and accessibility of rehabilitation services (including return-to-work interventions) that are supported by high-quality evidence must be prioritized.

Recommendation: aging spine

SPINE20 calls upon the G20 countries to adopt a strategy to promote daily physical activity and exercises among the elderly population to maintain an active and independent life with a healthy spine, particularly after COVID-19 pandemic

Background

The degenerative spinal diseases occurring later in adult life have a significant impact on lifestyle expectations and activities of the elderly population [21]. In addition, osteoporotic vertebral fractures are major problems for the elderly population [22]. These conditions effect the role of the elderly in their family, and also effect local economic productivity.

Problem

The social and financial burden placed upon local communities and on the G20 countries by spinal degenerative diseases and osteoporotic vertebral fractures in the elderly is significantly increasing.

Potential solutions

SPINE20 calls upon the G20 countries to adopt strategies to promote daily exercises among the elderly population to maintain an active and independent life with a healthy spine. Physical activity and exercises, proper nutrition, and a smoking-free lifestyle are proven to reduce the severity of osteoporosis and frailty of the trunk among the elderly, helping them to maintain the ability to ambulate and carry out daily activities [23]. Education for health care practitioners on prevention strategies for the aging population along with the concurrent education of the elderly population are the best tools to prevent degenerative changes and osteoporotic fractures that often lead to severe symptoms and disability [24]. Finally, a proper interprofessional treatment strategy for patients with osteoporosis and/or degenerative spinal diseases should be defined according to scientific evidence-based assessments, and these approaches must be subject to human and financial long-term outcome and cost analyses [25].

Recommendation: capacity building

SPINE20 calls upon the G20 countries to engage in capacity building with emerging countries and underserved communities for benefit of spine patients

Background

Spinal problems are among the most frequent causes of loss of function and disability [17]. It is one of the major causes of significant loss of quality-of-life, especially in the underserved areas of the world. Ignorance, cultural and financial problems, and geographical and political impediments are essential factors that limit people's access to care and these factors deserve to be considered and discussed in detail [26]. It is crucial to understand the role of inadequate information and lack of awareness of the general public in preventing spinal diseases and spinal injuries [27, 28].

Problem

There is a poor standard of spine care in different parts of the world, especially in underserved communities or in emerging countries.

Potential solutions

SPINE20 calls upon the G20 countries to increase spine care capacity-building in emerging countries and in all underserved communities [29]. To address the disproportionate distribution and access to optimal spine care, senior administrators and policymakers in developing and underserved countries need to network and create alliances with G20 countries, and to adopt specific strategies based on the best clinical practices of countries with robust spine health care systems [30]. Long-term, realistic, region-specific goals for the improvement in spine care need to be developed based on region-specific factors such as the local epidemiology, availability of resources, social beliefs, attitudes/mindset, and urban versus rural distribution of health services. Strategies to improve the standards of spine care also need to focus on cost-effective high-impact practices, locally relevant clinical guidelines, professional oversight, targeted education/professional training, organizational change, and dedicated research. More proactive collaboration and support from the G20 scientific communities, individually or in working groups, is needed to help build and promote autonomous local scientific bodies in underserved communities.

Recommendation: implementation and outcomes

SPINE20 calls upon the G20 countries to promote strategies to transfer evidence-based advances into patient benefit through effective implementation processes

Background

Proving the effectiveness of a clinical approach is not always enough to guarantee its adoption by health services and health care professionals. It has always been a challenge to find the best way to enhance the incorporation of evidence-based practices and thereby increase their public health impact. The lack of a common language, agreement on transformative goals, an embedded evaluation process, common plans, and a shared agenda, in addition to the mentality of 'short-termism', are some of the main obstacles to translating evidence-based scientific discoveries into widespread patient benefit [31].

Problem

It is reported that evidence-based practices take an average of 17 years to be incorporated into routine general practice in health care, even though research constantly produces confirmed findings that can contribute to more effective and efficient health care. [32]

Potential solutions

SPINE20 calls upon the G20 countries to promote strategies that enhance the translation of the evidence-based discoveries into patient benefit at a global level through effective implementation processes. Addressing the gaps between knowledge and practice with efficient strategies should be a policy priority. [33, 34] A range of strategies is available to overcome these gaps. Stakeholder engagement, effectiveness studies, research synthesis, artificial intelligence, and mathematical modeling are some of the methods used by implementation scientists to identify strategies that embed evidence-based interventions into clinical practice and public health programs. While there is insufficient evidence to adequately support the use of some guideline implementation strategies, such as traditional educational strategies and guideline dissemination in isolation, there is convincing evidence in favor of the use of multifaceted interventions, interactive education, and clinical reminder systems for the effective implementation of clinical guidelines. [33] Furthermore, one of the most important aspects of the implementation process is economic evaluation. It is a crucial tool that always needs to be incorporated into the implementation

decision-making process for any adopted strategy because it has been found to be the predominant reason (or "excuse") that change is not implemented. We need to further promote research on the costs and cost–benefit analyses of guideline implementation strategies, along with the other environmental, organization, and individual clinician factors that are associated with effective implementation strategies [33].

Conclusions

SPINE20 is created as an advocacy group for spine societies around the globe, and for governments, institutions, and other organizations to highlight evidence and valued-based spine care that can help prevent disability. Its recommendations are intended to reduce the burden of disease related to spinal disorders by engaging governing stakeholders in the development of evidence-based policies. SPINE20 can serve as a resource of expertise for local and/or global advisement to mitigate disability from spine ailments. It is the hope of the founding group that its advocacy will reduce needless suffering and costs from disabling pain through education about rehabilitation and other treatment modalities that can be instituted across the globe.

Author contributions SA, KT and MN led the drafting of this paper in collaboration with the other authors and were part of the team that coordinated the production of papers. GC, BM, LR and ED closely revised many sections. Thereafter all authors contributed to all sections of the paper and edited it for key intellectual content. All other authors have read and provided substantive intellectual comments to the draft and have approved the final version of the paper.

Funding No funding received.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflicts of interest All authors declares that they have no conflict of interest.

Consent to participate All authors have read and approved the final version of the paper.

Consent for publication All authors give our consent for the publication of identifiable details to be published in the European Spine Journal.

References

1. Diseases GBD, Injuries C (2020) Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of disease study 2019. Lancet 396:1204–1222. https://doi.org/10.1016/S0140-6736(20)30925-9
2. Beard JR, Officer A, de Carvalho IA, Sadana R, Pot AM, Michel JP, Lloyd-Sherlock P, Epping-Jordan JE, Peeters G, Mahanani WR, Thiyagarajan JA, Chatterji S (2016) The World report on ageing and health: a policy framework for healthy ageing. Lancet 387:2145–2154. https://doi.org/10.1016/S0140-6736(15)00516-4
3. Cieza A, Causey K, Kamenov K, Hanson SW, Chatterji S, Vos T (2021) Global estimates of the need for rehabilitation based on the global burden of disease study 2019: a systematic analysis for the global burden of disease study 2019. Lancet 396:2006–2017. https://doi.org/10.1016/S0140-6736(20)32340-0
4. World Health Organization, Rehabilitation 2030: A Call for Action. https://www.who.int/rehabilitation/rehab-2030-call-for-action/en/
5. https://global-health-summit.europa.eu/rome-declaration_en. Global Health Summit, European Union
6. https://www.who.int/publications/i/item/9789241580496. International Health Regulations (2005) Third Edition, World Health Organization
7. https://www.nhs.uk/conditions/coronavirus-covid-19/long-term-effects-of-coronavirus-long-covid/. Long-term effects of coronavirus (long COVID), NHS
8. Disease GBD, Injury I, Prevalence C (2018) Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the global burden of disease study 2017. Lancet 392:1789–1858. https://doi.org/10.1016/S0140-6736(18)32279-7
9. Hoy D, Bain C, Williams G, March L, Brooks P, Blyth F, Woolf A, Vos T, Buchbinder R (2012) A systematic review of the global prevalence of low back pain. Arthritis Rheum 64:2028–2037. https://doi.org/10.1002/art.34347
10. Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, Zhao X, Huang B, Shi W, Lu R, Niu P, Zhan F, Ma X, Wang D, Xu W, Wu G, Gao GF, Tan W (2020) A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med 382:727–733. https://doi.org/10.1056/NEJMoa2001017
11. Adams JG, Walls RM (2020) Supporting the health care workforce during the COVID-19 global epidemic. JAMA 323:1439–1440. https://doi.org/10.1001/jama.2020.3972
12. Kolcun JPG, Ryu WHA, Traynelis VC (2020) Systematic review of telemedicine in spine surgery. J Neurosurg Spine 34(2):1–10. https://doi.org/10.3171/2020.6.SPINE20863
13. Satin AM, Shenoy K, Sheha ED, Basques B, Schroeder GD, Vaccaro AR, Lieberman IH, Guyer RD, Derman PB (2020) Spine patient satisfaction with telemedicine during the COVID-19 Pandemic: a cross-sectional study. Global Spine J. https://doi.org/10.1177/2192568220965521
14. Moss RJ, Sule A, Kohl S (2019) eHealth and mHealth. Eur J Hosp Pharm 26:57–58. https://doi.org/10.1136/ejhpharm-2018-001819
15. Piche J, Butt BB, Ahmady A, Patel R, Aleem I (2021) Physical examination of the spine using telemedicine: a systematic review.

Global Spine J 11:1142–1147. https://doi.org/10.1177/2192568220960423
16. Thakar S, Rajagopal N, Mani S, Shyam M, Aryan S, Rao AS, Srinivasa R, Mohan D, Hegde AS (2018) Comparison of telemedicine with in-person care for follow-up after elective neurosurgery: results of a cost-effectiveness analysis of 1200 patients using patient-perceived utility scores. Neurosurg Focus 44:E17. https://doi.org/10.3171/2018.2.FOCUS17543
17. Hartvigsen J, Hancock MJ, Kongsted A, Louw Q, Ferreira ML, Genevay S, Hoy D, Karppinen J, Pransky G, Sieper J, Smeets RJ, Underwood M, Working LLBPSG (2018) What low back pain is and why we need to pay attention. Lancet 391:2356–2367. https://doi.org/10.1016/S0140-6736(18)30480-X
18. Kwon B, Tromanhauser SG, Banco RJ (2007) The spine service line: optimizing patient-centered spine care. Spine 32(Supplement):S44–S48. https://doi.org/10.1097/BRS.0b013e318053d491
19. Lessing NL, Zuckerman SL, Lazaro A, Leech AA, Leidinger A, Rutabasibwa N, Shabani HK, Mangat HS, Hartl R (2020) Cost-effectiveness of operating on traumatic spinal injuries in low-middle income countries: a preliminary report from a major east african referral center. Global Spine J. https://doi.org/10.1177/2192568220944888
20. Deer TR, Sayed D, Pope JE, Chakravarthy KV, Petersen E, Moeschler SM, Abd-Elsayed A, Amirdelfan K, Mekhail N, Workgroup AC (2020) Emergence from the COVID-19 pandemic and the care of chronic pain: guidance for the interventionalist. Anesth Analg 131:387–394. https://doi.org/10.1213/ANE.0000000000005000
21. Gibbs JC, MacIntyre NJ, Ponzano M, Templeton JA, Thabane L, Papaioannou A, Giangregorio LM (2019) Exercise for improving outcomes after osteoporotic vertebral fracture. Cochrane Database Syst Rev. https://doi.org/10.1002/14651858.CD008618.pub3
22. Cauley JA, Hochberg MC, Lui LY, Palermo L, Ensrud KE, Hillier TA, Nevitt MC, Cummings SR (2007) Long-term risk of incident vertebral fractures. JAMA 298:2761–2767. https://doi.org/10.1001/jama.298.23.2761
23. Sherrington C, Fairhall NJ, Wallbank GK, Tiedemann A, Michaleff ZA, Howard K, Clemson L, Hopewell S, Lamb SE (2019) Exercise for preventing falls in older people living in the community. Cochrane Database Syst Rev. https://doi.org/10.1002/14651858.CD012424.pub2
24. Salmi LR, Coureau G, Bailhache M, Mathoulin-Pelissier S (2016) To screen or not to screen: reconciling individual and population perspectives on screening. Mayo Clin Proc 91:1594–1605. https://doi.org/10.1016/j.mayocp.2016.07.017
25. Shamji MF, Goldstein CL, Wang M, Uribe JS, Fehlings MG (2015) Minimally invasive spinal surgery in the elderly: does it make sense? Neurosurgery 77(Suppl 4):S108-115. https://doi.org/10.1227/NEU.0000000000000941
26. Brady O, Nordin M, Hondras M, Outerbridge G, Kopansky-Giles D, Cote P, da Silva S, Ford T, Eberspaecher S, Acaroglu E, Mmopelwa T, Hurwitz EL, Haldeman S (2016) Global forum: spine research and training in underserved, low and middle-income, culturally unique communities: the world spine care charity research program's challenges and facilitators. J Bone Joint Surg Am 98:e110. https://doi.org/10.2106/JBJS.16.00723
27. Chou R, Cote P, Randhawa K, Torres P, Yu H, Nordin M, Hurwitz EL, Haldeman S, Cedraschi C (2018) The global spine care initiative: applying evidence-based guidelines on the non-invasive management of back and neck pain to low- and middle-income communities. Eur Spine J 27:851–860. https://doi.org/10.1007/s00586-017-5433-8
28. Oña A, Strøm V, Lee B-S, Le Fort M, Middleton J, Gutenbrunner C, Barzallo DP (2021) Health inequalities and income for people with spinal cord injury. a comparison between and within countries. SSM Popul Health 15:100854. https://doi.org/10.1016/j.ssmph.2021.100854
29. Jackson T, Thomas S, Stabile V, Han X, Shotwell M, McQueen K (2015) Prevalence of chronic pain in low-income and middle-income countries: a systematic review and meta-analysis. Lancet 385(Suppl 2):S10. https://doi.org/10.1016/S0140-6736(15)60805-4
30. Haldeman S, Nordin M, Outerbridge G, Hurwitz EL, Hondras M, Brady O, Kopansky-Giles D, Ford T, Acaroglu E (2015) Creating a sustainable model of spine care in underserved communities: the world spine care (WSC) charity. Spine J 15:2303–2311. https://doi.org/10.1016/j.spinee.2015.06.046
31. Rapport F, Clay-Williams R, Churruca K, Shih P, Hogden A, Braithwaite J (2018) The struggle of translating science into action: foundational concepts of implementation science. J Eval Clin Pract 24:117–126. https://doi.org/10.1111/jep.12741
32. Westfall JM, Mold J, Fagnan L (2007) Practice-based research: "Blue Highways" on the NIH roadmap. JAMA 297:403–406. https://doi.org/10.1001/jama.297.4.403
33. Prior M, Guerin M, Grimmer-Somers K (2008) The effectiveness of clinical guideline implementation strategies: a synthesis of systematic review findings. J Eval Clin Pract 14:888–897. https://doi.org/10.1111/j.1365-2753.2008.01014.x
34. Grimshaw J, Thomas R, MacLennan G, Fraser C, Ramsay C, Vale L, Whitty P, Eccles M, Matowe L, Shirran L, Wensing M, Dijkstra R, Donaldson C (2004) Effectiveness and efficiency of guideline dissemination and implementation strategies. Health Technol Assess. https://doi.org/10.3310/hta8060

Authors and Affiliations

Giuseppe Costanzo[1] · Bernardo Misaggi[2] · Luca Ricciardi[1] · Sami I. AlEissa[3] · Koji Tamai[4] · Fahad Alhelal[5] · Yahya Alqahtani[6] · Hana I. Alsobayel[7] · Markus Arand[8] · Massimo Balsano[9] · Thomas R. Blattert[10] · Marco Brayda-Bruno[11] · Jamiu O. Busari[12] · Marco Campello[13] · Harvinder S. Chhabra[14] · Francesco Ciro Tamburrelli[15] · Pierre Côté[16] · Bambang Darwono[17] · Frank Kandziora[18] · Giovanni A. La Maida[19] · Eric J. Muehlbauer[20] · Raghava D. Mulukutla[21] · Paulo Pereira[22] · Shanmuganathan Rajasekaran[23] · Dominique A. Rothenfluh[24] · William J. Sullivan[25] · Eeric Truumees[26] · Edward J. Dohring[27] · Tim Pigott[28] · Ajoy P. Shetty[23] · Marco G. A. Teli[29] · Jeffrey C. Wang[30] · Christopher Ames[31] · Johannes R. Anema[32] · Anand Bang[33] · Kenneth M. C. Cheung[34] · Douglas P. Gross[35] · Scott Haldeman[36] · Salvatore Minisola[37] · Rajani Mullerpatan[38] · Stefano Negrini[39,40] · Louis-Rachid Salmi[41] · M. Silvia Spinelli[42] · Adriaan Vlok[43] · Kwadwo P. Yankey[44] · Fabio Zaina[45] · Ahmed Alturkistany[46] · Jörg Franke[47] · Ulf R. Liljenqvist[48] · Michael Piccirillo[20] · Margareta Nordin[49]

1 Sapienza Rome University, Rome, Italy

2 Orthopaedic Institute Gaetano Pini-CTO, Milan, Italy

3 National Guard Health Affairs, Riyadh, Saudi Arabia

4 Department of Orthopedics, Graduate School of Medicine, Osaka Metropolitan University, Osaka, Japan

5 National Guard Hospital, Riyadh, Saudi Arabia

6 Presidency of State Security, Riyadh, Saudi Arabia

7 King Saud University, Riyadh, Saudi Arabia

8 Medical Faculty, University of Ulm, Ulm, Baden-Württemberg, Germany

9 University and Hospital Trust of Verona, Verona, Italy

10 Schwarzach Orthopaedic Clinic, Schwarzach, Germany

11 IRCCS Orthopedic Institute Galeazzi, Milano, Italy

12 Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, The Netherlands

13 New York University Grossman School of Medicine, New York, NY, USA

14 Indian Spinal Injuries Center, New Delhi, India

15 Orthopedic Catholic University, Rome, Italy

16 Ontario Tech University, Oshawa, ON, Canada

17 Gading Pluit Hospital, North Jakarta, Jakarta, Indonesia

18 Center for Spinal Surgery and Neurotraumatology, Frankfurt, Germany

19 Spine Surgery Department, Orthopedic Institute Gaetano Pini, Milan, Italy

20 North American Spine Society, Chicago, USA

21 Udaiomni Hospital, Hyderabad, India

22 University of Porto, Porto, Portugal

23 Ganga Hospital, Coimbatore, India

24 Oxford University Hospitals NHS Foundation Trust, Oxford, UK

25 Vanderbilt University Medical Center, Nashville, USA

26 University of Texas, Austin, USA

27 Spine Institute of Arizona, Scottsdale, AZ, USA

28 EUROSPINE, Zurich, Switzerland

29 Walton Centre NHS Trust, Liverpool, UK

30 University of Southern California Spine Center, Los Angeles, CA, USA

31 University of California San Francisco, San Francisco, CA, USA

32 Amsterdam University Medical Center, Amsterdam, The Netherlands

33 Society for Education, Action and Research in Community Health, Gadchiroli, Maharashtra, India

34 The University of Hong Kong, Hong Kong, China

35 University of Alberta, Edmonton, Canada

36 University of California, Irvine, CA, USA

37 Sapienza University of Rome, Rome, Italy

38 Mahatma Gandhi Mission Institute of Health Sciences, Navi Mumbai, India

39 University La Statale, Milan, Italy

40 IRCCS Istituto Ortopedico Galeazzi, Milan, Italy

41 Université de Bordeaux, Bordeaux, France

42 Gaetano Pini Institute, Milano, Italy

43 Stellenbosch University, Cape Town, South Africa

44 FOCOS Orthopaedic Hospital, Accra, Ghana

45 ISICO (Italian Scientific Spine Institute), Milan, Italy

46 King Faisal Specialist Hospital and Research Center, Jeddah, Saudi Arabia

47 Klinikum Magdeburg gGmbH, Magdeburg, Germany

48 St. Franziskus-Hospital, Münster, Germany

49 New York University, New York, NY, USA

Functioning of Older Adults in Low and Middle Income Countries: A Literature Review

Poonam Desai & Rajani Mullerpatan*

MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, India

*Address all correspondence to: Dr. Rajani Mullerpatan (Prof-Director), MGM Educational Campus, MGM School of Physiotherapy, Plot Number- 1&2, Sector-1, Kamothe, Navi Mumbai-410209 Maharashtra, India; Tel.: +9920048476, E-mail: rajani.kanade@gmail.com; ORCID: 0000-0003-4276-4976

ABSTRACT: The global population of older adults is rising, with the fastest surge in low and middle income countries (LMIC). Physical functioning determines independence in living. Therefore, it is critical to understand the functioning of older adults in LMIC. Extensive literature informs the functioning profile of older adults in developed nations; however, functioning of older adults in developing nations remains understudied. Physical functioning profile of older adults varies across the world due to differences in socio-demographic and economic factors alongside age-related physiological changes. The present study reviews the functioning profile, factors affecting physical functioning and health related quality of life (H-RQoL), and influence of physical co-morbidities on functioning of older adults in LMIC. Literature search was conducted in PubMed, Google Scholar, CINHAL, and Cochrane database. Eighteen cross-sectional, longitudinal, prospective cohort studies from Asia, Africa, North, South America, and Turkey were included. Most studies focused on singular domain of function. Hand-grip strength, lower extremity muscle strength, balance, and cognition were the most affected variables. Most older adults required partial assistance in bathing and housekeeping, and complete assistance in dressing. Individuals aged ≥ 75 years demonstrated greater limitation in activities of daily living (ADL). Older adults with cognitive impairment were at greater risk of functional decline. Low income, arthritis, and diabetes were major factors responsible for limitation in ADL and poor H-RQoL. Clinicians, researchers, and policymakers can use the present findings to plan culturally suitable rehabilitation programs to impart good health and well-being to older adults, which is central to the attainment of health-related sustainable development goals set forth by the United Nations.

KEY WORDS: functioning, geriatric, developing countries, low- and middle-income countries

ABBREVIATIONS: ADL, activities of daily living; **H-RQoL**, health related quality of life; **LMIC**, low-middle income countries

I. INTRODUCTION

Globally, the elderly population has increased rapidly over the last decades due to an increase in life expectancy. According to a World Health Organization report, there were 1 billion individuals 60 years and older in 2019. It is expected that the population of older adults will reach 1.4 billion by 2030 and 2.1 billion by 2050.[1]

By 2050, two-thirds of the world's population over 60 years will live in low- and middle-income countries.[1] The number of older adults in less developed countries will

0896-2960/22/$35.00

increase more than 250% from 2010 to 2050, compared to a 71% increase in developed countries.[1] Hence aging of the global population is the most important medical and social demographic issue today.

Aging is ultimately a combination of physiological changes and the effect of environmental factors on body systems. Hypertension, diabetes, arthritis (rheumatism and osteoarthritis), osteoporosis, stroke (cerebral embolism and thrombosis), chronic obstructive pulmonary disease, coronary artery disease, Alzheimer's disease, depression, dementia, cataract, and cancer are common conditions that affect many older adults.[2–5] Common conditions in older adults may lead to functional decline such as mobility limitation, restricted activities of daily living, impaired postural balance, and decline in muscle strength and flexibility.[6–8]

Age-related functional decline may lead to disability in some older adults. The burden imposed by disability in old age is one of the major challenges faced by healthcare systems worldwide not only in high-income countries (HICs) but also in low- and middle-income countries (LMICs). Literature reports that severe disability affects 8% of older adults in low and middle income countries. Being women, living in rural areas, being pre-frail or frail, and having sarcopenia or cognitive impairment were important socioeconomic and health factors associated with higher severity levels of disability.[9]

Apart from functional decline related to co-morbidities, normal aging results in an overall decline in physical, functional, and cognitive abilities. Integrated decline in function associated with normal aging process increases the likelihood of non-traumatic falls. Falls lead to mild-to-severe injuries such as bruises, internal injuries, sprains, grazes, cuts, fractures (hip fractures), traumatic brain injuries, upper limb and lower limb injuries, and are an underlying cause of emergency departmental visits.[10]

Besides physical factors, personal and environmental factors also negatively impact health-related quality of life of older adults. An increasing number of older adults live alone in both rural and urban areas due to urbanization, migration of young adult population, and the concept of the nuclear family. During the last decade, 36 million have moved from rural areas to urban areas in India.[11] According to a report by the United Nations, 18 million people from India live outside their homeland. The United Arab Emirates, United States of America, and Saudi Arabia host the largest number of migrants from India.[12] Older adults who live alone have difficulty complying with prescribed treatment regimens.[13] Poor compliance to treatment regimens can result in a low level of physical activity that can eventually lead to early functional decline. Maintaining optimal physical functioning of older adults is therefore crucial.

Additionally, low socioeconomic status and poor welfare systems are major factors responsible for lack of medical and financial support, deterioration of physical and mental health, and disability among older adults in low-middle income countries.[14]

The World Health Organization (WHO) highlights the role of function in healthy aging: "functional ability is about having the capabilities that enable all people to be and do what they have reason to value."[15]

Physical functioning in older adults can be described as a cumulative effect of medical conditions, lifestyle and age-related physiologic changes in the context of an

individual's environment.[15] Decline in physical functioning is a core determinant of health-related quality of life in old age, hence even a small decline in functioning is associated with increased mortality, need for caregiving assistance, and health-related expenditures.[16] Although physical function has become a common determinant for social, epidemiologic, and clinical research in high-income countries, it remains less explored in low and middle income countries.[17]

Current information on physical function and disability among older adults in low-middle income countries is very limited, though available evidence suggests older adults face a substantial burden of physical limitation in later life. Therefore, it is important to explore physical functioning of older adults from low and middle income countries because it is essential for sustainable development of the world including people of all age groups.[18] An exploration of physical function in older adults is crucial for understanding the level and profile of physical functioning, identification of most affected areas of physical functioning, and recommendations for rehabilitation and treatment strategies to support and maintain functional independence in older adults.

II. METHODOLOGY

A. Database Source and Search

A comprehensive electronic search was conducted through PubMed, Google Scholar, CINAHL, and Cochrane. Medical Subject Headings (MeSH) and text words including (functioning* OR functional impairment* OR functional limitation* OR functional decline* OR functional status* OR functional fitness* OR physical fitness* OR muscle strength* OR muscle flexibility* OR hand-grip strength* OR pinch grip* OR postural balance* OR coordination* OR cardio-respiratory endurance* OR Senior fitness test battery* OR agility* OR activities of daily living* OR instrumented activities of daily living* OR cognitive function* OR depression* OR quality of life*) AND (Older Adults* OR aged* OR elderly* OR older adults* OR geriatric* OR community-dwelling elderly individuals*) AND (low- and middle-income countries* OR developing countries*) were used. Papers describing original studies, available in English and conducted in the last 19 years were included (between 2003 and 2022).

B. Inclusion Criteria

Articles reporting assessment of functioning, profile of physical and cognitive function, and risk factors associated with functional decline in older adults from low- and middle-income countries in the title and abstract were screened for inclusion and 53 articles were identified. On further screening of 53 full-text articles for inclusion and exclusion criteria, 18 articles were finally included in the review. Study design, study setting, aims of study, number of participants, age group, method of assessment, outcomes of the study were noted from each article.

C. Exclusion Criteria

Articles reporting profile of functioning of individuals < 60 years from high income countries and not indexed in PubMed were excluded. Eighty-seven articles were retrieved from various databases, of which 53 articles were excluded after initial title and abstract screening. Finally, out of these 53 articles, only 18 articles fulfilling inclusion criteria were reviewed (Fig. 1). Quality of evidence was graded on the PEDro scale.

III. RESULTS

The present review was conducted to understand profile of functioning, factors determining functioning, influence of physical co-morbidities on functioning profile, and factors affecting H-RQoL of older adults in low- middle-income countries. Eighteen papers were included in the review, of which 15 cross-sectional articles from Asia, Africa, North and South America (China, India, Malaysia, Russia; Central and West Africa, Mexico and Brazil), one longitudinal study from South America (Brazil), and two prospective cohort studies from Turkey and Asia (India) were rated as Level IV evidence.

A. Characteristics of Included Studies

Articles included in the review reported findings on both males and females aged ≥ 60 years; with marital status single, married, divorced, or widowed; occupational status retired, pensioner, or housewife; education level illiterate, incomplete elementary, complete elementary, complete high school, or complete higher education; financial status completely dependent, partially dependent or independent and with or without co-morbidities.

B. Profile of Functioning

Profile of functioning was reviewed and described under two domains: body function and activity limitation.

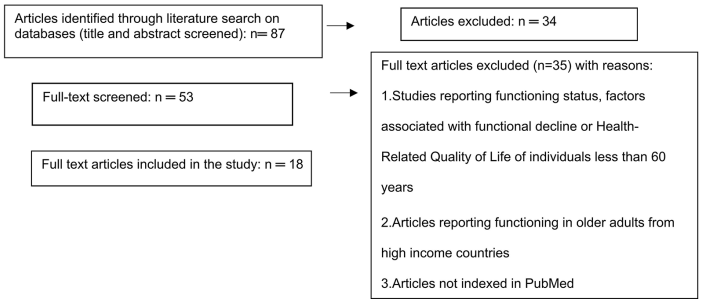


FIG. 1: Flowchart describing literature search strategy

1. Body Function

A prospective study was conducted to assess lower extremity muscle performance of individuals aged 65–95 years. Older adults demonstrated a slow walking velocity (65.51 ± 23.57 m/min), medium fall risk (Tinetti gait test score: 10.94 ± 1.71), and a low fall risk (Tinetti balance test score: 14.94 ± 2.05) during walking and balance activities, respectively. Older adults exhibited lower performance on both eccentric decline squat test (20.73 ± 13.47 repetitions/min) and half squat test (31.75 ± 15.6 repetitions/min).[19]

Association between hand-grip strength and gait speed with functional disability was explored in a cross-sectional study conducted on individuals ≥ 65 years from China, Mexico, Ghana, India, Russia, and South Africa. Hand-grip strength was assessed using hand-held dynamometer and gait speed was evaluated over a 4-meter flat surface. Gait speed of participants from Mexico, India, South Africa, Ghana and Russia was less than or equal to 0.8 m/s. Participants from Mexico had the lowest grip strength (21.6 kg), while South Africa exhibited the highest (36.0 kg) grip strength. Mean grip strength of participants from China, Ghana, India, and Russia was 25.5 kg, 25.8 kg, 22.1 kg, and 27.7 kg, respectively.[20]

Hand grip strength was also evaluated with Jamar Hand-held Dynamometer on 434 older adults from Pahang, Malaysia. Study results showed that males demonstrated significantly higher hand-grip strength (28.8 kg) than females (18.9 kg). On the other hand, when depressive symptoms were assessed using geriatric depression scale, females had higher geriatric depression score (GDS) (mean GDS score in females: 3.8, mean GDS score in males: 3.2). In males, as age and GDS score increased, hand-grip strength declined significantly.[21]

One thousand three hundred seventy-five (1,375) individuals aged ≥ 60 years were studied in São Paulo and Manaus, Brazil, to assess the prevalence of disability and identifying areas affected by disability. WHO Disability Assessment Schedule (WHODAS 2.0) questionnaire was used to assess the prevalence of global and severe disability. Prevalence of global disability was significantly higher in Manaus (66.2%) than in São Paulo (56.4%). Prevalence of disability was higher specifically in participants aged ≥ 80 years, with low level of schooling, low income, widow/living alone or divorced, White/Asian, ≥ 2 morbidities, depression, poor self-rated health, consulted family physicians in last 3 months, unhappy with support received from children or friends, and those who have not attended church in last one year. Participation and mobility were found to be most impaired domains of WHODAS 2.0, followed by cognition, life activities, self-care, and getting along. Females demonstrated more impairments than males in all WHODAS domains.[22]

Prevalence and correlates of functional limitation and physical disability were also examined in another study. Seven hundred sixty-five (765) older people aged ≥ 60 years were assessed using Barthel Index (10 items), Katz Index (6 items), 5-item scale (feeding, dressing, bathing, toileting, and transferring), Elderly Cognitive Assessment questionnaire, Geriatric Depression Scale (GDS-15 items), and Tinetti performance-oriented mobility assessment tool (TPOMA). In total, 10.4% older

adults exhibited borderline cognitive impairment, and 3.5% exhibited probable cognitive impairment. A total of 20.3% older adults exhibited depressive symptomology. Prevalence of functional limitation (gait and balance impairment-TPOMA) increased with advancing age (60–64 years: 6%, 65–69 years: 13%, 70–74 years: 24.5%, and 75 years and over: 48.3%). Overall, women had a higher prevalence of functional limitation (men: 14.5%, women: 22.3%), cognitive impairment (borderline cognitive impairment in men: 5.9% and women: 12.9%; probable cognitive impairment in men: 1.4% and women: 4.8%), and depressive symptomology (men: 24.2%, women: 22.7%) than men.[23]

2. Activity Limitation

Eight studies reported limitations in basic or instrumental activities of daily living. Pune-Functional Ability Assessment Tool (Pune-FAAT), Barthel Index, Lawton and Brody scale were used as assessment tools in these studies.

A cross-sectional study was conducted on 362 (≥ 65 years) older persons to assess social and functional status. A pre-designed and pre-tested interview technique was used to collect social and functional status information. In total, 7.5 % of older adults required partial assistance and 2% required total assistance in basic activities of daily living (BADL). The majority of older adults required assistance with dressing and getting in and out of bed (4.4%) followed by bathing (4.1%), toileting (3.1%), feeding (2.5%), and managing continence (2.2%), while one-fourth of the study population required partial or total assistance in instrumental activities of daily living (IADL). The amount of partial assistance needed in instrumental activities of daily living was as follows: higher percentage of older adults required assistance in housekeeping (15.7%) followed by cooking, using public toilets (10.5%), managing finances (8.6%), using telephones (8.3%), and shopping (4.7%). Difference in prevalence of activity limitation between men and women were not reported in this study.[24]

Similarly, another study reported data on prevalence of functional disability (defined as assistance required to execute at least one of the BADLs) in basic activities of daily living. Basic activities of daily living were evaluated using modified Barthel Index. Only 11.7% of the older adults were functionally independent, while the rest had functional disability. Among the functionally dependent individuals, 89.9% demonstrated minimal dependency, 9.2% mild dependency, 0.3% moderate dependency, and 0.6% total dependency. Performing personal hygiene, grooming, and transferring from bed to chair were most prevalent functional disabilities while bathing was least prevalent. Functional disability was higher in females than males.[25]

Older adults residing in urban area of Bagé-RS, Brazil required greater partial assistance in bathing (4.0%) and total assistance in dressing (7%) compared to other basic activities of daily living. Higher percentage of older adults could perform feeding independently (96.5%). Taking medicines (86.8%) was most independent activity with respect to instrumental activities. Housekeeping (11.6%) and telephone usage (11%) required greater amount of partial help than other instrumental activities.[26]

Prevalence of functional disability on 10-item basic activities of daily living scale among 495 older adults residing in a rural area of West Bengal, India was 16.6%. Amount of assistance required in each activity and most frequently affected activities of daily living were not specified by this study.[5]

A two-year follow-up study conducted in India demonstrated that ability to perform activities of daily living reduced over the years. Ability to perform squatting (55.5% to 44.3%), bending (59.1% to 48.4%), walking (62.5% to 54.9%), and climbing (56.8% to 46.3%) significantly declined with advancing age. Inability to perform at least one basic activity of daily living was 63% at baseline, which was elevated to 67.3% at follow-up. Nearly 73% of older adults at baseline and 73.6% at follow-up were unable to perform instrumental activities of daily living.[27]

Similarly, a four-year follow-up study conducted in Brazil, demonstrated that level of functioning in instrumental activities of daily living reduced over the years. Of the 24.2% older adults who were independent at baseline, their percentage dropped to 12.8% at follow-up, and the percentage of older adults in the partially dependent category dropped from 24.6% at baseline to 82.5% at follow-up. On the other hand, complete dependency percentage dropped from 41.2% at baseline to 4.7% at follow-up. Overall mean instrumental activity of daily living (IADL) score declined in both the genders from baseline to follow-up (men: mean IADL score: 16.02 ± 3.47 at baseline and 14.96 ± 3.88 at follow-up and women: mean IADL score: 18.26 ± 3.57 at baseline and 16.87 ± 4.05 at follow-up).[28]

Another study demonstrated that with advancing age both males and females needed help in at least one of the day-to-day activities on 10-item, 5-item, or 6-item scale, respectively. Overall, 24.7%, 14.3%, and 10.6% of older adults needed help in at least one of the day-to-day activities on 10-item, 5-item, or 6-item scale, respectively. Prevalence of activity limitation was greater in females than males in each age group.[15] Similarly, among older adults from rural Pahang, Malaysia, males (97.5 ± 7.0) demonstrated higher mean basic activity of daily living score than females (95.4 + 12.6).[21]

B. Factors Determining Functioning

Seven studies identified sociodemographic or socioeconomic or behavioral factors, or health status or extent of use of health services as determinants for activity limitation, decline in grip strength, and functional disability.

Age ≥ 75 years old, widower, low level of schooling, no alcohol consumption in the last 30 days, history of hospitalization in the past 12 months, receiving home care in the past 3 months,[26] female, and experience of memory loss and feeling of loneliness were factors associated with higher prevalence of limitation in basic activities of daily living.[27] Older adults satisfied with life had lower prevalence of limitation in basic activities of daily living.[26] Brown or indigenous or Asian older adults and former smokers had a higher prevalence of limitation in instrumental activities of daily living.[26]

A direct association was identified between nutritional status and instrumental activities of daily living. Malnourished older adults had higher limitation in instrumental activities of daily living.[29]

In males and females, body weight, height, activity of daily living score, and geriatric depression score were significant predictors for hand-grip strength. An increase in weight, height, and activity of daily living score was associated with an increase in hand-grip strength. Whereas, hand grip strength significantly declined in males and females with increase in geriatric depression score.[20]

A study conducted in the south of India evaluated timed gait at usual and fast pace over 10-m distance between older adults with dementia, mild cognitive impairment, and cognitively normal older adults. Older adults with dementia and mild cognitive impairment walked slower at their usual and fast pace over a 10-ft pathway compared to the cognitively normal older adults. A direct association between gait and cognition was identified.[30]

Global disability and severe disability are defined as having difficulty in executing at least one of the activities on 12 items on the World Health Organization Disability Assessment Schedule (WHODAS 2.0). Older adults who were current smokers were at a higher risk of global disability than non-smokers. Older adults with negative perception of health status were at a higher risk of severe disability.[22] Being male gender and having completed four years of schooling were two factors associated with a low risk of disability.[22]

Another study reported that older adults with impaired gait speed and grip-strength had higher prevalence of functional disability.[20]

C. Influence of Physical Co-Morbidities on Functioning

Four studies reported influence of physical co-morbidities on functioning.

A study conducted in Brazil on 405 individuals (mean age = 69.87 years) reported that cognitively impaired older adults were at a greater risk of functional decline, such as inability to use the telephone (OR = 3.01), and a higher risk of hospitalization (OR = 1.95). Similarly, frail older adults were at a higher risk of hospitalization (OR = 3.19).[28]

A cross-sectional study was conducted on individuals from six LMIC (Russia, Mexico, India, Ghana, South Africa, and China) to explore association between hand-grip strength and chronic physical conditions among middle-aged and older community dwellers. Individuals aged ≥ 65 years with > 2 co-morbidities, smokers, and people with depression exhibited weaker hand grip strength.[31]

Medical conditions such as osteoporosis (OR = 7.97), anemia (OR = 4.00), osteoarthritis (OR = 3.82), diabetes (OR = 3.53), and acid peptic disorder (OR = 3.15) were strongly associated with functional disability (limitation in daily activity). Age, gender, anemia, chronic obstructive pulmonary disease, scabies, hypertrophy of prostate, ischemic heart disease, osteoporosis, osteoarthritis, and acid peptic disorder were identified as risk factors of functional disability.[4] Similarly, another study reported that diabetes, stroke, depressive symptomology, and visual impairment were significantly associated

with physical disability (gait and balance impairment). Presence of arthritis and having depressive symptoms were significantly associated with activity limitation.[23]

D. Factors Affecting Health-Related Quality of Life (H-QOL)

A cross-sectional study conducted on 33,019 older adults in six low and middle income countries examined the factors influencing health-related quality of life (H-RQoL). Income, arthritis, and diabetes were three factors that affected H-RQoL of older adults in all six countries (China, Russia, Ghana, South Africa, Mexico, and India). Living environment and community support had a positive influence on H-RQoL across all countries except Ghana. Family support was positively associated with H-RQoL only in South Africa. Income, cognitive and physical function, and living environment were significantly associated with H-RQoL among male in all 6 countries. Diabetes or arthritis was negatively associated with quality of life among male older adults in China, Russia, and Ghana. Whereas, income, cognitive and physical function were significantly related to QoL among females in all six countries. Marital status as being married was positively associated with quality of life among female participants from all countries, except for Ghana, and diabetes or arthritis were negatively associated with QoL among female participants in all countries, except for Ghana.[32]

Similarly, a study conducted in rural Nepal reported the factors associated with high and low quality of life score (H-RQoL). Older adults aged < 75 years, residing in the urban areas, married ($p = 0.002$) employed, those who were literate, as well as those who were satisfied with the amount of time they spent with family members, perceived they were respected, and those who reported not to be abused verbally or physically by any family member demonstrated significantly higher H-RQoL scores. Older adults having any chronic physical health problems, those who were obese and had limited mobility demonstrated significantly lower H-RQoL score. Urban residence, employment status, absence of chronic physical health problems, and no depression were the four significant positive predictors of the H-RQoL in older adults.[33]

Musculoskeletal disorders, diabetes, low vision, hearing impairment, and impaired activity of daily living were significantly associated with physical domain of health-related quality of life. Only musculoskeletal disorders were associated with psychosocial domain, musculoskeletal disorders and low vision were associated with social relationship, and hearing impairment and impaired ADL were significantly associated with environmental domain of health-related quality of life. Factors such as advancement in age, no schooling, living alone/without spouse, nuclear family, musculoskeletal disorders, low vision, and impaired hearing were associated with low health-related quality of life score.[34]

IV. DISCUSSION

The present review describes the profile of functioning, determinants of functioning, influence of co-morbidities on functioning status, and factors affecting health-related quality of life of older adults in low and middle income countries.

Profile of functioning is described according to the domains of the WHO International Classification of Functioning, Disability and Health (ICF) model.

A. Profile of Functioning

1. Body Function

Lower-extremity muscle strength, hand-grip strength, balance, gait speed, and cognition were the most affected body function variables in individuals aged ≥ 60 years in low and middle income countries (LMIC).[19–23] Physiological changes that occur as part of natural aging process could be the source of affection of these body function variables. Older adults from high income countries (HIC) have reported decline in similar variables of body function. However, none of the studies from LMIC or HIC reported precise onset of decline in body function at a specific age group among older adults. Additionally, the magnitude of decline of body functions among older adults in LMIC with reference to HIC is not available. Variability in the use of functioning assessment tools in older adults across LMIC and HIC could account for the lack of information on the magnitude of decline in body functions.

2. Activity Limitation

Dressing, bathing, transfers, and housekeeping were the most affected activities of daily living.[24–26] Series of movements such as unipedal stance, good upper and lower-extremity muscle strength, flexibility and endurance, squatting, spinal flexion, extension, and side flexion movements are required to carry out these activities of daily living. Older adults may find it difficult to execute these series of movements with advancing age. Similar pattern of activity limitation was observed among older adults in a high-income country.[35]

3. Factors Determining Functioning

Body mass, body height, activity of daily living score, and geriatric depression score were significant predictors for hand-grip strength. An increase in body mass, body height, and activity of daily living score were associated with an increase in hand-grip strength. Whereas, increase in geriatric depression score was associated with decrease in hand-grip strength.[20] Lack of motivation to participate in daily living activities in a depressed older adult can be a reason for reduced hand-grip. In high income countries, hand-grip strength was negatively associated with instrumental activities of daily living.[36,37] Cognition had a positive association with gait.[30] Similar study findings were reported in older adults from a high-income country.[38] Being ≥ 75 years, widowers, low level of schooling, no alcohol consumption in the last 30 days, history of hospitalization in the past 12 months, receiving home care in the past 3 months, malnourished older adults, females, older adults with experience of memory loss, former smokers, brown or indigenous or Asian older adults,

extent of use of health services, and feeling of loneliness were factors associated with higher prevalence of limitation in activities of daily living.[26–29] Whereas, older adults satisfied with life had lower prevalence of limitation in activities of daily living.[26]

4. Influence of Physical Co-Morbidities on Functioning

Medical conditions such as osteoporosis, arthritis, anemia, osteoarthritis, diabetes and acid peptic disorder, chronic obstructive pulmonary disease, scabies, hypertrophy of prostate, ischemic heart disease, osteoporosis, stroke, and visual impairment were negatively associated with functional disability.[4,23] Co-morbidities have a major impact on cardiovascular, musculoskeletal, neurological, olfactory, and auditory systems, thus leading to negative influence on cardio-respiratory endurance, musculoskeletal strength, endurance and flexibility, postural balance, gait, vision, and hearing. Overall, co-morbidities lead to rapid decline in physical function of older adults, and eventually may lead to disability and lower health-related quality of life.

5. Factors Affecting Health-Related Quality of Life (H-RQOL)

Physical and cognitive function; environmental factors; marital, employment, and educational status; loneliness were major factors directly associated to health-related quality of life of older adults in low and middle income countries.[39]

Information on profile of physical functioning has been reported in different and singular domains by included studies. Hence, it is difficult to comment on comprehensive profile of physical functioning of older adults in LMIC. Therefore, further studies reporting comprehensive functioning profile of older adults from various low and middle income countries will enable exploration of association between functioning variables to understand interaction between domains because older adults present with multi-domain limitations in physical, psychological, and social health.

V. CONCLUSION

Hand-grip strength, lower extremity muscle strength, balance, cognition, and activities such as bathing, dressing and housekeeping were the most affected functioning variables in older adults.

Sociodemographic, socioeconomic, and behavioral factors; health status; and extent of use of health services were major factors responsible for functional decline in older adults. Older adults with arthritis and diabetes demonstrated greater limitation in basic activities of daily living. Chronic physical health problems, socio-economic, educational, employment status, and mild cognitive impairments were significant positive predictors of health-related quality of life in older adults.

The present information can be used by clinicians, researchers, and policymakers working in geriatrics to enhance care for older adults as well as to plan rehabilitation and treatment strategies to improve physical function.

A. LIMITATION

EMBASE database was not searched for pertinent literature.

B. CHALLENGES

1. A single model for comprehensive assessment of functioning of older adults is not available.
2. Hence none of the researchers have reported comprehensive functioning assessment based on a single model.
3. Thus mapping of the review results based on a single standardized model of functioning was not possible.

REFERENCES

1. Ageing and health [Internet]. Who.int. 2022 [cited 11 February 2022]. Available from: https://www.who.int/news-room/fact-sheets/detail/ageing-and-health.
2. Jagnoor J, Suraweera W, Keay L, Ivers RQ, Thakur JS, Gururaj G, Jha P. Childhood and adult mortality from unintentional falls in India. Bull World Health Organ. 2011;89:733–40.
3. Torres G, Reis L. Assessment of functional capacity in elderly residents of an outlying area in the hinterland of Bahia/Northeast Brazil. Arq Neuropsiquiatr. 2010;68(1):39–43.
4. Chakrabarty D, Mandal PK, Manna N, Mallik S, Ghosh P, Chatterjee C, Sardar JC, Sau M, Roy AS. Functional disability and associated chronic conditions among geriatric populations in a rural community of India. Ghana Med J. 2010;44(4).
5. Ambrose A, Noone M, Pradeep V, Johnson B, Salam K, Verghese J. Gait and cognition in older adults: Insights from the Bronx and Kerala. Ann Indian Acad Neurol. 2010 Dec;13(6):99.
6. Sinclair A, Conroy S, Bayer A. Impact of diabetes on physical function in older people. Diabetes Care. 2008;31(2):233–5.
7. Tomás M, Galán-Mercant A, Carnero E, Fernandes B. Functional capacity and levels of physical activity in aging: A 3-year follow-up. Front Med. 2018 Jan;4:244.
8. Stubbs B, Schofield P, Patchay S. Mobility limitations and fall-related factors contribute to the reduced health-related quality of life in older adults with chronic musculoskeletal pain. Pain Practice. 2016 Jan;16(1):80–9.
9. Patil SS, Suryanarayana SP, Dinesh Rajaram Murthy NS. Circumstances and consequences of falls in community-living elderly in North Bangalore Karnataka. J Krishna Inst Med Sci. 2015 Oct 1;4(4).
10. Bailey A, Hallad J, James KS. 'They had to go': Indian older adults' experiences of rationalizing and compensating the absence of migrant children. Sustainability. 2018 Jun;10(6):1946.
11. Census of India. Migration [Internet]. 2022 [cited 11 February 2022]. Available from: https://censusindia.gov.in/census_and_you/migrations.aspx.
12. Indian diaspora largest in the world, 18 million living outside India in 2020, says UN [Internet]. 2022 [cited 11 February 2022]. Available from: https://theprint.in/india/indian-diaspora-largest-in-the-world-18-million-living-outside-india-in-2020-says-un/586624/.
13. Kaplan D, Berkman B. Older adults living alone [Internet]. 2022 [cited 26 February 2022]. Available from: https://www.msdmanuals.com/professional/geriatrics/social-issues-in-older-adults/older-adults-living-alone.
14. Sudharsanan N, Bloom DE. The demography of aging in low- and middle-income countries: Chronological versus functional perspectives. In: National academies of sciences, engineering, and medicine; Division of behavioral and social sciences and education; Committee on population; Majmundar MK,

Hayward MD, editors. Future directions for the demography of aging: Proceedings of a workshop. Washington, DC: National Academies Press, US; 2018 Jun 26. 11. Available from: https://www.ncbi.nlm.nih.gov/books/NBK513069/.
15. Healthy ageing and functional ability [Internet]. Who.int. 2022 [cited 11 February 2022]. Available from: https://www.who.int/news-room/questions-and-answers/item/healthy-ageing-and-functional-ability.
16. Prince MJ, Wu F, Guo Y, Robledo LM, O'Donnell M, Sullivan R, Yusuf S. The burden of disease in older people and implications for health policy and practice. Lancet. 2015 Feb 7;385(9967):549–62.
17. Salinas-Rodríguez A, Rivera-Almaraz A, Scott A, Manrique-Espinoza B. Severity levels of disability among older adults in low-and middle-income countries: Results from the study on global ageing and adult health (SAGE). Front Med. 2020 Oct 15;7:562963.
18. Sustainable Development Goals | UNDP in India [Internet]. UNDP. 2022 [cited 11 February 2022]. Available from: https://www.in.undp.org/content/india/en/home/sustainable-development-goals.html.
19. Uysal I, Cetisli-Korkmaz N, Cavlak U. Assessment of the musculoskeletal performance with squat tests and performance-oriented measurements in older adults. J Back Musculoskelet Rehabil. 2020 Jan 1;33(5):735–41.
20. Brennan-Olsen SL, Bowe SJ, Kowal P, Naidoo N, Quashie NT, Eick G, Agrawal S, D'Este C. Functional measures of Sarcopenia: Prevalence, and associations with functional disability in 10,892 adults aged 65 years and over from six lower-and middle-income countries. Calcified Tissue Int. 2019 Dec;105(6):609–18.
21. Moy FM, Darus A, Hairi NN. Predictors of handgrip strength among adults of a rural community in Malaysia. Asia Pac J Public Health. 2015 Mar;27(2):176–84.
22. Montoro Pazzini Watfe G, Fajersztajn L, Ribeiro E, Rossi Menezes P, Scazufca M. Prevalence of older adult disability and primary health care responsiveness in low-income communities. Life. 2020 Aug;10(8):133.
23. Hairi NN, Bulgiba A, Cumming RG, Naganathan V, Mudla I. Prevalence and correlates of physical disability and functional limitation among community dwelling older people in rural Malaysia, a middle income country. BMC Public Health. 2010 Dec;10(1):1–3.
24. Swami HM, Bhatia V, Parashar A, Bhatia SP. Social and functional status of older persons in a north Indian community. Asia Pac J Public Health. 2003 Jan;15(1):10–6.
25. Ajayi SA, Adebusoye LA, Ogunbode AM, Akinyemi JO, Adebayo AM. Profile and correlates of functional status in elderly patients presenting at a primary care clinic in Nigeria. Afr J Prim Health Care Family Med. 2015;7(1):1–7.
26. Nunes JD, Saes MD, Nunes BP, Siqueira FC, Soares DC, Fassa ME, Thumé E, Facchini LA. Functional disability indicators and associated factors in the elderly: A population-based study in Bagé, Rio Grande do Sul, Brazil. Epidemiol Serv Saúde. 2017 Apr;26:295–304.
27. Nagarkar A, Kashikar Y. Predictors of functional disability with focus on activities of daily living: A community based follow-up study in older adults in India. Arch Gerontol Geriatr. 2017 Mar 1;69:151–5.
28. Brigola AG, Ottaviani AC, da Silva Alexandre T, Luchesi BM, Pavarini SC. Cumulative effects of cognitive impairment and frailty on functional decline, falls and hospitalization: A four-year follow-up study with older adults. Arch Gerontol Geriatr. 2020 Mar 1;87:104005.
29. Andre MB, Dumavibhat N, Ngatu NL, Eitoku M, Hirota R, Suganuma N. Mini nutritional assessment and functional capacity in community-dwelling elderly in Rural Luozi, Democratic Republic of Congo. Geriatr Gerontol International. 2013 Jan;13(1):35–42.
30. Ambrose AF, Noone ML, Pradeep VG, Johnson B, Salam KA, Verghese J. Gait and cognition in older adults: Insights from the Bronx and Kerala. Ann Indian Acad Neurol. 2010 Dec;13(Suppl 2):S99.
31. Vancampfort D, Stubbs B, Firth J, Koyanagi A. Handgrip strength, chronic physical conditions and physical multimorbidity in middle-aged and older adults in six low-and middle-income countries. Eur J Intern Med. 2019 Mar 1;61:96–102.
32. Lee KH, Xu H, Wu B. Gender differences in quality of life among community-dwelling older adults in

low-and middle-income countries: Results from the study on global AGEing and adult health (SAGE). BMC Public Health. 2020 Dec;20(1):1–0.
33. Risal A, Manandhar S, Manandhar K, Manandhar N, Kunwar D, Holen A. Quality of life and its predictors among aging people in urban and rural Nepal. Qual Life Res. 2020 Dec;29(12):3201–12
34. Ganesh Kumar S, Majumdar A, Pavithra G. Quality of life (QOL) and its associated factors using WHOQOL-BREF among elderly in urban Puducherry, India. J Clin Diagn Res. 2014 Jan;8(1):54.
35. Carmona-Torres JM, Rodríguez-Borrego MA, Laredo-Aguilera JA, López-Soto PJ, Santacruz-Salas E, Cobo-Cuenca AI. Disability for basic and instrumental activities of daily living in older individuals. PLoS One. 2019 Jul 26;14(7):e0220157.
36. Gopinath B, Kifley A, Liew G, Mitchell P. Handgrip strength and its association with functional independence, depressive symptoms and quality of life in older adults. Maturitas. 2017 Dec 1;106:92–4.
37. Mendes J, Amaral TF, Borges N, Santos A, Padrão P, Moreira P, Afonso C, Negrão R. Handgrip strength values of Portuguese older adults: A population based study. BMC Geriatr. 2017 Dec;17(1):1–2.
38. Kuan YC, Huang LK, Wang YH, Hu CJ, Tseng IJ, Chen HC, Lin LF. Balance and gait performance in older adults with early-stage cognitive impairment. Eur J Phys Rehabil Med. 2020 Dec 1:06550–8.
39. Schaap LA, Koster A, Visser M. Adiposity, muscle mass, and muscle strength in relation to functional decline in older persons. Epidemiol Rev. 2013 Jan 1;35(1):51–65.

Proc Inst Mech Eng H. 2022 May;236(5):686-696. doi: 10.1177/09544119211072971. Epub 2022 Jan 8.

Validation of wearable inertial sensor-based gait analysis system for measurement of spatiotemporal parameters and lower extremity joint kinematics in sagittal plane

Gunjan Patel [1 2], Rajani Mullerpatan [3], Bela Agarwal [3], Triveni Shetty [3], Rajdeep Ojha [4], Javeed Shaikh-Mohammed [1], S Sujatha [1]

Affiliations
PMID: 35001713 DOI: 10.1177/09544119211072971

Abstract

Wearable inertial sensor-based motion analysis systems are promising alternatives to standard camera-based motion capture systems for the measurement of gait parameters and joint kinematics. These wearable sensors, unlike camera-based gold standard systems, find usefulness in outdoor natural environment along with confined indoor laboratory-based environment due to miniature size and wireless data transmission. This study reports validation of our developed (i-Sens) wearable motion analysis system against standard motion capture system. Gait analysis was performed at self-selected speed on non-disabled volunteers in indoor (n = 15) and outdoor (n = 8) environments. Two i-Sens units were placed at the level of knee and hip along with passive markers (for indoor study only) for simultaneous 3D motion capture using a motion capture system. Mean absolute percentage error (MAPE) was computed for spatiotemporal parameters from the i-Sens system versus the motion capture system as a true reference. Mean and standard deviation of kinematic data for a gait cycle were plotted for both systems against normative data. Joint kinematics data were analyzed to compute the root mean squared error (RMSE) and Pearson's correlation coefficient. Kinematic plots indicate a high degree of accuracy of the i-Sens system with the reference system. Excellent positive correlation was observed between the two systems in terms of hip and knee joint angles (Indoor: hip 3.98° ± 1.03°, knee 6.48° ± 1.91°, Outdoor: hip 3.94° ± 0.78°, knee 5.82° ± 0.99°) with low RMSE. Reliability characteristics (defined using standard statistical thresholds of MAPE) of stride length, cadence, walking speed in both outdoor and indoor environment were well within the "Good" category. The i-Sens system has emerged as a potentially cost-effective, valid, accurate, and reliable alternative to expensive, standard motion capture systems for gait analysis. Further clinical trials using the i-Sens system are warranted on participants across different age groups.

Keywords: Wearable inertial sensor; gait analysis; gait kinematics; joint angles; motion capture system.

Related information

MedGen

LinkOut - more resources

Full Text Sources
Atypon

Physical Function in Critically Ill Patients during the Duration of ICU and Hospital Admission

Damini R Aglawe,[1] Bela M Agarwal,[2] and Bhoomika D Sawant[3]

[1–3]Department of Physiotherapy, MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, Maharashtra, India

Corresponding author.

Bela M Agarwal, Department of Physiotherapy, MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, Maharashtra, India, Phone: +91 9819000674, e-mail: belaagarwal@gmail.com

Abstract

Background

Impaired physical activity and functional ability is a significant problem in critical illness survivors. Measurement of physical functioning through intensive care unit (ICU) stay determines patients at risk of poor physical outcomes, monitors efficacy of intervention, and informs recovery trajectories.

Objectives

Study objective was to assess physical function trajectory and identify residual functional limitations in critically ill patients admitted to ICU at the point of discharge from the hospital using robust clinical measures.

Materials and methods

Following ethical approval, 100 patients (78 males and 22 females) admitted to medical and surgical ICUs were recruited. Scores on Functional Status Score in ICU (FSS-ICU), Physical Function ICU Test (PFIT), and Functional Independence Measure (FIM) were recorded. Day of physiother-

apy reference in the ICU was considered as day of ICU admission. Data were collected at three points, namely ICU admission, ICU discharge, and hospital discharge.

Results

Scores on all outcome measures increased linearly, and an upward functional trajectory was observed in patients from the point of ICU admission till hospital discharge (p >0.001).

Conclusion

Deficits in functional recovery exist until hospital discharge, substantiating the need to implement home-based rehabilitation to recover optimum physical function and independence in activities of daily living.

How to cite this article

Aglawe DR, Agarwal BM, Sawant BD. Physical Function in Critically Ill Patients during the Duration of ICU and Hospital Admission. Indian J Crit Care Med 2022;26(3):314–318.

Keywords: Critical illness, Intensive care units, Physical function, Physiotherapy

Introduction

Physical activity is key to healthy functioning of the body.[1] Physical function refers to the ability to carry out various activities ranging from self-care to more vigorous activities requiring increased degrees of mobility, strength, or endurance. Regular moderate physical activity has favorable effect on all systems of the body. Lack of regular physical activity results in dysfunction of body systems, impaired physical functional ability, and poor quality of life.[2]

Patients in ICUs need continuous intensive or invasive monitoring; support of airways, breathing, or circulation; stabilization of acute or life-threatening medical problems; comprehensive management of injury and/or illness; and maximization of comfort. Patients in the ICU with critical illness are exposed to prolonged bed rest and immobilization, leading to decreased physical activity and loss of functional abilities and dysfunctions of organ systems of the body. Impact of inactivity in the form of bed rest on musculoskeletal and cardiovascular systems is central to loss of functional independence.[1] Skeletal muscle atrophy, loss of muscle contractility and strength, and reduced bone mass due to increased rate of bone resorption than bone formation take place in the musculoskeletal system.[3] Response of cardiac muscles to inactivity is similar to the response of skeletal muscles. Cardiac muscle atrophy along with reduced stroke volume, increased resting heart rate, and reduced cardiac capacity occurs in response to physical activity.[4] Signs of orthostatic intolerance begin to develop after 3–4 days of bed rest. Increase in orthostatic intolerance and decrease in muscle strength together lead to a higher risk of fall and injury.[5]

Measuring physical functioning early and longitudinally in the ICU is key to determining patients at high risk of poor physical outcomes, monitoring intervention efficacy, and informing recovery trajectories. It is beneficial to knowing the current functional status and further planning of appropriate treatment for the individual.[6] Assessment followed by initiation of early rehabilitation

of patients during ICU stay helps to increase the success rate in ventilator weaning, reduce ICU and hospital stay, discharge early, and improve quality of life during and after ICU stay.[7] Physical function is not completely recovered after ICU discharge; various physical, psychological, clinical, and environmental factors influence physical activity of hospitalized patients.[8]

ICU functional scales have been administered primarily for the evaluation of physical activity of patients during ICU stay. Application of these scales during the post-ICU hospital phase is inadequate, resulting in lack of evaluation of physical activity status of patients during the post-ICU hospital phase, despite the presence of residual impairments. There is lacuna in the literature indicating functional limitations faced by patients post-ICU discharge. Hence, this study was designed to evaluate physical function recovery trajectory of patients during ICU stay until hospital discharge.

Methodology

Ethical approval was sought from the Institutional Ethical Committee. Patients of age-group 18–60 years admitted to medical and surgical ICUs from August to December 2020, with neurological, respiratory, medical and surgical conditions, and physiotherapy referral were included. Patients diagnosed with COVID-19 confirmed with reverse transcription polymerase chain reaction (RT-PCR) test and other infectious diseases, like acquired immunodeficiency syndrome (AIDS) and hepatitis B, were excluded.

The study protocol was explained to the patients/patients' caregivers, and written consent was sought. Demographic data and daily vital parameters (heart rate, respiratory rate, blood pressure, and oxygen saturation) were recorded. Patients were categorized into levels of function 0–6, based on the level of ventilatory support, consciousness, and activity levels (Table 1).

Physical function was evaluated using FSS-ICU, PFIT, and FIM.

Functional Status Score in Intensive Care Unit measures five items (rolling, supine-to-sit transfer, sitting at the edge of the bed, transfer from sit to stand, and walking) of physical function based on an individual's performance, scored on an eight-point ordinal scale of 0–7.[9]

Physical Function ICU Test is a test of physical function with high clinical utility and effective predictor of functional outcomes. Shoulder flexion and knee extension strength are graded from 0 to 5 (no visible or palpable contraction—full range of motion against gravity with maximal resistance). Sit-to-stand activity is scored based on the extent of assistance needed by the patient to safely transfer from sitting to standing position. Step cadence is the number of steps per minute. The patient was allowed to use assistive device if necessary. The test was concluded if the patient was unable to clear their feet from the ground for six consecutive steps or if the patient stopped marching for >2 seconds. The highest score of 3 was given if the patient demonstrated ability to march for >3 minutes.[10]

Functional Independence Measure is an 18-item physical function measurement tool, with 13 motor and 5 cognitive domains. Functional Independence Measure grades functional status from total independence to total assistance on the basis of level of assistance an individual requires to perform specific tasks.[11]

Physiotherapy treatment involving conventional therapeutic techniques based on the level of function was administered. Physiotherapist instituting care was blinded to objective scoring on functional scales. Physiotherapy care included positioning, airway clearance techniques, range-of-motion exercises, resistance exercises, breathing techniques, incentive spirometry, and early mobilization. Positioning included frequent alteration of body position, side-to-side turning in bed, upright sitting, and proning. It also included prescription of modified postural drainage positions to aid secretion removal. If needed, manual percussions and vibration techniques were applied. Airway clearance techniques were utilized along with positioning or as a sole intervention to facilitate secretion removal. Active cycle of breathing technique (ACBT), autogenic drainage (AD), huffing, and coughing techniques were appropriately selected and utilized. For intubated patients, postural drainage followed by suctioning and appropriate body positioning was done. Range-of-motion exercises for upper and lower limbs were utilized to maintain joint function. Resistance exercises targeted major muscle groups of upper and lower limbs using body weight and free weight resistance. Breathing techniques involved pursed lip breathing, diaphragmatic breathing, and thoracic expansion exercises aimed at improving the breathing pattern and relieving symptoms of dyspnea. Incentive spirometry provided a visual feedback to encourage sustained maximal inspiration to promote lung expansion. Early mobilization refers to utilizing progressive strategies to get the patient out of bed and facilitate physical activity. Intensity of exercises depended on the patient's clinical status and tolerance, starting with low intensity and gradually increasing the intensity throughout the course of rehabilitation. Each patient received two sessions per day from the day of reference until hospital discharge. Duration of each session was approximately 15–20 minutes.[12,13] Level-wise progression of treatment was achieved according to change in functional status.

Statistical Methods

Data collected at ICU admission, ICU discharge, and hospital discharge were utilized for statistical analysis Mean score was calculated for each scale component. One-way ANOVA was used for analysis of variance at the three data points. Tukey *post hoc* test was implemented to find out statistically significant difference or similarity between specific groups based on data points.

Results

The total number of patients included in the study was 100 (78 males and 22 females) in the age-groups of 20–29 years (N = 7), 30–39 years (N = 19), 40–49 years (N = 20), and 50–60 years (N = 54). Fifty patients were diagnosed with neurological conditions, 20 with respiratory conditions, and 30 with medical and surgical conditions. Average length of ICU stay and post-ICU hospital stay was 12.67 and 8.68 days, respectively; and average length of hospital stay from the point of ICU admission to hospital discharge was 21.33 days (Table 2).

Statistically significant between-group difference (p <0.001) was demonstrated for all pre-ambulatory (rolling f = 170.21, supine-to-sit f = 145.67, and unsupported sitting f = 113.40) and ambulatory (sit-to-stand f = 172.97 and walking f = 122.32) categories of the FSS-ICU scale. All components showed statistical difference (p <0.001) between ICU admission and ICU discharge, indicating that a maximum number of patients were able to achieve independent pre-ambulatory and ambulatory activities at hospital discharge.

Similarly, statistically significant improvement was observed in all categories of PFIT (shoulder strength $f = 85.97$, knee strength $f = 74.44$, sit-to-stand $f = 122.10$, cadence $f = 107.55$, cadence count $f = 111.87$, $p < 0.001$). Shoulder and knee strength, sit-to-stand, and cadence improved from ICU admission to ICU discharge and from ICU discharge to hospital discharge. Cadence count was nonsignificant from ICU admission to ICU discharge ($p = 0.016$) and was statistically significant ($p < 0.001$) from the point of ICU discharge to hospital discharge. Thus, both FSS-ICU and PFIT scales demonstrated similar results and were capable of identifying functional limitations during hospital stay.

With respect to self-care and transfer activities, statistically significant improvement was observed in all components of the FIM tool. *Post hoc* analysis revealed no change in scores at the point of ICU admission to ICU discharge for self-care activities, such as bathing ($p = 0.20$) and toileting ($p = 0.03$). However, scores for eating, grooming, and dressing upper and lower body activities were statistically significant ($p < 0.001$). Bed, chair, and wheelchair transfer activity improved significantly at each data point ($p < 0.001$). Further, nonsignificant change was observed in walking ($p = 0.001$) and stair-climbing ($p = 0.13$) scores. Significant improvement was observed in the cognitive domains of comprehension, expression, social interaction, memory, and problem-solving ($p < 0.001$).

All motor components of FIM self-care, sphincter control, transfers, and locomotion demonstrated statistical significance from the point of ICU discharge to hospital discharge ($p < 0.001$); cognitive domains, including comprehension ($p = 0.62$), expression ($p = 0.58$), social interaction ($p = 0.49$), problem-solving ($p = 0.26$), and memory ($p = 0.67$), were statistically nonsignificant from the point of ICU discharge to hospital discharge. All 18 items for motor and cognitive domains exhibited significant statistical difference ($p < 0.001$) from the point of ICU admission to hospital discharge. Self-care activities evaluated by FIM showed low scores during ICU stay, which can be attributed to the presence of disease, patients' health status, and ICU restrictions. During the post-ICU discharge phase, a faster improvement trajectory in performance of these activities was seen, indicating improved independence in performing simple motor tasks. Ability to perform transfers independently improved greatly during post-ICU hospital stay. Transfer activities remained underachieved during the period of ICU stay, possibly due to restrictions imposed by patients' health status and ICU environment. Walking function was underperformed until ICU discharge and later showed improvement until hospital discharge. Stair-climbing activity could not be scored in the ICU and remained less than satisfactory at hospital discharge. The post-ICU hospital phase showed improvement in ambulation and locomotory independence of patients.

All components demonstrated a gradual improvement trajectory from the point of ICU admission to hospital discharge. Although patients improved in function with more than 50th percentile at the point of hospital discharge, large deficits in function equivalent to 40–60% were observed in one domain of each outcome measure. Physical function ICU test cadence count (49.11%), FSS-ICU walking (56.71%), and FIM stair climbing (44.71%) showed less-than-satisfactory improvements at the point of hospital discharge.

Discussion

This study was undertaken to evaluate functional level of patients during ICU stay and post-ICU hospital stay. A gradual improvement in physical function was observed from the point of ICU admission until hospital discharge. Physical function measures were effective in identifying func-

tional impairments in the ICU. The chosen scales were applicable for use throughout the length of hospital stay as residual limitations continued to exist despite discharge from the ICU and even until hospital discharge.

Patients demonstrated a similar pattern of gradual rise in physical functional level in all outcome measures throughout the period of hospitalization in our study. Pre-ambulatory physical activities of rolling in bed, supine-to-sit transfer, and unsupported sitting displayed that these activities were well performed by patients during ICU stay. Similarly, weight-bearing ambulatory activities, sit-to-stand, and walking remained underachieved during ICU stay and showed gradual linear improvement during the post-ICU hospital phase. It can thus be said that applicability of FSS-ICU is a sensitive measure that can be used to objectively record improvement in preambulatory and ambulatory activities.

Loss of muscle strength is known to be acquired in critically ill patients who are mechanically ventilated for prolonged time periods. Studies show that ICU-acquired weakness (ICU-AW) is present in more than 50% of patients at ICU discharge who were mechanically ventilated for more than 48 hours. Significant muscle loss due to both bed rest and the presence of critical illness results in decreased ability to perform self-care and transfer activities and worsening of disability in ICU survivors. ICU-acquired weakness manifests even after discharge from acute healthcare centers as post-intensive care syndrome (PICS), resulting in impairment in physical functioning, cognitive dysfunction, and poor mental health status. Symptoms include generalized weakness, fatigue, decreased mobility, anxious or depressed mood, sexual dysfunction, sleep disturbances, and cognitive issues (memory disturbance/loss, slow mental processing, poor concentration, and so on) and can last for a few months to many years post-recovery. Physiotherapy interventions focused on exercise-based interventions in the ICU, including both bed exercises and mobilization out of bed, can help reduce incidence of ICU-AW and PICS.[14] Therefore, identification of these functional disabilities gains utmost importance prior to hospital discharge.

The physical function ICU test (PFIT) tool provides an objective measure of improvement in muscle strength of shoulder flexors and knee extensors; both these muscles groups showed gradual improvement from the point of ICU admission to ICU discharge and further up to hospital discharge. This supports effectiveness of adding resistive exercises in the treatment protocol of ICU patients. By identification of muscle weakness, physiotherapy interventions focusing on the management of the same can be utilized early in rehabilitation of ICU patients.

Results of our study supported the effectiveness of physiotherapy interventions and their effects on physical function post-ICU discharge. After ICU discharge, considerable improvement in physical activity and functional level status of patients was demonstrated on FIM. Self-care activities, such as eating, grooming, dressing, and toileting, showed greatest improvement in independence during and after ICU discharge. Level of physical activity displayed a steady increase during and after ICU discharge, with patients performing tasks of self-care and bed transfers much more independently than during ICU stay. Walking and stair-climbing activities remained underachieved at hospital discharge, achieving less than 60% improvement. FSS-ICU, PFIT, and FIM were useful for identifying limitations in walking and stair-climbing functions at the point of hospital discharge. The results from this study emphasize the need to monitor impaired cardiorespiratory function, muscle weakness, and malnutrition on a long-term basis as these are important factors for poor ambulatory performance after ICU discharge.[15] Similar observations are reported in previous studies conducted on individuals admitted to ICU for ≥72 hours.[16,17]

Difficulty in performing ADLs, transfers, and ambulation is commonly encountered by ICU survivors. ICU survivors with a low burden of preexisting comorbidities have little to no disability at hospital discharge and generally show good outcomes.[18] Higher test scores of FSS-ICU, PFIT, and FIM at ICU discharge can be used as significant factors in determining discharge to home.[19,20]

Out of all the outcome measures, only FIM scale evaluated cognitive aspects, including comprehension, expression, social interaction, problem-solving, and memory. All patients showed improvement in cognitive function from the point of ICU admission up to hospital discharge. Higher physical activity level aided achievement and maintenance of good cognitive functions during hospital stay. These findings support previous studies that conclude early rehabilitation of patients in the form of physical activity in the ICU improves cognitive function and helps to reduce symptoms of anxiety and depression. Early rehabilitation thus decreases risk of neuropsychiatric morbidities in critically ill patients.

Through this study, we were able to recognize barriers to early mobilization of ICU patients that prevented achieving higher levels of mobility during ICU stay. Dafoe et al. categorized these barriers as patient-related and institution-related barriers. Patient-related barriers include medical instability, sedation, level of consciousness, and the presence of vascular lines/monitor attachments. Institution-related barriers include poor staff awareness of the benefits of early progressive mobilization, resulting in a conservative culture where mobilization is undervalued, uncertainty regarding staff responsibility for mobilization (e.g., physiotherapists or nurses), and insufficient staff/equipment.[21] Patient barriers play a major role in lack of achieving ambulatory activities in the ICU. After ICU discharge, patients are exposed to greater functional freedom to perform physical activities with reduced or no barriers.

Our study demonstrated an upward trend in the physical functional trajectory of patients during ICU stay and post-ICU hospital stay. However, residual physical function limitations continue to persist at the point of hospital discharge, necessitating continuum of care. Thus, by informing caregivers regarding these limitations, strategies can be adopted to combat and help overcome long-term morbidity in these patients.

Conclusion

Objective assessment of the physical function trajectory helps to monitor and understand patients' level of functional status throughout their hospital stay. It helps in gaining better insight of patients' limitations to functional activities and can help in goal-setting and planning of physiotherapy care.

Early and progressive rehabilitation intervention programs are feasible for comprehensive management of ICU patients; this reduces physical and mental health complications that frequently occur in survivors of critical illnesses. Early physical rehabilitation benefits patients in domains of muscle strength, physical function, and quality of life, which helps in recovering optimum physical function and independence in daily life. Greater standardization of physiotherapy management of patients in the ICU can be achieved by continuing rehabilitation until hospital discharge and follow-up rehabilitation after hospital discharge.

Implementing and continuing early rehabilitation physiotherapy until hospital discharge and later implementing home rehabilitation after hospital discharge will help patients to recover optimum physical function and independence in activities of daily living.

Clinical Implication

Identification of functional limitations aids in prescribing a targeted treatment approach for patients starting early in the ICU, continuing throughout hospital stay and beyond hospital discharge.

Limitations

Our study included a wide variety of patients with neurological, respiratory, medical, and surgical conditions. Further research on patients admitted to various other ICUs with specific conditions needs to be undertaken for wider applicability of observations from this study.

Footnotes

Source of support: Nil

Conflict of interest: None

Orcid

Damini R Aglawe https://orcid.org/0000-0003-4986-8903

Bela M Agarwal https://orcid.org/0000-0001-7573-9844

Bhoomika D Sawant https://orcid.org/0000-0001-6856-8880

References

1. Topp R, Ditmyer M, King K, Doherty K, Hornyak J. The effect of bed rest and potential of prehabilitation on patients in the intensive care unit. *AACN Clin Issues.* 2002;13(2):263–276. doi: 10.1097/00044067-200205000-00011. [PubMed: 12011598] [CrossRef: 10.1097/00044067-200205000-00011]

2. Perme C, Chandrashekar R. Early mobility and walking program for patients in intensive care units: creating a standard of care. *Am J Crit Care.* 2009;18(3):212–221. doi: 10.4037/ajcc2009598. [PubMed: 19234100] [CrossRef: 10.4037/ajcc2009598]

3. Akima H, Kubo K, Kanehisa H, Suzuki Y, Gunji A, Fukunaga T. Leg-press resistance training during 20 days of 6 head-down-tilt bed rest prevents muscle deconditioning. *Eur J Appl Physiol.* 2000;82(1–2):30–38. doi: 10.1007/s004210050648. [PubMed: 10879440] [CrossRef: 10.1007/s004210050648]

4. Convertino VA. Cardiovascular consequences of bed rest: effect on maximal oxygen uptake. *Med Sci Sports Exerc.* 1997;29(2):191–196. doi: 10.1097/00005768-199702000-00005. [PubMed: 9044222] [CrossRef: 10.1097/00005768-199702000-00005]

5. Shoemaker JK, Hogeman CS, Sinoway LI. Contributions of MSNA and stroke volume to orthostatic intolerance following bed rest. *Am J Physiol Regul Integr Compar Physiol.* 1999;277(4):R1084–R1090. doi: 10.1152/ajpregu.1999.277.4.r1084. [PubMed: 10516248] [CrossRef: 10.1152/ajpregu.1999.277.4.r1084]

6. Parry SM, Huang M, Needham DM. Evaluating physical functioning in critical care: considerations for clinical practice and research. *Crit Care.* 2017;21(1):249. doi: 10.1186/s13054-017-1827-6. [PMCID: PMC5628423] [PubMed: 28978333] [CrossRef: 10.1186/s13054-017-1827-6]

7. Needham DM. Mobilizing patients in the intensive care unit: improving neuromuscular weakness and physical function. *Journal of the American Medical Association.* 2008;300(14):1685–1690. doi: 10.1001/jama.300.14.1685. [PubMed: 18840842] [CrossRef: 10.1001/jama.300.14.1685]

8. Parry SM, Knight LD, Connolly B, Baldwin C, Puthucheary Z, Morris P, et al. Factors influencing physical activity and rehabilitation in survivors of critical illness: a systematic review of quantitative and qualitative studies. *Intensive Care Med.* 2017;43(4):531–542. doi: 10.1007/s00134-017-4685-4. [PubMed: 28210771] [CrossRef: 10.1007/s00134-017-4685-4]

9. Hiser S, Toonstra A, Friedman LA, Colantuoni E, Connolly B, Needham DM. Interrater reliability of the functional status score for the intensive care unit. *J Acute Care Phys Ther.* 2018;9(4):186–192. doi: 10.1097/JAT.0000000000000086. [CrossRef: 10.1097/JAT.0000000000000086]

10. Denehy L, de Morton NA, Skinner EH, Edbrooke L, Haines K, Warrillow S, et al. A physical function test for use in the intensive care unit: validity, responsiveness, and predictive utility of the physical function ICU test (scored). *Phys Ther.* 2013;93(12):1636–1645. doi: 10.2522/ptj.20120310. [PubMed: 23886842] [CrossRef: 10.2522/ptj.20120310]

11. Gosman-Hedström G, Svensson E. Parallel reliability of the functional independence measure and the Barthel ADL index. *Disabil Rehabil.* 2000;22(16):702–715. doi: 10.1080/09638280050191972. [PubMed: 11117590] [CrossRef: 10.1080/09638280050191972]

12. Frownfelter D, Dean E. *Cardiovascular and pulmonary physical therapy-E-Book: evidence to practice.* Elsevier Health Sci; 2014.

13. Thomson AM, Skinner AT, Piercy J. *Tidy's physiotherapy.* Butterworth-Heinemann; 1991.

14. Hodgson CL, Tipping CJ. Physiotherapy management of intensive care unit-acquired weakness. *J Physiother.* 2017;63(1):4–10. doi: 10.1016/j.jphys.2016.10.011. [PubMed: 27989729] [CrossRef: 10.1016/j.jphys.2016.10.011]

15. Da Silva PB, Dos Santos LJ. Patient functionality and walking speed after discharge from the intensive care unit. *Rev Bras Ter Intensiva.* 2019;31(4):529. doi: 10.5935/0103-507X.20190066. . ISBN: 9780323291170. [PMCID: PMC7009006] [PubMed: 31967228] [CrossRef: 10.5935/0103-507X.20190066]

16. Vesz PS, Costanzi M, Stolnik D, Dietrich C, Freitas KL, Silva LA, et al. Functional and psychological features immediately after discharge from an intensive care unit: prospective cohort study. *Rev Bras Ter Intensiva.* 2013;25(3):218–224. doi: 10.5935/0103-507X.20130038. [PMCID: PMC4031842] [PubMed: 24213085] [CrossRef: 10.5935/0103-507X.20130038]

17. Van der Schaaf M, Dettling DS, Beelen A, Lucas C, Dongelmans DA, Nollet F. Poor functional status immediately after discharge from an intensive care unit. *Disabil Rehabil.* 2008;30(23):1812–1818. doi: 10.1080/09638280701673559. [PubMed: 19031208] [CrossRef: 10.1080/09638280701673559]

18. Shimogai T, Izawa KP, Kawada M, Kuriyama A. Factors affecting discharge to home of medical patients treated in an intensive care unit. *Int J Environ Res Public Health.* 2019;16(22):4324. doi: 10.3390/ijerph16224324. [PMCID: PMC6887772] [PubMed: 31698814] [CrossRef: 10.3390/ijerph16224324]

19. Tymkew H, Norris T, Arroyo C, Schallom M. The use of physical therapy ICU assessments to predict discharge home. *Crit Care Med.* 2020;48(9):1312–1318. doi: 10.1097/CCM.0000000000004467. [PubMed: 32639412] [CrossRef: 10.1097/CCM.0000000000004467]

20. Parry SM, Denehy L, Beach LJ, Berney S, Williamson HC, Granger CL. Functional outcomes in ICU–what should we be using? An observational study. *Crit Care.* 2015;19(1):127. doi: 10.1186/s13054-015-0829-5. [PMCID: PMC4404223] [PubMed: 25888469] [CrossRef: 10.1186/s13054-015-0829-5]

21. Dafoe S, Chapman MJ, Edwards S, Stiller K. Overcoming barriers to the mobilisation of patients in an intensive care unit. *Anaesth Intens Care.* 2015;43(6):719–727. doi: 10.1177/0310057X1504300609. [PubMed: 26603796] [CrossRef: 10.1177/0310057X1504300609]

Figures and Tables

Table 1

Level 0–6 for patient categorization based on functioning

Level 0	***Level 1***	***Level 2***	***Level 3***	***Level 4***	***Level 5***	***Level 6***
Patient on artificial ventilator on CMV mode	Change of ventilator mode (CMV to SIMV/ Spontaneous)	Patient off ventilator, extubated with or without O_2 support	Patient is conscious and oriented with or without O_2 support	Patient is conscious and oriented without O_2 support	Patient is full cooperative, able to do major things actively	Patient is full cooperative, able to do all things actively

Table 2

Mean scores on FSS-ICU, PFIT and FIM Scales (n = 100)

SI. No.	*Scale scores*	*ICU admission*	*ICU discharge*	*Hospital discharge*	*p value*
Functional Status Score in Intensive Care Unit (FSS-ICU) scores					
1	FSS Rolling	1.9 (1.5)	4.0 (1.6)	6.0 (1.4)	
2	FSS Supine to sit	1.4 (1.6)	3.2 (1.7)	5.5 (1.7)	
3	FSS Unsupported sitting	1.2 (1.7)	3.2 (2.2)	5.5 (1.9)	<0.001
4	FSS Sit to stand	0.1 (0.5)	1.5 (1.6)	4.7 (2.5)	
5	FSS Walking	0.0 (0.5)	1.0 (1.5)	3.9 (2.6)	
Physical Function ICU Test (PFIT) scores					
6	PFIT Shoulder strength	0.6 (0.5)	1.2 (0.5)	1.7 (0.5)	
7	PFIT Knee strength	0.6 (0.5)	1.1 (0.6)	1.6 (0.6)	
8	PFIT Sit to stand	0.0 (0.3)	0.6 (0.8)	2.1 (1.4)	<0.001
9	PFIT Cadence	0.0 (0.1)	0.4 (0.5)	1.3 (0.9)	
10	PFIT Cadence count	0.7 (4.3)	8.2 (12.7)	39.2 (30.6)	
Functional Independence Measure (FIM) scores					
11	FIM Eating	1.5 (1.1)	2.8 (1.6)	5.1 (1.6)	
12	FIM Grooming	1.6 (1.1)	2.7 (1.8)	4.9 (1.9)	
13	FIM Bathing	1.1 (0.8)	1.4 (1.1)	3.8 (1.9)	
14	FIM Dressing upper body	1.6 (1.1)	3.1 (1.6)	5.2 (1.7)	
15	FIM Dressing lower body	1.6 (1.1)	2.8 (1.7)	4.8 (1.9)	
16	FIM Toileting	1.1 (0.7)	1.6 (1.3)	4.4 (1.9)	
17	FIM Bladder management	1.3 (1.3)	2.4 (2.1)	5.1 (1.9)	
18	FIM Bowel management	1.3(1.3)	2.4 (2.1)	5.1 (1.9)	
19	FIM Bed chair wheelchair transfer	1.4 (0.8)	2.5 (1.6)	5.0 (2.0)	<0.001
20	FIM Toilet transfer	1.1 (0.5)	1.7 (1.4)	4.4 (2.1)	
21	FIM Tub shower transfer	1.0 (0.5)	1.7 (1.4)	4.4 (2.1)	
22	FIM Walk wheelchair	1.0 (0.4)	1.8 (1.3)	4.3 (2.3)	
23	FIM Stairs	1.0 (0.0)	1.3 (1.0)	3.1 (2.0)	
24	FIM Comprehension	5.1 (2.4)	6.5 (1.0)	6.7 (0.6)	
25	FIM Expression	5.0 (2.6)	6.2 (1.4)	6.5 (1.1)	
26	FIM Social interaction	4.9 (2.6)	6.0 (1.7)	6.3 (1.3)	
27	FIM Problem-solving	4.8 (2.6)	5.9 (1.8)	6.3 (1.3)	
28	FIM Memory	5.0 (2.6)	6.2 (1.4)	6.4 (1.1)	

Dough kneading exposure at the kitchen workstation: Influence on handgrip strength and implications for therapy in hand rehabilitation

Lubna Khan[a], Mamta Shetty[a], Shifa Kherada[a], Reema Kava[a], Mubina Kazi[a], Prachita Walankar[b] and Rajani Mullerpatan[a,*]

[a]*MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, Maharashtra, India*

[b]*MGM College of Physiotherapy, Maharashtra University of Health Sciences, Navi Mumbai, Maharashtra, India*

Received 18 June 2021
Accepted 7 December 2021

Abstract.

BACKGROUND: Dough kneading is a commonly performed activity in the kitchen, which influences hand grip strength.

OBJECTIVES: To study the influence of dough kneading exposure on hand grip strength and to evaluate the effect of dough kneading intervention on hand grip strength with the purpose of recommending dough kneading as a therapeutic exercise for improving hand grip strength.

METHODS: One hundred and fifty healthy females with varying levels of exposure to dough kneading, stratified as occupational dough kneaders, habitual dough kneaders and non-kneaders, were studied. Hand grip strength of all participants was measured with a standard protocol using the Jamar dynamometer. Hand grip strength of occupational, habitual and non-kneaders was compared. Non-kneaders followed a 6-week intervention of dough kneading and grip strength was recorded post-intervention.

RESULT: Comparison of hand grip strength between the three groups revealed significant difference (p value < 0.001). Linear contrast analysis, revealed the least hand grip strength in non-kneaders compared to habitual and occupational dough kneaders, with occupational dough kneaders presenting maximum hand grip strength (p value < 0.001). Significant improvement was demonstrated in hand grip strength post-intervention in non-kneaders (p value < 0.001).

CONCLUSION: Findings suggest that exposure to dough kneading has a positive influence on hand grip strength. Hand grip strength of non-kneaders was lowest compared to habitual and occupational kneaders. Kneading intervention improved hand grip strength and hence can be used therapeutically as a safe, low cost exercise in hand rehabilitation.

Keywords: Handgrip strength, hand rehabilitation, kitchen workers, kneading

1. Introduction

Kneading is a common kitchen activity performed globally by homemakers, cooks, chefs, independently living adults cooking their own food and food enthusiasts. Kneading dough requires spreading the dough on a floured surface, pressing and stretching it with the heel of the hand, folding it over with the fingers and thumb and repeatedly rotating it through 90 degrees. Repeated motion of alternate grip and release by fingers, accompanied by wrist motion demands work of intrinsic and extrinsic muscles of hand. The resistance offered to the intrinsic and extrinsic muscles of hand by the process of binding the flour with water is expected to increase strength of hand muscles. The type of flour and consistency of dough would demand varying levels of hand

*Address for correspondence: Dr. Rajani Mullerpatan, Professor, MGM School of Physiotherapy, MGM Institute of Health Sciences, Sector 1, Kamothe, Navi Mumbai, Maharashtra, India. E-mail: rajani.kanade@gmail.com.

ISSN 1051-9815/$35.00

muscle work but irrespective of the type of flour used, kneading would provide a resistance stimulus to the hand muscles. Kneading is also known to produce physiological stress to the cardio-vascular system, in addition to the physiological stress to the muscular system and result in energy expenditure [1]. Physiological stress in moderate intensity and duration can be used therapeutically for enhancement of physical fitness [1].

On the other hand, physical and psychological load factors are known to lead to musculoskeletal disorders in kitchen workers [2]. However, studies reporting the average hand grip strength of dough kneaders are unavailable. Collins et al. reported repetitive hand movements, static work postures and forceful exertions as precipitating factors which pose kitchen workers at risk of developing musculoskeletal disorders [3]. Prevalence rate of musculoskeletal disorders in the upper quadrant is reported to be highest in the shoulder region (62.3 %), wrist (43.9%), elbow/forearm (31.6%) and neck (38.6%) among kitchen workers [2]. It has also been reported that Indian flatbread preparation imposes a greater risk of musculoskeletal disorders than preparation of dosa and rice [2].

Overall, indirect evidence from previous studies suggests that dough kneading can produce strength training stimulus to hand muscles which can result in greater hand grip strength. Hence, kneading dough can be explored as a potential therapeutic exercise to improve hand grip strength, because hand grip strength is such a strong indicator of overall health and physical fitness [4]. Kneading is also used as a key variable to monitor treatment outcomes in hand rehabilitation [5]. Therefore, it would be useful to add various exercise options to the therapeutic toolbox which can improve hand grip strength.

It is known that athletes and sports players engaged in various sports demanding intense hand function such as golf, archery, volleyball, basketball and handball demonstrate greater hand grip strength compared to adults not engaged in these sports. In addition to specific demands of these sports on hand function, athletes and sports players practising these sports undergo intense training to improve and optimize hand function to enhance sport performance [6,7].

However, compliance of sports persons to exercise is notably greater than general people [8].

On the other hand, compliance of general people to exercise is poor [8]. Therefore, in order to improve compliance to hand exercise and enhance outcome of exercise, identification of suitable activities of daily living is prudent for general people. One such common activity in the kitchen is kneading. Kneading dough is a common activity performed by homemakers on a regular basis, which primarily targets muscles involved with gripping activities. Typically, the exposure to dough kneading varies in different work settings and different resource settings across the world ranging from daily exposure for domestic or occupational purpose to occasional weekly exposure for domestic purpose. Prolonged exposure in professional kitchen workers involving repetitive tasks and forceful exertion may increase muscle fatigue [2].

The present study was designed to quantify the influence of dough kneading exposure on hand grip strength among females with varying kneading exposure. The second objective was to study the effect of dough kneading intervention on hand grip strength with the purpose of recommending integration of dough kneading as a safe, low cost therapeutic exercise for the enhancement of hand grip strength.

2. Method

The study commenced after the Institute's Ethics Review Committee (IERC) approved the study. A total of 150 healthy female participants between the age group of 18 – 50 years with varying levels of exposure to dough kneading were recruited. The sample size was estimated based on the standard deviation of the previous study where hand grip strength was used as an outcome measure [9]. The sample size was estimated to be 33 with hand grip strength as a primary outcome variable [10]. Considering a high rate of dropout in healthy people, 50 participants were recruited in each group [8]. The participants were recruited using snowball sampling from the residential communities in the same city. Kneading exposure was determined by frequency of dough kneading sessions and volume of dough kneaded. Domestic cooks kneaded dough two/three times a day as a part of their occupation. The duration of kneading was approximately 10–15 minutes per session. In contrast, homemakers, independently living adults, etc. who were habitual in dough kneading, practiced it at least once a day as a part of their daily living activity. The participants were stratified in three groups: Occupational dough kneaders (domestic cooks), habitual dough kneaders (homemakers) and non-kneaders. Non-kneaders had no exposure to dough kneading. We hypothesized that dough kneading has a positive influence on hand grip strength.

Table 1
Demographic characteristics and hand grip strength

	Occupational dough kneaders ($n = 50$)	Habitual dough kneaders ($n = 50$)	Non-kneaders ($n = 50$)
	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	35.16 (3.17)	38 (7.81)	21.44 (1.60)
BMI (kg/m^2)	24.86 (1.93)	24.58(2.67)	22.54 (2.58)
Handgrip strength (kg)			
Dominant hand	35.48 (2.54)	25.56 (5.66)	22.02 (4.39)
Non-dominant hand	32.92 (2.53)	22.62 (5.81)	19.70 (4.02)

Women presenting with pain or pathology of upper extremity were excluded. The participants were informed about the study procedure and signed informed consent was sought. Demographic details along with body composition including height, weight and body mass index (BMI) were recorded. Hand grip strength was measured using the Jamar hand dynamometer in kilograms of force (kg). The handle of the dynamometer was set to second position for all participants. The participants were made to sit on a chair without arm rest, back straight, shoulders adducted and neutrally rotated, elbows flexed to 90^0, forearm in neutral position, wrist in 15 degrees of extension and ulnar deviation. Grip strength was recorded for dominant and non-dominant hands. An average of three trials was recorded for all measurements.

Non-kneaders followed a 6-week intervention protocol. The protocol included kneading a dough using 500 mg of flour with 200 ml of water. The flour was placed in a wide bowl and water was added gradually to bind the two ingredients into a dough. The dough was then pressed using heel of hand and fingers by repeatedly folding over and rotating it in the bowl. This process was repeated for 15 minutes until the dough was soft and malleable. The amount of water added to the flour and the time duration for kneading was kept constant for all the participants to ensure consistency of the dough; because the consistency of the dough would influence the extent of muscle work. All participants performed dough kneading once a day, three times a week, for six weeks.

Data were analysed using SPSS version 24. Mean and standard deviations were computed for all the variables. Level of significance was set at 0.05 for inferential statistics. The Wilcoxon signed rank test was used to compare means pre- and post-intervention in non-kneaders because the data did not follow requirements for normal distribution.

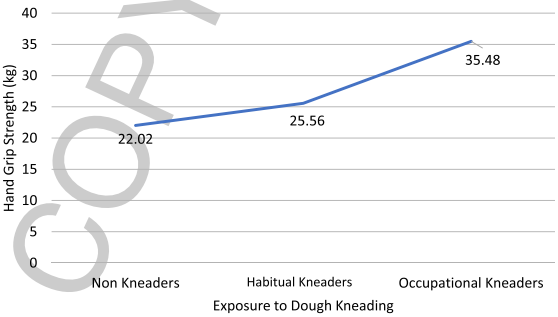


Fig. 1. Mean hand grip strength of occupational dough kneaders, habitual dough kneaders and non-kneaders.

3. Results

Reference values for hand grip strength were recorded for 150 participants stratified as occupational dough kneaders ($n = 50$), habitual dough kneaders ($n = 50$) and non-kneaders ($n = 50$). Comparison between dominant and non-dominant hands did not reveal a significant difference ($p = 0.168$). Demographic characteristics and mean values of hand grip strength for dominant hand are presented in Table 1. Figure 1 presents mean grip strength values for occupational dough kneaders, habitual dough kneaders and non-kneaders for dominant hand.

Normality of data was evaluated using the Shapiro-Wilk test and, because the data were not normally distributed, non-parametric tests were used for inferential statistics.

Comparison of hand grip strength between the three groups revealed a significant difference (p value < 0.001). Linear contrast revealed linear decline in hand grip strength; demonstrating maximum hand grip strength in occupational kneaders and the least in the non-kneaders group (p value < 0.001) (Table 2). The effect of intervention for non-kneaders was analysed using Wilcoxon signed rank test. Significant

Table 2
Comparison of handgrip strength between occupational, habitual and non-kneaders

Group	Occupational dough kneaders	Habitual dough kneaders	Non-kneaders	*t* value (Kruskal-Wallis test)	Significance *p* value
Dominant hand (mean rank)	2.92	1.72	1.36	15.118	0.000
Non-dominant hand (mean rank)	2.92	1.71	1.37	15.117	0.000

Table 3
Handgrip strength in non-kneaders pre- and post-intervention

Hand grip strength (kg)	Non-kneaders ($n = 50$) (pre-intervention)	Non-kneaders ($n = 50$) (post-intervention)	Wilcoxon signed rank test z value	Significance *p* value
Dominant hand Median (IQR)	22.02 (4.39)	25.32 (4.24)	–6.167	0.000
Non-dominant hand Median (IQR)	19.70 (4.02)	22.44 (3.79)	–5.608	0.000

improvement (p value < 0.001) was noted in hand grip strength post-intervention (Table 3).

4. Discussion

Findings from the present study report beneficial influence of dough kneading exposure on hand grip strength.

Kneading involves movement of both hands. It is a bimanual activity and that may be the reason for no difference in hand grip strength of right and left sides. The participants included in the study used the manual method for kneading dough, which is the most common method adopted by kitchen workers in domestic settings.

Kneading demands the activity of muscles of the upper quadrant from distal to proximal segment [1]. In the hand, it engages activity of small and large muscle groups of hand. Moderate exposure to kneading is known to produce beneficial effect of muscle strengthening [1], which was evident by greater hand grip strength of domestic cooks, followed by homemakers and the least in non-kneaders. However, prolonged exposure (more than 30 minutes) in kitchen workers is associated with discomfort and muscle fatigue [2]. The trapezius muscle is known to demonstrate greater fatigue during kneading [2].

On the other hand, kneading dough simulates a form of hand grip strengthening exercise. Because dough kneading demands all the three manipulative abilities unique to human hand, namely precision handling, forceful precision gripping and power squeeze gripping of cylindrical objects. Precision handling is the ability to rotate and manipulate objects with one hand using the fingertips and thumb. Forceful precision gripping uses pads of thumb and one or more fingers to forcefully stabilize or manipulate an object while withstanding large external forces. Power squeezing of cylindrical objects allows the fingers to grip the object diagonally across the palm with thumb either wrapped around the object or in line with the forearm. Kneading dough involves all three abilities necessary to maintain adequate hand function [9].

It is speculated that with a period of moderate resistance training, as early as 2 to 3 weeks, hypertrophy becomes an increasingly important adaptation accounting for strength gain in muscle. Hypertrophy of skeletal muscle occurs due to an increase in protein (actin and myosin) synthesis and a decrease in protein degradation. In addition, type II B muscle fibers appear to increase in size most readily with resistance training [9]. A recent study reported adaptation to endurance training to be better in females as compared to males due to a higher potential for oxidation

of fat [12]. The rate of glycogen depletion has been reported to be lower in females as compared to males during endurance activity. Hence, females are efficient in performing at workloads equal to 80 percent of maximum oxygen uptake [12].

It is known that in repetitive dynamic gripping, fatigability is low due to prolonged time available to the muscle fibers between contractions to clear the potassium in t-tubules of the muscle fibers [13]. Women are known to have low fatigability during sustained and intermittent contractions [13]. Women also demonstrate greater muscular endurance compared to males while working at submaximal levels, which is attributed to the higher proportion of type I muscle fibers in women compared to men [13].

On the other hand, a previous study which evaluated physiological stress of female workers, reported reduction in hand grip strength of female kitchen workers who were involved in kneading tasks at a commercial kitchen workstation. It was reported that hand grip strength decreased by 29% in left and right hand, whereas pinch strength reduced by 44% and 47% in the left and right hand, respectively; but the average hand grip and pinch strength were not reported [14]. It can be speculated that the kitchen workers who were studied from a commercial setting had long exposure to kneading activity resulting in fatigue and ultimately reduction in hand grip and pinch strength. However, the study does not provide information on duration of kneading exposure. Secondly, it is important to note that the kitchen workers were engaged in multiple kitchen tasks which engaged hand muscles, namely cutting, grating, rolling and dishwashing. Therefore, it is likely that the cumulative effect of all kitchen station tasks may have induced fatigue in hand muscles, resulting in lower hand grip strength. Thirdly, the instrument and protocol used for measurement of hand grip strength varied from the standard protocol for measurement [14]. Therefore, it is likely that the results from the present study differ from the previous study because the present study reports immediate positive difference in hand grip strength after dough kneading intervention performed for a short duration (15minutes). The dosimetry of kneading intervention was defined to achieve a therapeutic effect of improved hand grip strength. It is already known that precise dosimetry of exercise duration is crucial to avoid fatigue induced by the exercise [14].

A wide spectrum of exercises is known to improve hand grip strength over a period ranging from 8 weeks to 24 weeks among patients with various hand conditions. Patients with hand osteoarthritis demonstrated greater hand grip strength after an 8-week finger exercise program [15]. Rubber ball exercises by elderly over a period of one month demonstrated improvement in hand grip strength [17]. Patients with rheumatoid arthritis showed improved hand grip strength following a strengthening exercise protocol ranging from 12 weeks to 24 weeks in duration [18,19,20].

Similarly, CrossFit training has demonstrated improvement in hand grip strength among sedentary individuals with a mean age of 24 years post 12-week intervention [16]. Hand grip strength was reported to increase by 8.5 percent in sedentary individuals following an intervention of high-intensity CrossFit training for 12 weeks [16]. These findings corroborate with findings of the present study, wherein exposure to dough kneading was associated with increased hand grip strength by 10 percent.

To summarize, findings from the present study are consistent with previous studies which report increased hand grip strength after a particular exercise intervention. Therefore, dough kneading may be recommended as an effective intervention for improvement of hand grip strength. Moreover, dough kneading is feasible in a routine daily home setting and can be self-administered by the patient. Although it is known that kneading dough is the second activity in the kitchen, which causes fatigue of kitchen workers followed by grating [9]. It is also known that hand-intensive and repetitive activities are a major cause of work-related musculoskeletal disorders [9]. However, it is evident that moderate regular exposure to kneading can be considered promising for improvement of hand grip strength. Hence, it can be explored as a potential exercise form to improve hand grip strength in various hand conditions such as osteoarthritis, rheumatoid arthritis, complex regional pain syndromes and fractures around the wrist and hand.

5. Limitations

Further studies are required to define the precise duration of exercise in each session, particularly in the acute phase of inflammatory disorders such as osteoarthritis, rheumatoid arthritis, complex regional syndrome, etc. It is necessary to identify the threshold for hand muscle work before the onset of fatigue, to plan the safest application of dough kneading in hand rehabilitation. Also, it may not be appropriate

to include this as an intervention in post-operative cases until complete wound healing to avoid any contamination of the wound. The present study did not account for the level of physical fitness and hobbies of the participants which demand a dextrous, prehensile, or power grip of hand. Findings of the present study are restricted to adult females.

6. Conclusion

Findings from the present study suggest that exposure to dough kneading has a beneficial influence on hand grip strength. Hand grip strength was lowest in non-kneaders and maximum in occupational kneaders. Kneading dough also helps to improve hand grip strength. Six weeks of kneading intervention improved hand grip strength by approximately 10 percent. Therefore, kneading dough in moderation can be used as a therapeutic intervention in rehabilitation of patients with hand dysfunction.

Acknowledgments

The authors thank the volunteers for their participation in the study.

Conflict of interest

The authors have no conflict of interest to report.

References

[1] Bhatt H, Sidhu MK. Physiological stress assessment of female workers at kitchen workstation. Work. 2012;41(Supplement 1):441-6.
[2] Subramaniam S, Murugesan S, Jayaraman S. Assessment of shoulder and low back muscle activity of male kitchen workers using surface electromyography. International Journal of Occupational Medicine and Environmental Health. 2018;31(1):81-90.
[3] Collins RM, Janse Van Rensburg DC, Patricios JS. Common work-related musculoskeletal strains and injuries: CPD article. South African Family Practice. 2011;53(3):240-6.
[4] Choudhary AK, Jiwane R, Alam T, Kishanrao SS. Grip strength and impact on cognitive function in healthy kitchen workers. Achievements in the Life Sciences. 2016;10(2):168-74.
[5] Incel NA, Ceceli E, Durukan PB, Erdem HR, Yorgancioglu ZR. Grip strength: effect of hand dominance. Singapore Medical Journal. 2002;43(5):234-7.
[6] Iermakov SS, Podrigalo LV, Jagiełło W. Hand-grip strength as an indicator for predicting the success in martial arts athletes.
[7] Barut C, Demirel P, Kiran S. Evaluation of hand anthropometric measurements and grip strength in basketball, volleyball and handball players. Anatomy. 2008;2(1).
[8] Reljic D, Lampe D, Wolf F, Zopf Y, Herrmann HJ, Fischer J. Prevalence and predictors of dropout from high-intensity interval training in sedentary individuals: A meta-analysis. Scandinavian Journal of Medicine & Science in Sports. 2019;29(9):1288-304.
[9] Rajani P. Mullerpatan, Gayatri Karnik and Rebecca John. Grip and pinch strength: Normative data for healthy Indian adults. Hand Therapy 2013;18:11–16(1)
[10] Chang HY, Chou KY, Lin JJ, Lin CF, Wang CH. Immediate effect of forearm Kinesio taping on maximal grip strength and force sense in healthy collegiate athletes. Physical Therapy in Sport. 2010;11(4):122-7.
[11] Kivell TL. Evidence in hand: recent discoveries and the early evolution of human manual manipulation. Philosophical Transactions of the Royal Society B: Biological Sciences. 2015;370(1682):20150105.
[12] Kisner C, Colby L.Therapeutic Exercise. 5th Edition. 158:163-64.
[13] Baxi G, Tigdi SR, Palekar TJ, Basu S, Sule K. Static and dynamic handgrip endurance in young adults. Indian Journal of Physiotherapy and Occupational Therapy. 2017;11(4):118.
[14] Bhatt H, Sidhu MK. Physiological stress assessment of female workers at kitchen workstation. Work. 2012;41(Supplement 1):441-6.
[15] Nicolay CW, Walker AL. Grip strength and endurance: Influences of anthropometric variation, hand dominance, and gender. International Journal of Industrial Ergonomics. 2005;35(7):605-18.
[16] Kang TW, Lee JH, Park DH, Cynn HS. Effects of a finger exercise program on hand function in automobile workers with hand osteoarthritis: A randomized controlled trial. Hand Surgery and Rehabilitation. 2019;38(1):59-66.
[17] Dilber AO, Doğru Y. The effect of high-intensity functional exercises on anthropometric and physiological characteristics in sedantery. Uluslararası Spor Egzersiz ve Antrenman Bilimi Dergisi. 2018;4(2):64-9.
[18] Pangaribuan IN, Nugroho N, Oenarta DG. Hand Muscle Grip Strength on Pre-and Post-Rubber Ball Performing Exercises of Older People. Journal of Widya Medika Junior. 2020;2(3):168-73.
[19] Azeez M, Clancy C, O'Dwyer T, Lahiff C, Wilson F, Cunnane G. Benefits of exercise in patients with rheumatoid arthritis: a randomized controlled trial of a patient-specific exercise programme. Clinical Rheumatology. 2020;8:1-0.
[20] Pineda-Juarez JA, Lozada-Mellado M, Hinojosa-Azaola A, García-Morales JM, Ogata-Medel M, Llorente L, Alcocer-Varela J, Orea-Tejeda A, Martín-Nares E, Castillo-Martínez L. Changes in hand grip strength and body weight after a dynamic exercise program and Mediterranean diet in women with rheumatoid arthritis: a randomized clinical trial. Physiotherapy Theory and Practice. 2020;12:1-9.

Physical Function Assessment Tools in the Intensive Care Unit: A Narrative Review

Bela Agarwal,* Damini Aglawe, & Bhoomika Sawant

MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, India

*Address all correspondence to: Dr. Bela Agarwal, MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, India; Tel.: +91-9819000674, E-mail: bagarwal@mgmsopnm.edu.in

ABSTRACT: Prolonged immobilization and bed rest in critically ill patients leads to loss of physical functional ability. Therefore, assessment of physical functional ability during intensive care unit (ICU) stay and at discharge plays a central role in planning early intervention and instituting rehabilitation measures to improve physical function outcomes. Various scales have been developed, modified, and applied to assess functional ability, impairments, and disabilities in ICU patients. The selection of the most appropriate assessment scale depends on the specific patient population, the diagnosis, the phase of rehabilitation and the psychometric properties of the measurement tool. This narrative review aims to describe the various physical function assessment tools applicable to patients in the ICU, to determine the psychometric evidence for reliability and validity, and to summarize the strengths and weaknesses of each of these scales in order to enable clinicians to make an informed choice while selecting outcome variables during rehabilitation of patients in the critical care unit.

KEY WORDS: intensive care, physical function, assessment, outcome measures

ABBREVIATIONS: BADL, basic activities of daily living; **BI**, Barthel index; **CPAx**, Chelsea critical care physical assessment tool; **DRS**, disability rating scale; **FIM**, functional independence measure; **FSS-ICU**, functional status score–ICU; **GOS**, glasgow outcome scale; **ICU**, intensive care unit; **KPS**, Karnofsky performance scale; **MBI**, modified Barthel index; **MDC**, minimal detectable change; **mRS**, modified rankin scale; **PCFS**, post COVID-19 functional status score; **PFIT**, physical function ICU test; **PRFS-ICU**, patient-reported functional scale–ICU

I. INTRODUCTION

Physical function is the ability to carry out various activities that require physical capability and is the key to healthy functioning of the body. It ranges from self-care to more vigorous activities requiring higher degrees of mobility, strength, or endurance.[1,2] Patients with critical illness are exposed to prolonged bed rest and immobilization leading to decreased physical activity and loss of functional abilities, which results in decline or dysfunction of organ systems.[1] Continuous intensive or invasive monitoring; support of airways, breathing, or circulation; stabilization of acute or life-threatening medical problems; comprehensive management of injury and/or illness; and maximization of comfort for patients admitted in intensive care units (ICUs) confines patients to their beds and decreases physical activity.[3]

Considerable functional disabilities in activities of daily living is seen in patients post ICU-discharge.[4] Reduced physical activity and functional ability is a significant

0896-2960/22/$35.00

problem in ICU survivors.[5] Therefore, assessment of physical function during ICU stay is valuable in gaining perspective on current functional status and to further plan appropriate treatment of the individual. Functional limitations of ICU survivors often remain unassessed. Hence, measuring physical functioning early and longitudinally in the ICU is important to determine patients at risk of poor physical outcomes, monitor intervention efficacy, and inform recovery trajectories. These insights are important to improve the outcomes of critically ill patients.[6]

Several scales have been used to assess functional ability, impairment, and disability in ICU patients. Functional scales in ICU have been administered mainly for evaluation of patient physical activity at ICU admission and during ICU stay. The choice of most appropriate assessment scale depends on the specific patient population, the diagnosis and rehabilitation phase, and the psychometric properties of available measurements. Selecting an appropriate functional assessment outcome measure is crucial for evaluation, goal setting, and administration of the best possible rehabilitation measures. The aim of the current narrative review is to describe the commonly used tools for measuring physical function in patients admitted to the ICU along with the psychometric properties of the scales and their applicability in various patient groups.

II. METHODOLOGY

A literature search was performed using PubMed, Google Scholar, Cochrane Library, and Science Direct. Among the 495 titles/abstracts identified using the key words "physical function," "functional ability," "disability," "impairment," "scales," "assessment," "intensive care unit," "critical-illness" with Boolean operators "AND" and "OR;" 64 full text articles were examined and evaluated for inclusion. Reference lists of relevant articles were examined to identify additional eligible studies. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidance was used.

A. Inclusion Criteria

Full-text articles published in English, reviews and randomized control trials utilizing these scales, and articles reporting the psychometric properties of the physical function scales applicable to patients with critical illness were included in this review.

B. Exclusion Criteria

Articles published in languages other than English, studies on neonatal and pediatric populations, studies not reporting description or psychometric properties of the measurement tools and studies reporting health-related quality of life, mental health, and aspects other than physical function were excluded.

III. RESULTS

Sixteen scales were identified through the literature review. A brief summary of each scale, domains of function evaluated by the scale, scoring system, and psychometric properties of each scale is provided to enable clinicians to make an informed choice while selecting measurement tools for evaluation of physical function in the ICU.

A. Glasgow Outcome Scale

Optimal arousal and adequate neurological function is mandatory to perform physical activities. The glasgow outcome scale (GOS), first published by Jennett and Bond in 1975, provides a global assessment of function, has been consistently used in ICU settings, and is highly cited in studies on brain injury. A GOS score of 1 = good recovery, 2 = moderate disability, 3 = severe disability, 4 = persistent vegetative state, and 5 = death. The range of outcomes includes minimal or no disability (GOS 1), moderate disability (GOS 2), and severe disability (GOS 3 or 4).[7,8,9] McMillan et al. charted the development, refinement, and application of GOS. Other versions of the original GOS are the glasgow outcome scale-extended (GOS-E), the glasgow outcome at discharge scale (GODS), and the GOS pediatric revision.[9] Wier et al. reported higher sensitivity of GOS-E than GOS.[10] Excellent inter-rater reliability $k = 0.95$ was reported by the developers of GOS, while other studies involving trained raters with direct or simultaneous contact with patients reported low inter-rater reliability $k = 0.76$.[11]

B. Richmond Agitation-Sedation Scale

Patients in the ICU often demonstrate altered neurological status with agitation and require sedation in order to ensure synchrony between the ventilators and patient and comfort with artificial intubation. However, prolonged sedation can substantially impact the length of ICU stay and related complications. The richmond agitation-sedation scale (RASS) was developed by critical care physicians, nurses, and pharmacists with an objective of enhancing communication between care givers and optimizing rehabilitation. The RASS is a 10-point scale ranging from +4 to −5, where +4 denotes a combative stage; +2/3, agitation; +1, restlessness; and 0, alert and calm; −1 denotes drowsy; and −5, unarousable of sedation. Sessler et al. tested the reliability and validity of the RASS in adult critically ill patients. Excellent inter-rater reliability (r = 0.922–0.983) is reported in ventilated and nonventilated patients with medical and surgical conditions.[12]

C. Barthel Index

The Barthel Index (BI) was developed by Mahoney and Barthel in 1955. It scores the ability of a patient to perform 10 basic self-care activities of daily living. Periodical

reassessment can be performed to assess the progress of physical activity status. Items include self-care activities like feeding, grooming, bathing, dressing, bowel and bladder care and toileting, and mobility activities such as ambulation, wheelchair transfers, and stair climbing. The scale gives a measurable estimation of the patient's level of independence with scoring from 0 (totally dependent) to 100 (totally independent). A score of 100 indicates that the patient is able to feed, dress, bathe, walk, and ascend and descend stairs independently. The BI classifies the patients as having minimal or no disability (BI score > 90), moderate disability (BI = 55–90), or severe disability (BI score < 55).[13] Statistically high significance in coefficients of concordance between the four different methods of BI rating have been reported (Kendall's coefficient of concordance $W = 0.93$; $p < 0.001$). Internal consistency of BI was found to be 0.87.[14]

D. Modified Barthel Index

Barthel Index was considered a standard measure of ADLs until Shah et al. in 1989 reported that BI sensitivity can be improved by variations in scoring of each ADL in the scale. The updated BI is known as the Modified Barthel Index (MBI). The items of the scale remain the same, whereas the scoring of each ADL is expanded to include more categories to record each item. A score of 0 indicates total dependence while 100 indicates complete independence. The MBI also serves as a predictor of hospital discharge. A score < 40 indicates unlikely chances of discharge and a score > 85 indicates early discharge. The MBI is reported to have greater sensitivity, improved reliability, and excellent test-retest reliability compared to the original BI. The ICC of the MBI was reported to be 0.94, indicating high test-retest reliability. The MDC (minimal detectable change) of the MBI was 19% indicating that MBI scores are less affected by random measurement errors.[15,16]

E. Functional Independence Measure

The functional independence measure (FIM) was developed in 1983 by a task force created by the American Congress of Rehabilitation Medicine and the American Academy of Physical Medicine and Rehabilitation and headed by Carl Granger and Byron Hamilton.[17] It is a widely used functional evaluation tool for assessing patients' basic functional activities and their progress during their ICU stay and in-patient rehabilitation. It includes two separate domains: the motor domain consists of 13 items and the cognitive domain consists of 5 items. The FIM is a multidimensional measure assessing self-care, sphincter control, transfers, locomotion, communication, and social cognition. FIM scores range from 1 to 7:7 indicates complete independence, while 1 indicates total assistance. The sum of all components generates a total score between 18 (complete dependence) and 126 (complete independence). The precision, inter-rater reliability, and validity of FIM have been well established at rehabilitation discharge and particularly at one-year post injury. Ceiling effects of the FIM have been studied in

patients with moderate and severely neurological impairment. Previous studies indicate that FIM scores are associated with mortality in critically ill elderly patients and difficulty in weaning from a mechanical ventilator.[18,19]

F. Functional Status Score–ICU

The FSS-ICU is an ordinal scale used for in-patient rehabilitation in the ICU. It consists of three preambulation categories: rolling, supine-to-sit transfers, and unsupported sitting; and two ambulation categories: sit-to-stand transfers and ambulation. Each category is rated using score values from 1 (total dependent assistance) to 7 (complete independence) and total scores range 0–35. If a patient is unable to perform a task due to physical limitations or medical status, a score of 0 is assigned. The reliability and validity of the FSS-ICU had not been reported[20] until Huang et al. conducted a clinimetric analysis and concluded that it has good internal consistency and is a valid and responsive measure of physical function.[21]

G. 4P Questionnaire

The 4P questionnaire was named after its major content: patients, physical, psychosocial, and problems. This questionnaire was developed by Eva Akerman et al. in 2008 to assess ICU patients' physical and psychosocial problems after ICU discharge, and to recognize the need for follow-up.[22] It evaluates physical and psychosocial problems following ICU recovery and includes 53 items: 16 physical, 26 psychosocial, and 11 follow-up. The items are scored on a 5-point Likert scale from "strongly agree" to "do not agree at all." There is also a "not relevant" option. The questionnaire shows good construct validity in all three sets and has strong factor loadings for all three sets. Internal consistency (Cronbach's α for physical problems = 0.75, psychosocial problems = 0.81, follow-up = 0.91) has been shown to have reliable indices and good stability reliability on retesting for the physical and psychosocial factors.[23]

H. Physical Function ICU Test

The physical function ICU test (PFIT) is a reliable outcome measure developed for critically ill patients who may be unable to get out of bed. The four test domains are assistance required to perform sit-to-stand transfers, strength of shoulder flexion, strength of knee extension, and marching in place. The assistance required to stand is rated from 0 (no physical assistance required) to 3 (assistance of three people required). Strength for shoulder flexion and knee extension is rated on the Oxford Muscle Test Scale. For marching in place, the examiner records the number of steps taken and the time required to complete them. The PFIT has demonstrated reliability and good responsiveness to change.[24] Denehy et al. conducted a nested cohort study to test the clinimetric properties of PFIT. Their observations indicate that scoring of sit-to-stand assistance is subjective, and cadence cut-points used may not be generalizable to a large population.[25]

I. Karnofsky Performance Scale Index (Karnofsky Status Scale/Karnofsky Index/Karnofsky Score)

The Karnofsky Index is a highly recommended outcome measure for scoring ICU patients and emphasizes physical performance and dependency to indicate the patient's functional status. It is a descriptive, ordinal scale that ranges from 100 (good health) to 0 (dead). A Karnofsky Index of 70–100 is generally considered a favorable functional outcome measure. This measurement tool is well-established with proven validity and reliability for the assessment of independent functioning in critically ill patients.[26] Grieco et al. investigated the Karnofsky Performance Scale (KPS) as a measure of quality of life, reporting it as a reliable and valid global measure although it does not sufficiently capture the quality-of-life domain.[27] Nikoletti et al.[28] reported the use of KPS as a gold standard for quantifying physical function in cancer patients. A comparative study of KPS and its modified version Throne-KPS (T-KPS) suggested that T-KPS may be a more objective and sensitive measure of physical function in cancer patients residing in terminal care facilities. T-KPS avoids reference to the location of care. The middle and lower levels of T-KPS are modified such that they provide clinically relevant change in function as compared to KPS.[28] A study undertaken by Carlos et al. to identify quality-of-life predictors in Brazilian women undergoing palliative care reported that lower KPS scores were closely related to reduced quality of life.[29] Recently, Nagihan et al. evaluated the reliability and validity of KPS and found a strong positive correlation (r = 0.895) between KPS and Katz ADL and a strong negative correlation (r = –0.894).[30]

J. Modified Rankin Scale

Rather than performance of specific tasks, the modified rankin scale (mRS) quantifies independence and disability. The scale consists of 6 grades from 0 to 5 as follows: 0 = no symptoms; 1 = no significant disability despite symptoms; 2 = slight disability, with the subject unable to carry out all previous activities but able to look after their own affairs without assistance; 3 = moderate disability, with the subject requiring some help but able to walk without assistance; 4 = moderately severe disability, with the subject being unable to attend to bodily needs without assistance; and 5 = severe disability, with the subject bedridden, incontinent, and requiring constant nursing care and attention.[31,32] The scale was found to have good inter-rater agreement ICC = 0.675 in acute stroke patients, but problems with interpretation and relevancy in the hospital setting have been reported.[33]

K. Disability Rating Scale

The disability rating scale (DRS) is a common outcome measure used to determine impairment, disability, and handicap. The scale assesses general functional changes over the course of recovery. The first three items—"Eye Opening," "Communication Ability," and "Motor Response" indicate impairment ratings. "Feeding,"

"Toileting," and "Grooming" indicate level of disability. "Level of Functioning" and "Employability" indicate handicap. Each area of functioning is rated on a scale of 0 to 3 or 5, higher scores representing higher levels of disability. The maximum achievable scores are 29 (extreme vegetative state) and 0 (no disability).[34] Eliason et al. reported good reliability and validity coefficients for DRS in traumatic brain injury patients. Significant correlation was reported between initial DRS scores and length of hospital stay ($r = 0.50$, $p < 0.01$); at discharge DRS scores ($r = 0.66$, $p < 0.01$); and discharge status ($r = 0.40$, $p < 0.01$).[35] Struchen et al. reported that DRS provides a greater range of scores and is thus more sensitive to change than GCS.[36]

L. Patient-Reported Functional Scale–ICU

The patient-reported functional scale (PRFS-ICU) is a recently developed self-reported tool that measures patients' perceptions of their ability to perform six activities— rolling in bed, sitting at the edge of the bed, sit-to-stand activity, bed-to-chair transfer, ambulation, and stair climbing. Items are scored from 0 (unable) to 10 (able to perform at pre-ICU level) with a maximum of 60.[37]

M. Katz Index of Independence in Activities of Daily Living

The Index of Independence in Activities of Daily Living, commonly known as the Katz Index, was developed by Dr. Sidney Katz in 1963. It was developed as a tool to measure function which can be used in objective evaluations of chronically ill and aging populations and the effectiveness of treatment in the same. The index is based on primary biological and psychosocial functions, and provides an objective guide to the course of chronic illness and aids in rehabilitation and summarizes six functions, namely, bathing, dressing, going to toilet, transferring, continence, and feeding.[38,39] Patients are scored 1 for "yes" and 0 for "no," for independence in each of the six functions. A score of 6 indicates full function; 4, moderate impairment; and 2 or less, severe functional impairment.[40] Haack et al. in 2019 reported that the Katz Index of ADL is significant in predicting hospital discharge and the need for disposition to outpatient or rehabilitation facilities for long-term rehabilitation. Katz et al. assessed the inter-rater reliability, reporting only insignificant differences between observers.[39,41]

N. Chelsea Critical Care Physical Assessment Tool

The development of this tool began in 2009 by Evelyn J. Corner, with the aim to formulate a bedside scoring system to evaluate and grade physical morbidity in the critically ill population.[42] The Chelsea Critical Care Physical Assessment Tool (CPAx) is a numeric and pictorial composite of 10 common components: physical function; respiratory function, cough, moving within the bed, supine-to-sitting transfer to the edge of the bed, dynamic sitting, standing balance, sit-to-stand transfer, transferring from bed to chair, stepping, and grip strength. These are graded on a 6-point Guttman

Scale, from complete dependence to independence (0 to 5). The component scores are added to produce a total score out of 50; 0 = complete dependence, and 50 = full independence. The score can also be plotted on a "radar" chart, giving a pictorial representation of patients' physical functions and highlighting the problem areas.[43] Corner et al. reported high content validity and limited ceiling and floor effects for CPAx in critical illness survivors. Lower CPAx scores are associated with mortality.[43] In an observational study, Corner et al. reported responsiveness of CPAx in measuring functional recovery in patients with acute severe burns.[44] Whelan et al. evaluated postsurgical patients and patients admitted to ICUs with traumatic injuries using CPAx. They reported that CPAx can be used as a part of physical therapy assessment to formulate problem-oriented rehabilitation resulting in improved levels of physical function, and that higher CPAx scores at admission are related to shorter hospital stays.[45]

O. Post COVID-19 Functional Status Score

The Post COVID-19 Functional Status Score (PCFS) was developed by Klok et al.[46] and emphasizes relevant aspects of daily life during follow-up after COVID-19 infection. The scale is ordinal, scoring from 0 (no symptoms) to 5 (death, D). It covers a vast range of functional outcomes by focusing on limitations in usual duties/activities either at home or at work/study, as well as changes in lifestyle. The scale scores are intuitive and can easily be grasped by both clinicians and patients. The PCFS is applied at different time intervals: time of discharge from the hospital, first weeks after discharge to monitor direct recovery (e.g., at four and eight weeks postdischarge, and six months after a COVID-19 diagnosis.[46] A recent study reported wide degrees of functional limitations in COVID-19 patients at hospital discharge and at six months follow-up assessed using the PCFS.[47]

P. Perme ICU Mobility Score

The Perme ICU Mobility Score was developed to measure a patient's mobility status, commencing with the ability to follow commands and culminating in distance walked in two minutes. It includes 15 items in 7 categories: mental status, potential mobility barriers, functional strength, bed mobility, transfers, gait, and endurance. The scores range from 0 to 32, with higher scores indicating fewer potential mobility barriers and lower requirements for mobility assistance, and lower scores indicating more potential barriers and more assistance needed. Each of the 15 items is scored within the maximum range of 2–4. The total score that reflects the patient's mobility status at one moment in time. Questions 1–8 require yes or no answers. For Questions 9–14, a score of 0 is assigned to patients who need total assistance (< 25% of the effort) or when the activity does not occur. A score of 3 is assigned to patients who need minimum assistance (> 75% of the effort) or when the activity requires supervision. Item 15 is scored from 0 to 3 based on the distance walked in two minutes. Perme et al. reported high validity and reliability

and good clinical applicability. Kappa values for specific items were described with overall median agreement between raters of 94.29%.[48]

Timenetsky et al. assessed mobility in COVID-19 patients using the Perme Mobility Score, and identified low mobility in patients at ICU admission and improved mobility during the course of their stay.[49] Luna et al. reported minimal detectable change (MDC) for a Perme Mobility Score of 1.36 points, thus giving evidence of sensitivity to changes in mobility.[50] The tool is available in Spanish, Portuguese, and German. Psychometric properties of the translated versions have been established.[50,51,52]

IV. DISCUSSION

The ICU is a high-dependency zone, where patients present with severely compromised multisystemic dysfunction. An altered level of consciousness makes it difficult to evaluate physical function. Breathing difficulties, mechanical ventilators, pain, sedation, medication lines, catheters, and other devices further hinder mobility. Therefore, it becomes imperative to undertake a structured evaluation of pain and dysfunction in order to maximize functional recovery.

Very few reviews are available on the functional scales used in ICUs to evaluate physical function and pain. The scales need to demonstrate satisfactory psychometric properties in terms of internal reliability and validity, intertester reliability, and test-retest reliability in order to enable comparison between outcomes evaluated on a periodic basis to assess function. Clinicians need to be knowledgeable about available tools to enable identification of the right one based on specific patient needs.

In this narrative review, we have summarized the most commonly used scales that evaluate physical function of patients in the ICU, presented the strengths and weaknesses of each tool, and reviewed the studies that have validated the clinimetric properties of the scales in different patient populations. Despite the number of scales available, no single one addresses all clinical or research conditions. The tools have been developed over the decades to provide measures of patient activity, capacity, disability, and dependency.

Application of assessment tools is dependent on patients' level of functioning. Patients progress through complete dependency while unconscious, with poor ventilatory function requiring artificial ventilatory support, no spontaneous motor activity to gradually improving function (Fig. 1). Through the recovery trajectory, patients show linear improvement in neurological function, ventilatory function, voluntary activity, and physical function. Many of the scales are applicable through the complete functional trajectory while some can be used in the later phases of recovery. Each scale has its strengths and limitations. All scales included in this review along with application guidelines are freely available and therefore can be easily accessed and applied in practice by professionals. During the initial stages of recovery, scales such as the RASS, IMS-ICU, FSS-ICU, KPS, MRS, DRS, PRFS-ICU, and CPAx may be more applicable whereas greater objective assessment can be performed during later stages of recovery

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	LEVEL 6
Patient on artificial ventilation on CMV mode	**Change of ventilation mode (CMV to SIMV/ Spontaneous)**	**Patient off ventilator, extubated with or without O_2 support.**	**Patient conscious and oriented with or without O_2 support, either in ICU/ward**	**Patient conscious and oriented without O_2 support, either in ICU/ward**	**Patient fully co-operative, able to do major things actively, either in ICU/ward**	**Patient fully co-operative, able to do all things actively, medically stable, ready for discharge from ICU/ward**
Assessment scales: GCS: up to 3, RASS, IMS-ICU, FSS-ICU, KPS, MRS, DRS, CPAx	**Assessment scales:** GCS: >3 to 8, RASS, IMS-ICU, FSS-ICU, KPS, MRS, DRS, CPAx	**Assessment scales:** GCS: 9-12, RASS, IMS-ICU, FSS-ICU, KPS, MRS, DRS, PRFS-ICU, CPAx	**Assessment scales:** GCS: >12, RASS, BI/MBI, IMS-ICU, FSS-ICU, PFIT, KPS, MRS, DRS, PRFS-ICU, CPAx, PIMS	**Assessment scales:** GCS: >12, RASS, BI/MBI, IMS-ICU, FSS-ICU, PFIT, KPS, MRS, DRS, PRFS-ICU, CPAx, PIMS	**Assessment scales:** GCS: 15, RASS, RASS, BI/MBI, IMS-ICU, FSS-ICU, PFIT, KPS, MRS, DRS, PRFS-ICU, CPAx, PIMS, Katz Scale	**Assessment scales:** GCS: 15, RASS, BI/MBI, IMS-ICU, FSS-ICU, PFIT FIM, 4P, KPS, MRS, DRS, PRFS-ICU, CPAx, PIMS, Katz Scale, PCFS

FIG. 1: Applicability of scales based on level of functioning

using scales such as the FSS-ICU and PFIT. Typically, patients demonstrate a linear rise in function with higher scores on the functional scales.

The Barthel Index provides accurate results when used by both trained and untrained clinicians. It is a time-tested tool and can be reliably self-reported,[14] providing a quick assessment of self-care and mobility in patients with head injury and stroke. Good reliability has been observed with a change in two points reflecting change in patient status from dependent to independent. Collin et al.[14] reported that transfer and self-care items present challenges in reliable scoring and vary with observer skills. Variations in type of meal fed to patients create a difficulty in perceived difficulty in feeding. Ambiguity in dressing function led to modification of the tool. Further, observation of activities such as bathing and continence are time consuming, and patient input needs to be confirmed with nursing personnel. Thus, greater random error measurement and insensitivity to change due to scoring criteria make the modified Barthel Index a better measure of ADL.

The Modified Barthel Index with five-point scoring demonstrates better internal consistency than the Barthel Index in patients with stroke.[15] Yang et al. reported excellent test-retest reliability, lower randomized measurement error, and greater consistency in scoring than the modified Barthel Index.[16] Minimal detectable change (MDC), adjusted at 18.4% variation of the basal score was reported to be a better measure of actual change in functional status, and recommendations indicate that clinicians and researchers use MDC% adjusted scores to identify effects of novel therapies with greater accuracy. High interclass correlation coefficients with the Barthel Index are consistent among studies (ICC 0.94–0.99), indicating that either test can be used as a clinical measure.[9] Hsueh et al followed up a large cohort of stroke patients for six months and reported high internal consistency (alpha value 0.89–0.92) at different data points. In their observations, BI scores were well associated with scores of motor impairment on the Fugl-Meyer Motor Assessment Scale, the Berg Balance Scale, and the Frenchay Activities Index, which is a measure of instrumental activities of daily living. Thus, both the BI and the MBI emerge

as strong tools with high convergent and predictive validity and satisfactory responsiveness in assessing ADL functions in stroke patients.[53]

The Functional Independence Measure has been used extensively in geriatric populations to identify functional impairments from a biopsychosocial perspective. Andrea et al. reported that low FIM scores were associated with higher 28-day, 90-day, and one-year mortality compared to high FIM scores.[18] The tool has also been used as a long-term predictor for measuring quality of life among patients with neurological disorders, demonstrating good reliability, validity, repeatability.[54] FIM has also been used in patients with chronic obstructive pulmonary disease (COPD) having difficulty in weaning from the ventilator.

The FSS-ICU appears to address the limitation of FIM as it includes detailed evaluation of graded ICU-applicable transfer activities, such as rolling in bed, supine-to-sit transfer, sitting at the edge of the bed, and sit-to-stand transfer. A major limitation of the FSS-ICU is that it does not take into account mental, cognitive, or social aspects of functioning. However, high inter-rater reliability makes it a useful tool for large multicentric trials.[55]

The physical function ICU test has been demonstrated to have good reliability and validity.[25] However, certain components such as spot-march may not be feasible in many patients in the ICU. Further, the walking ability of patients is not evaluated and a floor and ceiling effect may be observed. The PFIT scale was revised to delete certain components such as the shoulder lift in the PFIT-Scored version.[56] The scale displayed moderate convergent validity with the Timed "Up & Go" Test, and the Six-Minute Walk Test, was responsive to change and was predictive of key outcomes such as likelihood of discharge from the hospital, reduced length of hospital stay, and higher MRC scores.[56]

A recent study evaluated the inter-rater reliability of three physical function measures: the Physical Function ICU Test score, 30-second sit-to-stand repetitions, and Two-Minute Walk Test distance in an ICU setting. Low standard errors and good inter-rater reliability were observed between the three measures when used by trained clinicians, thus demonstrating the value of all three tools in assessing physical function in the ICU.[57]

Most tools are administered by clinicians, and the patient's perception of ability to perform physical functions remains unknown. The patient reported functional scale-ICU is a recently developed self-reported tool that measures patients' perception of their functional ability. The convergent validity of the PRFS-ICU has been tested against the FSS-ICU and the PFIT-Scored, and good correlation has been demonstrated.[58] Thus adding it to tools that can be administered following discharge to monitor long-term functional recovery.

The Karnofsky Index has been predominantly used in cancer survivors. It has demonstrated good correlation with the Katz activities of daily living (ADL) scale, and the basic activities of daily living (BADL).[30] However, it seems to be a less accurate scale of performance compared to tools such as the physical performance test.[59]

The disability rating scale is a commonly used outcome measure to assess impairment, disability, and handicap in neurological patients. A recent randomized controlled

trail evaluated 508 patients with moderate to severe traumatic brain injury to identify the factor structure of DRS and its predictive validity. At one-year post-injury, the three disability items—feeding, toileting, and grooming—accounted for 58.4% of the variance; the three impairment items—eye opening, communication ability, and motor response—accounted for 14.8% of the variance; and the two handicap items—level of functioning and employability—accounted for 8.9% of the variance.[60]

The modified rankin scale (mRS) is used extensively in stroke patients. Its strength lies in its simplicity and coverage of functional outcomes ranging from no symptoms to death. Studies have demonstrated a strong correlation with outcome measures such as infarct volumes and good agreement with other stroke scales. However, the limited number of levels renders the scale less responsive to change in functional status, although a single-point change on the mRS has been shown to be clinically relevant.[61,62] Another limitation is score reproducibility. Therefore, further studies are warranted to explore the psychometric properties of the modified ranking scale.

Most recently, the COVID-19 pandemic has demonstrated that humans will continue to be challenged with new surging health conditions for which they may not be prepared. Novel clinical presentations may not be adequately addressed using existing tools, thus necessitating newer tools that can effectively examine functional status. The novel corona virus is known to bring about a strong immunological reaction leading to acute respiratory distress syndrome, inadequate ventilatory function, and lack of oxygenation, along with a myriad of other symptoms. This leads to the necessity of ICU admission in approximately 2% of COVID-19 patients. The post COVID-19 functional status score (PCFS) is one such tool, just formulated to evaluate functional recovery. However, further studies are needed to evaluate the tool's efficiency and psychometric properties.

Furthermore, early mobilization is a safe and feasible rehabilitation strategy that provides benefits in terms of reduced length of hospital stay, reduced days on mechanical ventilator, reduce bed rest complications, and improved ICU patient outcomes.[63] The Perme ICU Mobility Score measures the mobility of an ICU patient and also recognizes barriers to mobilization. Nawa et al. reported it to reliably assess mobility and to be an excellent candidate for further application in clinical and research setups.[64]

V. CONCLUSION

Evaluation of physical function provides invaluable information regarding functional abilities and can aid clinicians in providing structured care to facilitate rehabilitation. Key considerations in selecting the measurement scales are applicability, clinimetric properties, reproducibility, rehabilitation stage, functional domain, patient functional activity level, across rehabilitation, and need for ongoing evaluation.

VI. FUTURE IMPLICATIONS

The present study has provided a narrative overview of commonly used scales to assess physical function in the ICU. A systematic review is warranted to report evidence

garnered by the various scales in specific patient populations to identify the most sensitive measures capable of identifying change in clinical status.

Future studies may be undertaken to administer these scales in a large patient population across various ICU settings and to examine their cross-cultural validity. Principal factor analysis and regression modeling may be used to identify key components related to other outcome variables in various disease conditions.

REFERENCES

1. Topp R, Ditmyer M, King K, Doherty K, Hornyak J III. The effect of bed rest and potential of prehabilitation on patients in the intensive care unit. AACN Clin Issues. 2002;13:263–76.
2. Morris PE. Moving our critically ill patients: Mobility barriers and benefits. Crit Care Clin. 2007;23:1–20.
3. Perme C, Chandrashekar R. Early mobility and walking program for patients in intensive care units: Creating a standard of care. Am J Crit Care. 2009 May 1;18(3):212–1.
4. Van der Schaaf M, Dettling DS, Beelen A, Lucas C, Dongelmans DA, Nollet F. Poor functional status immediately after discharge from an intensive care unit. Disabil Rehabil. 2008 Jan 1;30(23):1812–8.
5. Bakhru RN, Davidson JF, Bookstaver RE, Kenes MT, Welborn KG, Morris PE, Files DC. Physical function impairment in survivors of critical illness in an ICU recovery clinic. J Crit Care. 2018 Jun 1;45:163–9.
6. Parry SM, Huang M, Needham DM. Evaluating physical functioning in critical care: Considerations for clinical practice and research. Crit Care. 2017 Dec;21(1):249.
7. Jennett B, Bond M. Assessment of outcome after severe brain damage. Lancet. 1975;1:480–4.
8. Conlon N, O'Brien B, Herbison GP, Marsh B. Long-term functional outcome and performance status after intensive care unit re-admission: A prospective survey. Brit J Anaesth. 2008;100:219–23.
9. McMillan T, Wilson L, Ponsford J, Levin H, Teasdale G, Bond M. The glasgow outcome scale—40 years of application and refinement. Nature Rev Neurol. 2016 Aug;12(8):477–85.
10. Weir J, Steyerberg EW, Butcher I, Lu J, Lingsma HF, McHugh GS, Roozenbeek B, Maas AI, Murray GD. Does the extended glasgow outcome scale add value to the conventional glasgow outcome scale? J Neurotrauma. 2012 Jan 1;29(1):53–8.
11. Anderson SI, Housley AM, Jones PA, Slattery J, Miller JD. Glasgow outcome score: An inter-rater reliability study. Brain Inj. 1993;7:309–17
12. Sessler CN, Gosnell MS, Grap MJ, Brophy GM, O'Neal PV, Keane KA, Tesoro EP, Elswick RK. The Richmond agitation–sedation scale: Validity and reliability in adult intensive care unit patients. Am J Respir Crit Care Med. 2002 Nov 15;166(10):1338–44.
13. Mahoney FI, Barthel DW. Functional evaluation: The Barthel Index: A simple index of independence useful in scoring improvement in the rehabilitation of the chronically ill. MD State Med J. 1965 Feb;14:61–5.
14. Collin C, Wade DT, Davies S, Horne V. The Barthel ADL index: A reliability study. Int Disabil Studies. 1988 Jan 1;10(2):61–3.
15. Shah S, Vanclay F, Cooper B. Improving the sensitivity of the Barthel Index for stroke rehabilitation. J Clin Epidemiol. 1989 Jan 1;42(8):703–9.
16. Yang CM, Wang YC, Lee CH, Chen MH, Hsieh CL. A comparison of test–retest reliability and random measurement error of the Barthel Index and modified Barthel Index in patients with chronic stroke. Disabil Rehabil. 2020 Sep 4:1–5.
17. Granger CV, Hamilton BB, Keith RA, Zielezny M, Sherwin FS. Advances in functional assessment for medical rehabilitation. Topics Geriatr Rehabil. 1986 Apr 1;1(3):59–74.
18. D'Andrea A, Le Peillet D, Fassier T, Prendki V, Trombert V, Reny JL, Roux X. Functional independence measure score is associated with mortality in critically ill elderly patients admitted to an intermediate care unit. BMC Geriatr. 2020 Dec;20(1):1–8.

19. Montagnani G, Vagheggini G, Panait Vlad E, Berrighi D, Pantani L, Ambrosino N. Use of the functional independence measure in people for whom weaning from mechanical ventilation is difficult. Phys Ther. 2011 Jul 1;91(7):1109–15.
20. Thrush A, Rozek M, Dekerlegand JL. The clinical utility of the functional status score for the intensive care unit (FSS-ICU) at a long-term acute care hospital: A prospective cohort study. Phys Ther. 2012 Dec 1;92(12):1536–45.
21. Huang M, Chan KS, Zanni JM, Parry SM, Neto SC, Neto JA, da Silva VZ, Kho ME, Needham DM. functional status score for the intensive care unit (FSS-ICU): An international clinimetric analysis of validity, responsiveness, and minimal important difference. Crit Care Med. 2016 Dec;44(12): e1155.
22. Åkerman E, Fridlund B, Ersson A, Granberg-Axéll A. Development of the 3-SET 4P questionnaire for evaluating former ICU patients' physical and psychosocial problems over time: A pilot study. Intensive Crit Care Nurs. 2009 Apr 1;25(2):80–9.
23. Åkerman E, Fridlund B, Samuelson K, Baigi A, Ersson A. Psychometric evaluation of 3-set 4P questionnaire. Intensive Crit Care Nurs. 013 Feb 1;29(1):40–7.
24. Skinner EH, Berney S, Warrillow S, Denehy L. Development of a physical function outcome measure (PFIT) and a pilot exercise training protocol for use in intensive care. Crit Care Resus. 2009;11:110–5.
25. Denehy L, de Morton NA, Skinner EH, Edbrooke L, Haines K, Warrillow S, Berney S. A physical function test for use in the intensive care unit: Validity, responsiveness, and predictive utility of the physical function ICU test (scored). Phys Ther. 2013 Dec 1;93(12):1636–45.
26. Schag CC, Heinrich RL, Ganz PA. Karnofsky performance status revisited: Reliability, validity, and guidelines. J Clin Oncol. 1984 Mar;2(3):187–93.
27. Grieco A, Long CJ. Investigation of the Karnofsky performance status as a measure of quality of life. Health Psychol. 1984;3(2):129.
28. Nikoletti S, Porock D, Kristjanson LJ, Medigovich K, Pedler P, Smith M. Performance status assessment in home hospice patients using a modified form of the Karnofsky performance status scale. J Palliat Med. 2000 Sep 1;3(3):301–11.
29. Silva CH, Morais SS, Sarian LO, Derchain SF. Association of the Karnofsky performance scale with the quality of life of Brazilian women undergoing palliative care. J Palliat Med. 2011 Jun;27(2):164–9.
30. Çeltek NY, Süren M, Demir O, Okan İ. Karnofsky performance scale validity and reliability of Turkish palliative cancer patients. Turkish J Med Sci. 2019 Jun 18;49(3):894–8.
31. Van Swieten JC, Koudstaal PJ, Visser MC, Schouten HJA, van Gijn J. Inter-observer agreement for the assessment of handicap in stroke patients. Stroke. 1988;19:604–7.
32. Bonita R, Beaglehole R. Modification of rankin scale: Recovery of motor function after stroke. Stroke. 1988;19:1497–500
33. Zhao H, Collier JM, Quah DM, Purvis T, Bernhardt J. The modified rankin scale in acute stroke has good inter-rater- reliability but questionable validity. Cerebrovasc Dis. 2010;29:188–93
34. Rappaport M, Hall KM, Hopkins K, Belleza T, Cope DN. Disability rating scale for severe head trauma: Coma to community. Arch Phys Med Rehabil. 1982 Mar 1;63(3):118–23.
35. Eliason MR, Topp BW. Predictive validity of Rappaport's disability rating scale in subjects with acute brain dysfunction. Phys Ther. 1984;64:1357–60
36. Struchen MA, Hannay HJ, Contant CF, Robertson CS. The relation between acute physiological variables and outcome on the glasgow outcome scale and disability rating scale following severe traumatic brain injury. J Neurotrauma. 2001 Feb 1;18(2):115–25.
37. Reid JC, Clarke F, Cook DJ, Molloy A, Rudkowski JC, Stratford P, Kho ME. Feasibility, reliability, responsiveness, and validity of the patient-reported functional scale for the intensive care unit: A pilot study. J Intensive Care Med. 2020 Dec;35(12):1396–404.
38. Katz S, Ford AB, Moskowitz RW, Jackson BA, Jaffe MW. Studies of illness in the aged: The index of ADL: A standardized measure of biological and psychosocial function. JAMA. 1963 Sep 21;185(12):914–9.

39. Katz S, Downs TD, Cash HR, Grotz RC. Progress in development of the index of ADL. Gerontologist. 1970 Mar 1;10:20–30
40. Silveira LT, Silva JM, Soler JM, Sun CY, Tanaka C, Fu C. Assessing functional status after intensive care unit stay: The Barthel index and the Katz Index. Int J Quality Health Care. 2018 May 1;30(4):265–70.
41. Hartigan I. A comparative review of the Katz ADL and the Barthel index in assessing the activities of daily living of older people. Int J Older People Nurs. 2007 Sep;2(3):204–12.
42. Corner EJ, Wood H, Englebretsen C, Thomas A, Grant RL, Nikoletou D, Soni N. The Chelsea critical care physical assessment tool (CPAx): Validation of an innovative new tool to measure physical morbidity in the general adult critical care population: An observational proof-of-concept pilot study. Physiotherapy. 2013 Mar 1;99(1):33–41.
43. Corner EJ, Soni N, Handy JM, Brett SJ. Construct validity of the Chelsea critical care physical assessment tool: An observational study of recovery from critical illness. Crit Care. 2014 Apr;18(2):1–0.
44. Corner EJ, Hichens LV, Attrill KM, Vizcaychipi MP, Brett SJ, Handy JM. The responsiveness of the Chelsea critical care physical assessment tool in measuring functional recovery in the burns critical care population: An observational study. Burns. 2015 Mar 1;41(2):241–7
45. Whelan M, Van Aswegen H, Corner E. Impact of the Chelsea critical care physical assessment (CPAx) tool on clinical outcomes of surgical and trauma patients in an intensive care unit: An experimental study. South African J Physiother. 2018 May 7;74(1):1–8.
46. Klok FA, Boon GJ, Barco S, Endres M, Geelhoed JM, Knauss S, Rezek SA, Spruit MA, Vehreschild J, Siegerink B. The post-COVID-19 functional status scale: A tool to measure functional status over time after COVID-19. Eur Resp J. 2020 Jul 1;56(1).
47. Mohamed-Hussein A, Galal I, Saad M, Zayan HE, Abdelsayed M, Moustafa M, Ezzat AR, Helmy R, Abd Elaal H, Aly K, Abderheem S. Post-COVID-19 functional status: Relation to age, smoking, hospitalization and comorbidities. MedRxiv. 2020 Jan 1.
48. Perme C, Nawa RK, Winkelman C, Masud F. A tool to assess mobility status in critically ill patients: The perme intensive care unit mobility score. Methodist DeBakey Cardiovasc J. 2014 Jan;10(1):41.
49. Timenetsky KT, Serpa Neto A, Lazarin AC, Pardini A, Moreira CR, Corrêa TD, Caserta Eid RA, Nawa RK. The perme mobility index: A new concept to assess mobility level in patients with coronavirus (COVID-19) infection. PLoS One. 2021 Apr 21;16(4):e0250180
50. Wilches Luna EC, de Oliveira AS, Perme C, Gastaldi AC. Spanish version of the perme intensive care unit mobility score: Minimal detectable change and responsiveness. Physiother Res Int. 2021 Jan;26(1):e1875.
51. Kawaguchi YM, Nawa RK, Figueiredo TB, Martins L, Pires-Neto RC. Perme intensive care unit mobility score and ICU mobility scale: Translation into Portuguese and cross-cultural adaptation for use in Brazil. J Brasil Pneumol. 2016 Nov;42:429–34.
52. Nydahl P, Wilkens S, Glase S, Mohr LM, Richter P, Klarmann S, Perme CS, Nawa RK. The German translation of the Perme intensive care unit mobility score and inter-rater reliability between physiotherapists and nurses. Eur J Physiother. 2018 Apr 3;20(2):109–15.
53. Hsueh IP, Lee MM, Hsieh CL. Psychometric characteristics of the Barthel activities of daily living index in stroke patients. J Formosan Med Assoc. 2001 Aug 1;100(8):526–32.
54. Linacre JM, Heinemann AW, Wright BD, Granger CV, Hamilton BB. The structure and stability of the functional independence measure. Arch Phys Med Rehabil. 1994 Feb 1;75(2):127–32.
55. Huang M, Chan KS, Zanni JM, Parry SM, Neto SC, Neto JA, da Silva VZ, Kho ME, Needham DM. Functional status score for the intensive care unit (FSS-ICU): An international clinimetric analysis of validity, responsiveness, and minimal important difference. Crit Care Med. 2016 Dec;44(12):e1155.
56. Denehy L, de Morton NA, Skinner EH, Edbrooke L, Haines K, Warrillow S, Berney S. A physical function test for use in the intensive care unit: Validity, responsiveness, and predictive utility of the physical function ICU test (scored). Phys Ther. 2013 Dec 1;93(12):1636–45.
57. Costigan FA, Rochwerg B, Molloy AJ, McCaughan M, Millen T, Reid JC, Farley C, Patterson L, Kho

ME. I SURVIVE: Inter-rater reliability of three physical functional outcome measures in intensive care unit survivors. Can J Anesth/J Can Anesth. 2019 Oct;66(10):1173–83.
58. Reid JC, Clarke F, Cook DJ, Molloy A, Rudkowski JC, Stratford P, Kho ME. Feasibility, reliability, responsiveness, and validity of the patient-reported functional scale for the intensive care unit: A pilot study. J Intensive Care Med. 2020 Dec;35(12):1396–404.
59. Terret C, Albrand G, Moncenix G, Droz JP. Karnofsky performance scale (KPS) or physical performance test (PPT)? That is the question. Crit Rev Oncol/Hematol. 2011 Feb 1;77(2):142–7.
60. Krch D, Lequerica AH. The factor structure of the disability rating scale in individuals with traumatic brain injury. Disabil Rehabil. 2019 Jan 2;41(1):98–103.
61. Broderick JP, Adeoye O, Elm J. Evolution of the modified rankin scale and its use in future stroke trials. Stroke. 2017 Jul;48(7):2007–12.
62. Harrison JK, McArthur KS, Quinn TJ. Assessment scales in stroke: Clinimetric and clinical considerations. Clin Interventions Aging. 2013;8:201.
63. Alaparthi GK, Gatty A, Samuel SR, Amaravadi SK. Effectiveness, safety, and barriers to early mobilization in the intensive care unit. Crit Care Res Pract. 2020 Nov 26;2020.
64. Nawa RK, Lettvin C, Winkelman C, Evora PR, Perme C. Initial interrater reliability for a novel measure of patient mobility in a cardiovascular intensive care unit. J Crit Care. 2014 Jun 1;29(3):475–e1.

Editorial

National Education Policy 2020: Call for Reconfiguration of Physiotherapy Education and Research in India

Physiotherapy education has a pivotal role in health promotion, prevention, and outcome of rehabilitation of people with neuro-musculo-skeletal and cardiovascular and pulmonary conditions across life-span. Physiotherapy training took shape in the era of polio virus epidemic in 1952 with a futuristic vision of significant contribution to improve health and wellbeing of people.

Physiotherapy education commenced in South East Asia in 1953 at Physiotherapy School and Centre, Seth GS Medical College and KEM Hospital, Mumbai, Maharashtra, India. Training in physiotherapy has evolved from a Certificate Course in Physiotherapy to a Diploma Program in Physiotherapy of 2-year duration to a Degree Program: Bachelor of Science in Physical Therapy (BSc in PT 1967) of 3 years and 6 months to Bachelor of Physiotherapy (BPT) program of 4 years and 6 months duration (1998).

Physiotherapy education in India has focussed on integration of theoretical knowledge of basic and applied physiotherapy and medical courses along with allied courses and hands-on practical and clinical skills to develop necessary competency skills.

However, with the outbreak of coronavirus disease epidemic, as health education is transforming worldwide across all disciplines of health to address changing and growing needs of socio-economically diverse populations, physiotherapy education also warrants urgent transformation.

The National Education Policy of India was revamped in 2020 in cognizance of 4th Sustainable Development Goal of United Nations to "ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" by 2030. It focusses on recognizing, identifying, and fostering the unique capabilities of each student in academic and non-academic spheres; multidisciplinary, holistic learning; creativity and critical thinking; developing life skills; regular formative assessment for learning rather than summative assessment; continuous professional development of teachers and faculty members; interdisciplinary outstanding research and continuous review for ongoing need-based education.

Further development of physiotherapy education in alignment with National Education Policy 2020 demands reconfiguration of physiotherapy education and research in India.

Reconfiguration of physiotherapy education calls for certain major action points such as attempts to adopt innovative pedagogical methods for millennial and generation Z learners; emphasize on ongoing formative assessment for learning; encourage continuing professional development of faculty members; offer choice-based courses in allied subjects; focus on integration of research and innovation at an early stage in education programs; adopt an inter-disciplinary research approach; and build academia–industry partnership.

(i) *Adopt innovative andragogic and pedagogical methods for millennial and generation Z learners*: Each student is gifted with exclusive sets of talents and abilities to learn. Millennial (generation Y) and generation Z learners have different affinities toward learning methods. They are particularly attracted by interactive technology tools. Therefore, it is an urgent need of the hour to review our training methods adopted for learning and evaluation and adopt innovative andragogic methods in addition to interactive pedagogical methods to enhance the learning experience of physiotherapy students and catalyze participatory learning with self-accountability.

(ii) *Emphasize on ongoing formative assessment for learning*: Physiotherapy education in India includes formative and summative assessment. However, summative assessment assumes a large part in the complete evaluation of students. Ongoing formative assessment will not only facilitate both knowledge building and skill training, but also reduce the stress of summative assessment.

(iii) *Encourage continuing professional development of faculty members*: In the Indian field of physiotherapy education, the faculty members range from Baby Boomers to generation X to generation Y (millennial) to generation Z. The wide gap in learning affinities of the generation of faculty members and students demands an urgent and intense focus on equipping our trainers with necessary training to achieve effective learning of students.

(iv) *Offer choice-based courses in physiotherapy and allied subjects*: Physiotherapy curriculum for Bachelors and Masters programs has evolved over the years to ensure that it addresses local needs and global merits of physiotherapy practice. We have invested heavily in attempts for development of core elements of the curricula to excel in physiotherapy, leaving nil-to-negligible opportunities to students

to select courses of their choice. Choice-based curricula will offer the much needed academic flexibility to Indian physiotherapy students to choose various career trajectories, which will open doors to a wide spectrum of employment roles. Academic flexibility will also facilitate movement of physiotherapy students within different states of India and globally in the present era, where students have greater access to global movement.

(v) *Integration of research and innovation at an early stage in education programs*: Physiotherapy research has an immense and critical scope in enhancing health promotion, rehabilitation outcome, and design of pertinent healthcare technology. Currently, research is a part of physiotherapy curriculum in India, within Bachelor of Physiotherapy program and Master of Physiotherapy program; but often its implementation has a narrow focus limited in novelty, design, and rigor. Hence, it is necessary to widen the lens of research to focus on original, meaningful research which leads to an innovation to address unmet needs in pertinent areas of health care.

Sowing seeds of research and innovation at an earlier stage in Bachelor's program will sensitize students about the urgent need, great value, and wide scope of research in physiotherapy training and practice and its ultimate impact on health care. Such a strategy will help to create the much needed research "sanskar" on their inquisitive and creative minds. As the research sensitized, BPT graduates travel into Master's program with "sanskar" of research they can be guided to participate in rigorous translation research activities.

(vi) *Adoption of inter-disciplinary research approach*: The need of the hour is to engage with allied health, engineering, and social sciences disciplines to conduct interdisciplinary research to generate the impetus needed to develop comprehensive cost-effective solutions to challenges in health promotion, prevention, and problems in rehabilitation. Research conducted in silos in individual disciplines has limited application and hence limited value in patient care. Such an inter-disciplinary approach to research will also distribute the cost of research and make it feasible.

(vii) *Develop academia–industry partnership*: Typically, academia is associated with creation of knowledge and industry is associated with creation of wealth. In most fields of healthcare education, including physiotherapy education, academia and industry work in silos, despite the fact that knowledge creates wealth and wealth is needed to acquire formal education. Therefore, it is becoming increasingly essential to build mutually beneficial partnerships between academia and industry to create a sustainable ecosystem for producing evidence-based robust physiotherapy solutions to address unmet needs in health promotion, prevention of disability, and rehabilitation. Such a productive partnership between academia and industry in health care will help to attain the 3rd Sustainable Development Goal of the United Nations to "ensure healthy lives and promote well-being for all at all ages."

To summarize, nationwide efforts on strategic planning for reconfiguration of physiotherapy education and research call for engagement of all stakeholders including students, parents, faculty members, physiotherapy employers, and policy-makers at the level of State and Central Government and professional bodies such as the Society of Indian Physiotherapists. Together, we need to create an overall refreshed, vibrant, and interactive environment for physiotherapy education in India, conducive for training a competent physiotherapy workforce which will contribute to a "AtmaNirbhar Bharat" in knowledge and health care.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Rajani P. Mullerpatan

MGM School of Physiotherapy, MGM Centre of Human Movement Science, MGM Institute of Health Sciences, Navi Mumbai, Maharashtra, India

Address for correspondence: Dr. Rajani P. Mullerpatan, MGM School of Physiotherapy, MGM Centre of Human Movement Science, MGM Institute of Health Sciences, Navi Mumbai, Maharashtra, India.
E-mail: rajani.kanade@gmail.com

Received : 03-03-22.
Accepted : 04-03-22.
Published : 16-03-22.

Access this article online

Quick Response Code:

Website: www.jsip-physio.org

DOI: 10.4103/jsip.jsip_2_22

How to cite this article: Mullerpatan RP. National Education Policy 2020: Call for reconfiguration of physiotherapy education and research in India. J Soc Indian Physiother 2022;6:1-2.

Article

Differences in Foot Characteristics Between Bharatanatyam Dancers and Age-Matched Non-Dancers

Rajani P. Mullerpatan, PhD, and Juhi K. Bharnuke, MPT

INTRODUCTION: The ankle–foot complex is the third most common site of pain in Indian dancers. In Bharatanatyam dance, rhythmic stamping performed barefoot at varying speeds may influence the height of the medial longitudinal arch, causing structural alteration of the ankle-foot complex. As little information is available on the ankle-foot complex of Bharatanatyam dancers, the present study was conducted to test the hypothesis that foot characteristics of Bharatanatyam dancers differ from those of non-dancers. **METHODS:** Female professional Bharatanatyam dancers (n=21), aged 18–30 years, with a minimum of 8 years of performance experience after completing formal dance training, and 21 control non-dancers participated in this study. Physical foot examination included navicular drop test and Feiss line. Foot geometry and pedobarography were recorded as participants walked barefoot at self-selected walking pace over a pressure-platform. An average of five gait cycles was computed to analyse maximum peak pressure (MPP), pressure time integral, contact time, and foot geometry of the midfoot, forefoot, great toe, and second to fifth toes. Analysis of covariance was performed for intergroup comparison of all variables with gait speed as a covariate. **RESULTS:** During walking, dancers presented a higher medial-longitudinal-arch, wider midfoot, and wider forefoot (cm) (p<0.001), indicating an over-pronated foot due to lower medial longitudinal arch height. Total plantar peak pressure (kPa) was 37% higher among dancers, whereas MPP was 24% higher on midfoot and 13% higher on forefoot, indicating greater plantar loading during walking. **CONCLUSION:** Greater plantar loading and an over-pronated foot during the most commonly performed weight-bearing activity of daily living (e.g., walking) explain the common prevalence of ankle and foot pain among dancers. These findings will inform clinicians and Bharatanatyam dancers on dancer's foot function and guide strategies for prevention and management of foot pain. *Med Probl Perform Art* 2022;37(1):53–57.

Dr. Mullerpatan is Professor-Director, and J.K. Bharnuke is Assistant Professor, MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, India.

The authors report no funding or conflicts of interest.

Address for correspondence: Dr. Rajani Mullerpatan, MGM School of Physiotherapy, MGM Institute of Health Sciences, MGM Campus, Sector 1, Kamothe, Navi Mumbai, 410209, India. Tel +91-022-27437866. rajani.kanade@gmail.com.

https://doi.org/10.21091/mppa.2022.1009

A RECENT SURVEY of musculoskeletal pain prevalence among Indian classical, folk, and freestyle dancers revealed the ankle and foot to be the third most common site of pain, accounting for a prevalence of 19%.[1] The most commonly performed classical Indian dance form, Bharatanatyam, involves footwork occurring on the entire foot during sustained poses such as *aramandi* and *muzhumandi* which are performed in semi-squat and full squat. Footwork occurring at the forefoot is typically observed during transition from one pose to another and while performing *kuditta metta adavu* (leaps or jumps), where the forefoot has to support the entire body weight.[2]

Foot stamping, known as *tatta adavus* is commonly performed as alternate foot pounding in fundamental dance postures. Bharatanatyam is characterized by constantly varying footwork ranging from slow foot tapping to vigorous foot stamping. Alternate heel and forefoot stamping performed barefoot is a characteristic framework of footwork exclusive to the Bharatanatyam dance form.[3]

The fundamental stance position of the Bharatanatyam dancer during performance includes overtly turning out of the feet. We postulate that the outwardly turned-out foot adopted in Bharatanatyam dance beyond the anatomical axis may add additional strain along the medial aspect of the entire foot. Such foot turn-out is not observed in commonly performed weight-bearing activities of daily living. Foot abduction beyond 45° in the horizontal plane is known to cause talar plantarflexion and adduction, causing downward displacement of navicular tuberosity. Such foot turn-out is likely to result in a functionally hyperpronated foot.[4]

It is observed that most dancers carry over the dance foot posture into routine daily activities outside the dance studio.[5] We speculate that Bharatanatyam dancers may adopt the same tendency of carrying over the effect of dance exposure even after the practice or performance period; i.e., Bharatanatyam dancers may carry over the same walking pattern even outside a dance studio following prolonged years of dance training. Moreover, the presence of ankle bells (*ghungroos*) adds an external load on the joints of the ankle-foot complex. Each ankle bell consists

around 150 *ghungroos* which adds approximately 1.5 kg weight on each ankle.[6] Repetitive foot stamping on hard flooring is likely to produce high vertical compressive forces over talonavicular, subtalar, and metatarsal joints and ultimately alter foot structure, as it is noticed in western dance forms.[7,8]

Foot loading among ballet dancers is extensively reported. Ballet dancers are known to walk with higher forefoot pressure and foot hyper-pronation in comparison to healthy age-matched non-dancers.[9,10] However little information is available on musculoskeletal adaptations among Southeast Asian dancers. To the best of our knowledge, only one study has reported morphometric foot characteristics of Bharatanatyam dancers. Findings of the study revealed that 70% of Bharatanatyam dancers presented with acquired flat foot.[11]

Although there is no unequivocal evidence to support an association between foot shape and foot pain, it is essential to explore the geometry and posture of the ankle-foot complex in resting foot position and upon weight-bearing among Bharatanatyam dancers. Evaluation of plantar pressure distribution during walking will inform the dynamic function of the dancer's foot in terms of plantar loading during walking. Currently available cursory information on the ankle-foot complex of Bharatanatyam dancers, which is subjected to high biomechanical demands, motivated the present study to test the hypothesis that foot characteristics of Bharatanatyam dancers differ from non-dancers.

METHODS

Twenty-one trained Bharatanatyam dancers and 21 healthy non-dancers participated in this exploratory cross-sectional study. The sample size was calculated for the primary outcome variable, i.e., navicular drop test to assess foot posture in loading condition, using cross-sectional study design formula. The sample size was estimated based on data presented in a study which reported navicular drop in healthy elite athletes. The estimated sample size was 21 in each group.[12] Hence, 21 trained Bharatanatyam dancers and 21 healthy non-dancers participated in the exploratory cross-sectional study. The study was approved by Ethics Committee for Research on Human Subjects (ECRH), MGM Institute of Health Sciences, Navi Mumbai, India. All participants signed informed consent.

Female professional Bharatanatyam dancers (n=21), between ages 18–30 years, with a minimum of 8 years of performance experience after completing formal dance training, voluntarily participated in this study. Healthy age-, body height-, and weight-matched non-dancers formed the control group. Volunteers with neuromusculoskeletal injuries in past 6 months; not involved in an active form of physical activity such as sports, athletics or other dance form, and body mass index (BMI) ≥25 kg/m^2 or ≤18 kg/m^2 were excluded.

Owing to its high reliability to quantify downward displacement of the navicular bone, which directly corresponds to the medial longitudinal arch height, and the ease of performing this clinical test with minimal instruments (measuring tape and skin marker), the navicular drop test was used to evaluate foot pronation in dancers. Physical foot examination in barefoot weight-bearing position was performed with the navicular drop test (ICC=0.83–0.95)[13] and Feiss line (ICC=0.88–0.97)[14] using standard testing procedures.[14,15]

In full weight-bearing standing position, the participant's navicular tuberosity was marked and its distance from the floor was measured. The participants were then instructed to stand relaxed, and the excursion of navicular bone in the sagittal plane excursion (cm) was measured with measuring tape.[15] Static foot alignment in weight-bearing was measured using the Feiss line in the standing position. Using a skin marker, the medial malleolus, navicular tubercle, and first metatarsophalangeal (MTP) joint were marked. A straight line connecting the medial malleolus to the MTP was drawn. The line intersecting navicular tubercle indicated a normally aligned foot. If the line ran below the tubercle, it was reported as an over-pronated foot, and if the line passed below the tubercle, it was reported as high-arched foot.[16]

Foot geometry and plantar pressure measurements (pedobarography) were recorded using the E med-sf system (Novel GmbH, Munich, Germany).[16] Plantar pressure distribution (kPa) was recorded as maximum peak pressure (MPP), pressure time integral (PTI) (kPa/s), maximum force (N) contact time over forefoot (ms), mid-foot, hallux, and second to fifth toes. Foot length (FL), forefoot width (FFW), mid-foot width (MFW), hindfoot width (HFW), and arch index (AI) were recorded to evaluate foot geometry (cm). Participants were instructed to walk barefoot across the E med pressure platform at a self-selected walking pace.[17] Three practice trials were given prior testing. Data from an average of five mid-gait cycles was used for statistical analyses using IBM SPSS (ver. 20.0, 2011; IBM Corp., Armonk, NY). Both clinical and instrumented foot evaluation were performed by the same researcher. Data recorded by the E med pressure platform was analysed using Novel software to compute the results for foot pressure and geometry.

Comparison of all outcome variables between the right and left feet in both groups did not reveal significant differences (p>0.05). Therefore, measurements from only one foot (e.g., right foot) were considered for statistical analyses. Inter-group comparison between dancers and non-dancers was performed using analysis of covariance, with gait speed as the covariate. Statistical significance was set at p<0.05.

RESULTS

The dancer and non-dancer groups were matched for age and BMI on marginal distribution. Mean dance training

TABLE 1. Participants' Demographic Information

	Dancers (n=21)	Non-Dancers (n=21)
Age (yrs)	21 (2.12)	20 (1.97)
Height (cm)	159.0 (0.52)	156.0 (0.53)
Mass (kg)	52.06 (9.15)	53.42 (8.35)
BMI (kg/m^2)	21.77 (3.51)	22.81 (3.42)
Dance training (yr)	11.25 (3.55)	NA
Dance exposure (hr/wk)	4.48 (2.91)	NA

Data given as mean (SD). NA, not applicable.

exposure was 11 years with an average dance exposure of 5 hours/week (Table 1 and 2). It was observed that dancers presented higher arch index during walking, suggesting attenuation of medial longitudinal arch height (p<0.001), wider mid-foot (p<0.001), wider forefoot (p=0.001), and longer foot (p=0.001) compared to non-dancers (Table 3). Dancers demonstrated an overall 33% greater force over the total plantar surface (p=0.002). On further analysis, it was observed that the forces were greater on the mid-foot and forefoot region than other regions of plantar surface of the foot among dancers (p<0.001).

Dancers walked with significantly higher MPP on the total surface area of foot (p<0.001). Maximum peak pressure was higher on midfoot (p<0.001) and forefoot (p<0.001). Dancers presented significantly higher contact time over mid-foot (p=0.028) and forefoot (p=0.043). Pressure time integral was higher on mid-foot (p= 0.003), forefoot (p=0.009), and great toe (p=0.002) (Table 3).

DISCUSSION

The present study reports musculoskeletal foot adaptations in young female, trained Bharatanatyam dancers, supporting our hypothesis. Dancers presented lower medial longitudinal arch height, wider mid-foot and forefoot, higher maximum peak pressure, higher contact time, and greater pressure time integral over total plantar surface, mid-foot, and forefoot.

Medial Longitudinal Arch Height

Dancers demonstrated 21% lower medial longitudinal arch height. Attenuation of medial longitudinal arch height during walking may be attributed to early commencement of dance training before complete maturation of the foot arches and repetitive foot-stamping, which is a fundamental characteristic of the Bharatanatyam dance form. Dancers in the present study may have commenced dance training at an age of 8–10 years, as they reported an average age of 11 years of dance practice at an average age of 21 years. It is known that maturation of the foot arch occurs by the age of 8–11 years.[18] Hence, we speculate that repetitive practice of foot stamping from the age of 4–6 years, performed barefoot may have resulted in excessive vertical loading of the talonavicular joint, which forms the summit of the medial longitudinal arch.

It is known that the talonavicular joint is the weakest part of medial longitudinal arch, supported by a weak plantar calcaneofibular ligament inferiorly.[19] Excessive vertical loading of the subtalar joint results in calcaneal eversion, talar adduction, talar plantar flexion, and tibiofibular medial rotation, causing pronation of the subtalar joint and flat feet.[20] A combined effect of talar adduction and talar plantar-flexion may result in downward displacement of the navicular from its original position. Hence, high impact forces sustained by the talonavicular joint are known to result in downward displacement of navicular tuberosity over the head of talus, ultimately flattening the arch.[20,21] Notable downward displacement of the navicular tuberosity (11.5 mm) in standing and the position of Feiss line (14/21) in the dancer's foot corroborate the previous postulation of hyper-pronated feet in dancers and explain attenuation of the medial longitudinal arch height observed in Bharatanatyam dancers.

Foot Geometry

Anatomical composition of the mid-foot and forefoot excludes the contact of the talar head and navicular with the ground.[18] An evident sequel of attenuation of the medial longitudinal arch height was presented as nearly 50% wider mid-foot and 15% wider forefoot among dancers during walking. Dancers presented 32% increased contact time over the mid-foot compared to non-dancers, suggesting that dancers stayed longer on the mid-foot during walking. It is likely that the roll over process from heel loading to push-off occurring during forward propulsion is slower due to attenuation of medial longitudinal arch height.

Plantar Pressure Distribution

In addition to the alterations in foot geometry, dancers walked with 37% higher total peak plantar pressure over the sole of the feet. On the foot, the highest peak plantar pressure and pressure–time integral was recorded on the forefoot; which warrants attention to foot care (MPP 440.6 kPa). Plantar pressure distribution is defined as cumulative

TABLE 2. Participants' Foot Characteristics

	Dancers (n=21)			Non-Dancers (n=21)			
Biomechanical Foot Evaluation	Low Arched Foot	High Arched Foot	Normally Aligned	Low Arched Foot	High Arched Foot	Normally Aligned	p-Value
Feiss line (frequency)	14	0	4	2	1	15	
Navicular drop test (mm)		11.51 (1.04)			8.79 (1.92)		0.034

vertical force applied per unit area of sole of foot.[22] It was observed that the dancers walked with 12% higher total contact area of the foot and 30% higher vertical force over the total surface area of foot and forefoot compared to non-dancers. Although, both force and contact area of the dancers' feet was higher, the vertical force exerted on the feet was more than twice compared to the contact area, which explains higher plantar pressure distribution on the total foot and forefoot among dancers.

Sullivan et al. (2015)[23] reported that training-induced adaptations occurring in the central nervous system during dance foot-work result in habituation and are reflected in the form of increased foot stamping during daily walking. Previous studies have reported that continued practice of training results in neuromuscular adaptations, which are characterized by greater skilled control of movement and carryover effects of muscle recruitment patterns observed in routine activities such as walking.[24,25] The present findings concur with earlier observations by the authors of pronounced anterior pelvic tilt during gait of Bharatanatyam dancers.[26] Similar observations are also reported among ballet dancers, who are observed to walk with higher forefoot pressure even outside the studio.[27]

Decreased navicular drop height combined with foot pronation is associated with increased laxity of non-contractile structures around the ankle and foot complex, such as medial deltoid ligament, talo-crural, and sub-talar joint capsule which can predispose not only to stress fractures of the ankle-foot complex, ligament sprains, and early degenerative arthritis, but also affect proximal joints leading to patellar tendinitis and iliotibial band friction syndrome. Excessive navicular drop has been reported in patients with a history of ACL tears and is known to predispose individuals to shin splints and medial tibial stress syndrome.[28] Hence, findings of the present study are of value in gaining insight in the mechanics of the Bharatanatyam dancer's foot in order to understand foot pain.

To summarize, the Bharatanatyam dance form involves repeated loading of the lower-extremity and intricate footwork performed barefoot, resulting in altered foot structure, geometry, and plantar pressure distribution. A longitudinal study designed to explore musculoskeletal foot adaption following dance exposure would have been ideal to unfold the link between ankle-foot geometry and pain prevalence. However, the limitations and challenges of a longitudinal study prompted the authors to adopt a cross-sectional study design. Nonetheless, the present findings will help to educate Bharatanatyam dancers about the structural adaptations occurring in the foot. Knowledge of altered foot biomechanics will also guide clinicians and dance trainers in designing preventive and therapeutic strategies to maximize foot function and prevent ankle and foot pain while dancers focus on performance enhancement. Tailor-made exercise programs can be designed for Bharatanatyam dancers to attenuate the biomechanical alterations noted in these dancers' feet to maximize function and minimize risk for injury.

TABLE 3. Foot Geometry and Plantar Pressure Distribution Among Dancers and Non-Dancers During Walking

	Mean Difference Between Groups	Effect Size Between Groups	*p*-Value	*f*-Value
Foot length (cm)	1.24	1.4	0.001*	1.098
Forefoot width (cm)	1.44	1.3	0.001*	2.138
Mid-foot width (cm)	2.31	3.16	0.001*	1.880
Hindfoot width (cm)	0.16	0.44	0.238	1.175
Arch index	0.06	1.86	0.001*	0.677
Total pressure (kPa)	214.52	1.8	0.001*	0.809
Forefoot (kPa)	221.19	1.7	0.001*	0.601
Midfoot (kPa)	110.24	0.0	0.001*	0.504
Hindfoot (kPa)	21.66	0.9	0.268	1.645
Great toe (kPa)	113.28	1.06	0.006*	1.771
2nd-5th toes (kPa)	42.85	1.06	0.053*	0.627
PTI forefoot (kPa/s)	39.19	3.2	0.009*	1.883
PTI midfoot (kPa/s)	24.81	1.38	0.003*	2.284
PTI hindfoot (kPa/s)	13.77	0.57	0.062	2.420
PTI great toe (kPa/s)	28.72	0.28	0.002*	1.913
Maximum force over total plantar surface (N)	242.2	1.21	0.002*	1.344
Maximum force over forefoot (N)	46.05	0.47	0.002*	2.646
Maximum force over midfoot (N)	49.7	0.70	0.000*	0.956
Contact time of forefoot (ms)	221.6	7.4	0.043	0.657
Contact time of midfoot (ms)	151.7	4.3	0.028*	1.439
Contact time of hindfoot (ms)	−133.1	3.6	0.891	0.581

df value is 28 (between groups) and 13 (within groups) for all outcome variables using analysis for covariance.
*Significant at $p < 0.05$.

Conclusion

Training in Bharatanatyam dance alters foot geometry, loading, and plantar pressure distribution during walking. Musculoskeletal adaptations resulting in a lower medial longitudinal arch, wider mid-foot and forefoot, and higher plantar pressure over the mid-foot and forefoot during walking are key features. Such alterations in the ankle-foot complex of dancers may have implications on risk for injury. Therefore, the present findings will be useful to Bharatanatyam dancers, dance trainers, and clinicians in planning therapeutic strategies for prevention, early detection, and rehabilitation of ankle-foot injury and maximize ankle-foot function and dance performance.

Acknowledgments: The authors thank all the participants for volunteering to participate in the study. We also thank Aishwarya Sakhare for her input in the style of footwork in the Bharatanatyam dance form.

Authors' Contributions: RM conceptualized and designed the study including the methods, outcome variables, and plan for statistical analysis, manuscript writing and editing. JB collected the data, ana-

lyzed it, and contributed to manuscript writing. RM interpreted the findings, structured, wrote, reviewed, and edited the manuscript. Both authors read and approved the final manuscript

.

REFERENCES

1. Nair SP, Kotian S, Hiller C, Mullerpatan R. Survey of musculoskeletal disorders among Indian dancers in Mumbai and Mangalore. *J Dance Med Sci*. 2018;22(2):67–74. https://doi.org/10.12678/1089-313X.22.2.67.
2. Chatterjee A. The therapeutic value of Indian classical, folk, and innovative dance forms. *Rupkatha J Interdiscip Stud*. 2013;5(1):75–83.
3. Natyarambha.com. Available at: https://www.natyarambha.com/Natyarambha/Glossary
4. Anbarasi V. Analysis of lower extremity muscle flexibility among Indian classical Bharathnatyam dancers. *Int J Med Health Sci*. 2012; 6(6): 225–230. https://doi.org/10.1005/5887
5. Sukhatankar O. Indian classical dance forms (ICDs): three dimensions of analysing their unity and diversity. *Chitrolekha Int Mag Art Design*. 2016;6(1).
6. Teplá L, Procházková M, Svoboda Z, Janura M. Kinematic analysis of the gait in professional ballet dancers. *Acta Gymnica*. 2014;44(2):85–91. https://doi.org/10.5507/ag.2014.009
7. Pillai, S. Rethinking global Indian dance through local eyes: the contemporary Bharatanatyam scene in Chennai. *Dance Res J*. 2002;34(2):14–29. https://doi.org/10.2307/1478457.
8. Hamilton WG. Foot and ankle injuries in dancers. *Clin Sports Med*. 1988;7(1):143–73.
9. Prochazkova M, Tepla L, Svoboda Z, et al. Analysis of foot load during ballet dancers' gait. *Acta Bioeng Biomech*. 2014;16(2): 41–50. https://doi.org/10.5277%2Fabb140205
10. Nielsen RO, Buist I, Parner ET, et al. Foot pronation is not associated with increased injury risk in novice runners wearing a neutral shoe: a 1-year prospective cohort study. *Br J Sports Med*. 2014;48(6):440–7. https://doi.org/10.1136/bjsports-2013-092202
11. VijaykumarK, Kumar S. Morphometric analysis of ankle and foot in classical Bharathanatyam dancers using foot posture index (FPI) and plantar scan images (PSI). *J Dent Med Sci*. 2016; 15(6):20–25. https://doi.org/10.9790/0853-1506052025
12. Kim T, Park JC. Short-term effects of sports taping on navicular height, navicular drop and peak plantar pressure in healthy elite athletes: a within-subject comparison. *Medicine*. 2017;96(46):e8714.
13. Deng J, Joseph R, Wong CK. Reliability and validity of the sit-to-stand navicular drop test: do static measures of navicular height relate to the dynamic navicular motion during gait. *J Stud Phys Ther Res*. 2010;2(1):21–8. https://doi.org/10.11901/154771.2010.17002
14. Spörndly-Nees S, Dåsberg B, Nielsen RO, Boesen MI, Langberg H. The navicular position test–a reliable measure of the navicular bone position during rest and loading. *Int J Sports Phys Ther*. 2011;6(3):199.
15. Vinicombe A, Raspovic A, Menz HB. Reliability of navicular displacement measurement as a clinical indicator of foot posture. *J Am Podiatr Med Assoc*. 2001;91(5):262–268. https://doi.org/10.7547/87507315-91-5-262
16. Hafer JF, Lenhoff MW, Song J, et al. Reliability of plantar pressure platforms. *Gait Posture*. 2013;38(3):544–8. https://doi.org/10.1016/j.gaitpost.2013.01.028
17. Bryant AR, Tinley P, Singer KP. Normal values of plantar pressure measurements determined using the EMED-SF system. *J Am Podiatr Med Assoc*. 2000;90(6):295–299. https://doi.org/10.7547/87507315-90-6-295
18. Tong JW, Kong PW. Medial longitudinal arch development of children aged 7 to 9 years: longitudinal investigation. *Phys Ther*. 2016;96(8):1216–1224. https://doi.org/10.2522/ptj.20150192
19. Mojica MN, Early JS. Foot biomechanics. In: *Atlas of Orthoses and Assistive Devices E-Book*, 5th ed. Elsevier; 2017: p216.
20. Prachgosin T, Chong DY, Leelasamran WI, et al. Medial longitudinal arch biomechanics evaluation during gait in subjects with flexible flatfoot. *Acta Bioeng Biomech*. 2015;17(4):121–130. https://doi.org/10.5277/ABB-00296-2015-02
21. Arachchige SN, Chander H, Knight A. Flat feet: biomechanical implications, assessment and management. *The Foot*. 2019;38:81–85. https://doi.org/10.1016/j.foot.2019.02.004
22. Rosenbaum D, Becker HP. Plantar pressure distribution measurements: technical background and clinical applications. *J Foot Ankle Surg*. 1997;3(1):1–4. https://doi.org/10.1046/j.1460-9584.1997.00043.x
23. Sullivan J, Burns J, Adams R, et al. Plantar heel pain and foot loading during normal walking. *Gait Posture*. 2015;41(2):688–93. https://doi.org/10.1016/j.gaitpost.2015.01.025
24. Chen SJ, Gielo-Perczak K. Effect of impeded medial longitudinal arch drop on vertical ground reaction force and center of pressure during static loading. *Foot Ankle Int*. 2011;32(1):77–84. https://doi.org/10.3113/FAI.2011.0077.
25. Mulligan EP, Cook PG. Effect of plantar intrinsic muscle training on medial longitudinal arch morphology and dynamic function. *Man Ther*. 2013;18(5):425–30. https://doi.org/10.1016/j.math.2013.02.007.
26. Mullerpatan R, Bharnuke J, Hiller C. Gait kinematics of Bharatanatyam dancers with and without low back pain. *Crit Rev Phys Rehabil Med*. 2019;31(1):1–10. https://doi.org/10.1615/CritRevPhysRehabilMed.2019030243
27. Prochazkova M, Tepla L, Svoboda Z, et al. Analysis of foot load during ballet dancers' gait. *Acta Bioeng Biomech*. 2014;16(2):41–45. https://doi.org/10.5277/abb140205
28. Nigg B, Behling AV, Hamill J. Foot pronation. *Footwear Sci*. 2019; 11(3):131–4. https://doi.org/10.1080/19424280.2019.1673489.

Received 14-Oct-2019, accepted 31-Jan-2022
Published online 1-Mar-2022
https://doi.org/10.21091/mppa.2022.1009

Evaluation of Early Knee Osteoarthritis Using Biomechanical and Biochemical Markers

Bela M. Agarwal,[a] Raman P. Yadav,[b] Sanketa D. Tambe,[b] Chandana C. Kulkarni,[b] & Rajani P. Mullerpatan[a,*]

[a]MGM School of Physiotherapy, MGM Institute of Health Sciences, Sector 1, Plot Number 1&2, Kamothe, Navi Mumbai, Maharashtra, India; [b]MGMIHS OMICS Research Center, MGM Medical College, MGM Institute of Health Sciences, Sector 1, Plot Number 1&2, Kamothe, Navi Mumbai, India

*Address all correspondence to: Rajani P. Mullerpatan, PhD, MGM School of Physiotherapy, MGM Institute of Health Sciences, Sector 1, Plot Number 1&2, Kamothe, Navi Mumbai, Maharashtra, 410209, India; Tel.: +91 9920048476, E-mail: rajani.kanade@gmail.com

ABSTRACT: Altered cellular mechano-transduction and biochemistry lead to degeneration of articular cartilage in people with knee osteoarthritis. However, the influence of low-moderate exposure to weight-bearing activity such as squatting on cartilage metabolism has not been adequately studied. The current study explored associations between knee adduction moment (KAM) during walking, biochemical markers and daily squat exposure. 3D gait analysis was used to determine external loads acting on the knee as indicators of joint compressive forces whereas biomarkers-Urine type-II-collagen-telopeptide (uCTxII), antioxidant and phospholipase A_2 (PLA_2) activity reflected on articular cartilage status. Following ethical approval, 66 participants with varying daily squat exposure (non-squatters [$n = 21$, exposure = 0 min]; activity of daily living [ADL] squatters [$n = 16$, exposure = 34 min]; occupational squatters [$n = 13$, exposure = 102 min]) and people with grade 2–3 knee osteoarthritis ($n = 16$, exposure = 28 min) were evaluated using 3D gait and biomarker analysis. The PLA_2 activity was lowest in ADL squatters while occupational squatters demonstrated highest activity ($p < 0.05$). KAM and urine biomarker were similar among the groups. Moderate–strong positive association was observed between sweat PLA_2 activity and age ($r = 0.819$, $p = 0.004$), daily squat exposure and biomarker uCTxII ($r = 0.604$, $p = 0.013$), antioxidant activity and Right-KAM ($r = –0.917$, $p = 0.001$), and Left-KAM ($r = –0.767$, $p = 0.016$), in people with knee OA. Healthy people demonstrated weak positive associations between KAM, uCTxII, and BMI. Associations between non-invasive biomechanical and biochemical markers indicate their potential use to identify early knee osteoarthritis. Studies with larger sample size are necessary to support prescription of body weight joint loading activities such as squatting in moderation, to delay functional decline caused by knee OA.

KEY WORDS: knee osteoarthritis, biomarkers, body fluids, non-invasive, biomechanics

ABBREVIATIONS: ADL squatter, activity of daily living squatter; **BMI**, body mass index; **KAM**, knee adductor moment; **KOA**, knee osteoarthritis; **MGM GLAE**, MGM ground level activity exposure questionnaire; **PLA_2 L**, phospholipase A_2; **uCTxII**, urinary talopeptides of type II collagen

I. INTRODUCTION

Regular loading stimulus is necessary to maintain joint health. Lack of healthy movement stimulus leads to thinning of articular cartilage, decrease in strength of muscles controlling joint motion, and results in early degenerative changes.[1–3] Changing lifestyle, physical inactivity, and increasing engagement in non-weight-bearing sedentary pursuits are gaining the attention of researchers interested in pathogenesis of knee osteoarthritis (OA).

Knee OA leads to pain, stiffness, loss of mobility, progressive functional disability, and poor health-related quality of life.[4] Biomechanical alterations lead to high compressive forces acting on the medial compartment of the knee during walking. In addition to clinical evaluation, knee osteoarthritis is typically diagnosed using radiographs. However, early stages of cartilage degeneration are not identified, as soft tissue is not visible on radiographs. Hence magnetic resonance imaging (MRI) emerges as a gold standard for diagnosing OA. MRI provides structural mapping of the articular cartilage but does not provide information on knee loading. Gait analysis in three dimensions (3D gait) has been used extensively as a non-invasive method to derive outcome measures such as knee adductor moment (KAM), which is indicative

0278-940X/21/$35.00

of compressive loading forces acting on the tibio-femoral joint surface and it is associated with increasing severity of knee osteoarthritis.[5,6] There are positive associations between KAM and medial tibial plateau size on MRI ($r = 0.63$, $P < 0.005$), although cartilage volume remains unaffected in healthy people.[7] Collins et al. reported worsening cartilage thickness (odds ratio 2.8), cartilage surface area (odds ratio 2.4), worsening synovitis effusion (odds ratio 2.7), meniscal morphology (odds ratio 2.2), and Hoffa synovitis (odds ratio 2.0) and greater odds of progressive knee OA compared to people with no worsening changes on MRI.[8]

Overexposure to high flexion activities such as squatting and kneeling is believed to serve as a risk factor predisposing an individual to developing knee OA due to greater compressive force on medial tibial plateau.[9–12] Changes in mechano-transduction due to altered loading disrupts the articular cartilage morphology and causes inflammation of synovium and menisci.[13,14] Hunt et al. observed that KAM impulse predicted significant variation in urinary cartilage telopeptide of type II collagen (uCTX-II) levels ($p = 0.04$), and in the ratio uCTX-II: serum C-propeptide of type II procollagen ($p = 0.04$).[13] Thus, excessive compressive forces on the knee articular cartilage generates an imbalance between cellular regeneration and degeneration. The resultant fibrillation and degradation of collagen tissue releases biochemical metabolic by-products into body fluids.[6,14] Urinary cartilage telopeptide type II is one such biomarker indicative of articular cartilage damage.

Furthermore, increased formation of reactive oxygen species and decreased antioxidant defense activity can damage cellular DNA, lipids, and proteins and serve as a causative mechanism for inflammatory diseases such as knee OA.[15,16] Cells and biological fluids have an array of protective antioxidant mechanisms, for preventing production of free radicals and for repairing oxidative damage.[17,18] Currently, antioxidant activity has been studied from blood and synovial fluid samples using invasive methods. However, researchers are examining the relevance of non-invasive methods to study biomarkers in body fluids such as sweat that can be collected easily using non-invasive methods. Biomarkers from body fluids such as sweat can be used to probe pathogenesis of osteoarthritis and identification of early rehabilitation measures to delay dysfunction.[19–21]

Lifestyle solutions are gaining interest as components of non-pharmacological and non-surgical alternatives for management of knee OA. Although, squatting was adopted commonly for several ADL in the early ages and it continues to be a lifestyle practice for people from densely populated continents such as Asia and Africa.[22] Lack of clarity on the quantum of squat exposure as a causative mechanism for knee OA and functional outcome of people with knee OA generates scientific curiosity to study the influence of varying the duration of daily squat exposure on knee articular cartilage metabolism.

The primary objective of this study was to review the available research on biomechanical–biochemical profile among people with varying squat exposure. The secondary objective was to explore associations between knee adductor moment (KAM), knee flexion angle in deep squat and non-invasive biochemical biomarkers (urine type II collagen telopeptide [uCTxII]), superoxide radical scavenging activity (a measure of antioxidant activity) and phospholipase A_2 (release in localized sweat enabling identification of inflammatory activity). Results from this study will enable identification of a novel non-invasive marker of early OA even before radiological evidence of OA sets in and evidence to support prescription of squatting as a potentially healthy therapeutic lifestyle practice.

II. MATERIALS AND METHODS

Following institutional ethical approval (MGMIHS/RS/2015-16/190), written consent was sought from 66 participants recruited for this cross-sectional study. Convenience sampling method was used to recruit participants from Navi Mumbai and Mumbai, during the period 2017–2019. Demographic characteristics such as age, height, body mass, and BMI of the participants were recorded (Table 1). Daily squat exposure was quantified using a validated tool, i.e., MGM Ground Level Activity

TABLE 1: Demographic characteristics, habitual physical activity, and deep squat exposure in non-squatters, ADL squatters, occupational squatters, and people with knee OA

Variable	Non squatters $n = 21$ mean (SD)	ADL squatters $n = 16$ mean (SD)	Occupational squatters $n = 13$ mean (SD)	p value using ANOVA	People with knee OA $n = 16$ mean (SD)
Age, years	36.8 (4.3)	36.3 (4.9)	38.6 (7.2)	0.605	49.8 (4.3)
Height, cm	157.6 (9.0)	161.6 (11.6)	154.2 (8.8)	0.187	154.8 (8.6)
Weight, kg	65.6 (12.9)	60.2 (17.5)	51.3 (11.3)	0.035*	67.0 (11.9)
BMI, kg/m^2	26.3 (4.0)	22.8 (4.7)	21.5 (4.3)	< 0.001*	28.0 (5.0)
IPAQ MET min/week	353.1 (546.3)	1585.9 (3459.5)	2634.6 (3654.6)	< 0.001*	758.4 (892.2)
Daily squat exposure, min	0	34.7 (30.1)	102.3 (97.1)	< 0.001*	28.2 (40.3)

*Level of significance $p < 0.05$.

Exposure Questionnaire (MGM GLAE).[22] Squat exposure was used to stratify healthy participants (age range 30–45 years) into non squatters, i.e., people who did not squat for any activity ($n = 21$); ADL squatters ($n = 16$), people who squatted for activities of daily living (ADL), and occupational squatters ($n = 13$) i.e. people who squatted for occupational activity in addition to ADL. Further, people with knee osteoarthritis ($n = 16$, age 40–60 years, grade 2–3 on Kellegren Lawrence scale, pain less than 4 on visual analog scale, onset 1–2 years) were studied to observe established biomechanical–biochemical changes of knee OA.[23] Adults with known cardiorespiratory, musculoskeletal, neurological, metabolic, or autoimmune disorders; joint replacement surgery; or traumatic conditions were excluded. People with knee OA grade 4, pain on visual analog scale > 4 were not included.

Regular level of physical activity was quantified using international physical activity questionnaire (IPAQ) short version.[24] Functional ability was scored on WOMAC scale for knee OA, in the domains of pain, stiffness, and difficulty while performing function.[25]

Sweat sample analysis was performed in a subset of 32 people from the cohort. Participants underwent 3D gait analysis at MGM Centre of Human Movement Science.

A. Methodology for Urine CTXII Analysis

Urine cartilaps (CTX-II) EIA is based on competitive binding of a monoclonal antibody to urinary fragments of uCTxII or to biotinylated synthetic peptides bound to the surface of streptavidin coated microtiter plates.[26] Morning urine sample (5 ml) was collected in an Eppendorf and stored at –20°C until analysis to measure uCTX II levels using Urinary Cartilaps Elisa kit (IDS Ltd., Germany) at MGM OMICS Research Center, as per standard procedure.

B. Methodology for Analysis of Anti-Oxidant Activity in Locally Produced Sweat Sample

Antioxidant and PLA_2 activity in locally produced sweat was analyzed to establish that metabolic by-products reflecting on activity of the region can be expressed in sweat as follows.

1. Methods Used for Sweat Collection

Sample of sweat was collected using absorbent patch method described herewith. Skin on knee above right medial knee joint line (active site) and right forearm (reference site) was wiped dry and swabbed with ethanol. A 1.5 × 1.5 cm patch of absorbable material (Whatman Paper 1) was prepared and covered with a non-absorbing plastic sheet to prevent sweat absorption from other sites. The whole patch was covered with adhesive tape.[27] Sub-maximal exercise in the form of modified Bruce's treadmill test was carried out to induce sweating and provide a uniform exercise load.[28] Patch was removed immediately after the test, sealed in aluminum foil,

inserted in a zip lock bag, and stored at 4–8°C for further analysis.

2. Superoxide Scavenging Activity Using NBT Assay

Superoxide scavenging effect of sweat samples was determined by methods described by Beauchamp and Fridovich, with slight modification.[29,30] The assay was based on capacity of the sample to enhance aerobic photochemical reduction of nitrobluetetrazolium (NBT) in presence of riboflavin. The volume of tested sample was of 6 µL/assay.

3. Phospholipase A_2 (PLA_2) Assay

Methods used by Petrovich et al. were used to analyze PLA_2 activity.[31] 10 µl of sweat sample was added to 90 µl substrate solution for the assay.

C. Method Used for 3D Gait Analysis

3D gait analysis was performed at Centre of Human Movement Science. Anthropometric data such as shoulder offset, elbow, wrist, hand, knee and ankle width, and inter anterior superior iliac spine (ASIS) distance, leg length were recorded and used for inverse dynamic calculations (see Fig. 1). As part of the study protocol, participants were instructed to keep hands outstretched in front of the body and descend to a complete deep squat, stay in position for 5 sec, and ascend to standing. Forty-three retro reflective spherical markers were placed on anatomical landmarks using plug-in-gait full body marker set. 3D data were captured at 100 Hz using a 12 camera Vicon motion capture system (Oxford Metrics Ltd., UK). Ground reaction force data were collected using 2 AMTI force plates (Advanced Mechanical Technology Inc., USA). A static anatomical calibration trial was used to align joint axis, followed by capture of 5 trials of walk activity. Participants walked at self-selected habitual speed across a 10-meter walkway. Five trials of deep squat activity were captured. Mid-gait data were filtered with a Butterworth filter at cut off frequency of 6 Hz for marker trajectories and 10 Hz for analog data.[32] Data were processed within Vicon Nexus 2.1 to compute KAM. SPSS Version 24 (IBM) was used to perform statistical analysis. Knee flexion angle at deep squat, knee adductor moment during walk and deep squat were used as

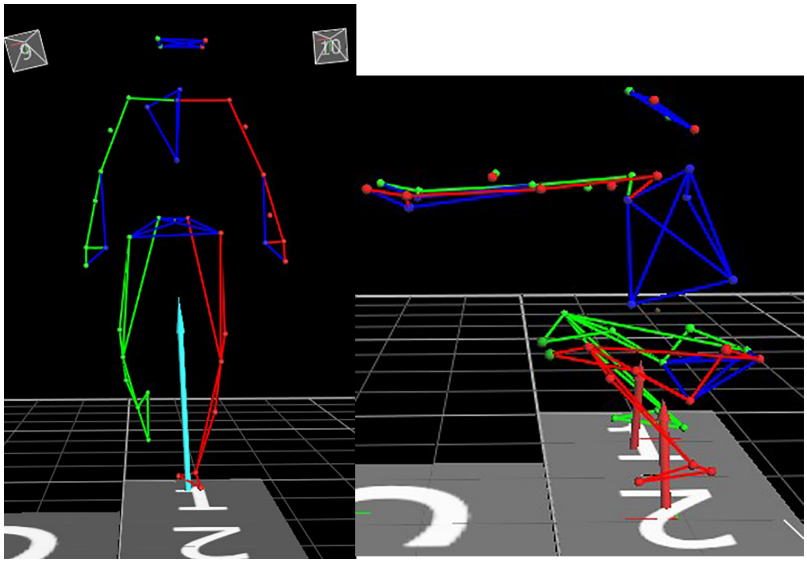


FIG. 1: Stick figure of 3D motion capture of walk for measurement of knee adductor moment and deep squat for measurement of knee flexion angle

outcome variables for biomechanical analysis (see Figs. 1 and 2).

D. Statistical Analysis

Central tendency and dispersion of data were presented in form of mean and standard deviation. Normal distribution of data was ascertained using Shapiro–Wilk test.[33] Associations between urine CTxII, antioxidant activity, PLA_2 activity, and knee adductor moment was analyzed using Pearson's correlation coefficient. Level of urine CTxII, antioxidant activity, sweat PLA_2 activity, and knee adductor moment were compared among the three healthy groups using one-way ANOVA test. Difference between sweat produced at knee and forearm was analyzed using paired Student's *t*-test. People with knee OA were studied as a reference group to understand biomechanical and biochemical changes in people with established damage in the knee articular cartilage.

III. RESULTS

Demographic characteristics, habitual physical activity, and deep squat exposure in non-squatters, ADL squatters, occupational squatters, and people with knee OA are presented in Table 1. Non squatters demonstrated greater body mass and BMI compared to occupational squatters. People with knee OA were older and presented with higher body mass and BMI than healthy people. There was no daily squat exposure in non-squatters, moderate (34.7 ± 30.1 min) in ADL squatters and people with OA (28 ± 40.4 min), and high in occupational squatters (102.3 ± 97.1 min). IPAQ score indicated low level of habitual physical activity in non-squatters and people with knee OA, moderate level of physical activity in ADL squatters, and high physical activity in occupational squatters (Table 1).

The influence of varying squat exposure was observed on the biochemical and biomechanical variables (Table 2). Values of uCTxII and superoxide scavenging activity were comparable among the groups. Activity of PLA_2 in localized sweat from knee was significantly different among healthy people with varying squat exposure ($p < 0.05$).

Lowest values of knee PLA_2 activity were observed in ADL squatters with moderate squat exposure while occupational squatters and people with knee OA demonstrated higher knee PLA_2 activity. Further, we compared between sweat PLA_2 activity and antioxidant activity (%) at active site, i.e., knee, and reference site, i.e., forearm, to observe whether metabolic activity varied at different areas. However, no difference was observed between the knee and forearm in sweat PLA_2 activity.

Biomechanical variables, namely knee flexion angle in deep squat, increased linearly with increase in squatting exposure ($p < 0.001$). People with knee OA ($n = 16$) demonstrated a reduction in knee flexion angle and ability to perform a deep squat. Knee adductor moment while walking was comparable in healthy

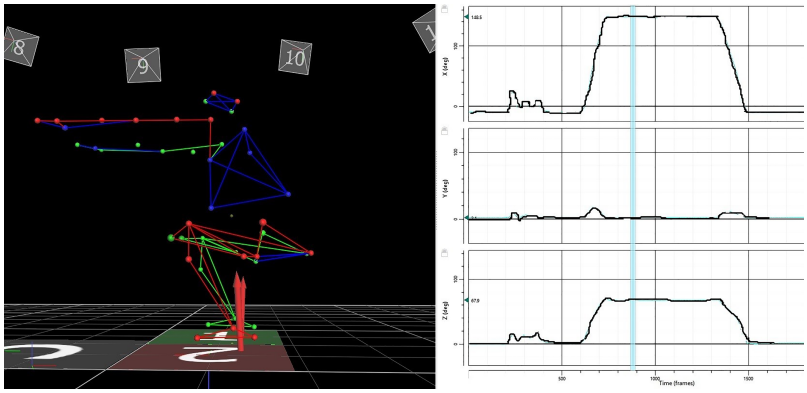


FIG. 2: Kinematic graphs of knee angles during deep squat in a non-squatter, where the *x* axis represents time frame in millisecond and *y* axis represents joint angles in degrees

TABLE 2: Comparison of uCTxII concentration, knee adductor moment, antioxidant activity and PLA_2 activity, among non-squatters, ADL squatters, occupational squatters, and people with knee OA

Variable	Non squatters $n = 21$ mean (SD)	ADL squatters $n = 16$ mean (SD)	Occupational squatters $n = 13$ mean (SD)	p value using ANOVA among healthy people	People with knee OA $n = 16$ mean (SD)	p value using ANOVA among the 4 groups
uCTxII mmol/l	375.0 (243.4)	466.4 (294.1)	275.3 (207.6)	0.923	439.7 (442.6)	0.397
R walk KAM Nm/kg	0.605 (0.215)	0.548 (0.164)	0.532 (0.238)	0.531	0.566 (0.201)	0.733
L walk KAM Nm/kg	0.597 (0.140)	0.588 (0.271)	0.528 (0.252)	0.665	0.706 (0.689)	0.628
R squat KAM Nm/kg	0.197 (0.261)	0.393 (0.213)	0.320 (0.295)	0.056	0.156 (0.313)	0.028*
L squat KAM Nm/kg	0.147 (0.400)	0.511 (0.217)	0.230 (0.336)	0.003*	0.195 (0.212)	0.001*
R knee flexion angle degrees	151.9 (7.2)	157.6 (5.6)	162.0 (4.8)	< 0.001*	120.6 (44.5)	< 0.001*
L knee flexion angle degrees	153.5 (7.8)	159.7 (4.1)	161.2 (6.9)	0.001*	109.4 (48.4)	< 0.001*
Variable	**Non squatters $n = 6$**	**ADL squatters $n = 11$**	**Occupational squatters $n = 4$**	**p value using ANOVA**	**People with knee OA $n = 10$**	
Antioxidant activity knee (%)	20.5 (10.2)	30.5 (9.2)	30.8 (21.7)	0.416	22.3 (14.8)	0.336
Antioxidant activity forearm (%)	18.0 (10.9)	29.8 (11.2)	31.7 (28.4)	0.303	29.0 (14.3)	0.338
PLA_2 activity knee (IU)	1.36 (0.65)	1.49 (0.85)	3.0 (1.6)	0.046*	2.03 (0.95)	0.049*
PLA_2 activity forearm (IU)	1.51 (0.75)	2.03 (1.80)	3.25 (1.72)	0.278	2.00 (0.97)	0.265

*Level of significance $p < 0.05$.

people ($n = 50$), thus indicating that people with varying squat exposure did not show signs of increased joint loading. Although people with knee OA and non-squatters presented higher KAM during walk, the difference did not reach statistical significance. People with knee OA demonstrated low knee adductor moment during squat at left knee indicative of inability to complete deep squat motion and low muscle forces required to maintain the posture (Table 2).

Secondly, associations between the clinical characteristics, biomechanical, and biochemical variables were explored. Daily squat exposure demonstrated weak negative correlation with BMI, weak–moderate positive correlation with knee flexion angle in deep squat and superoxide scavenging activity (Table 3).

Weak positive correlations were observed between biomarker uCTxII and BMI ($r^2 = 0.336$, $p = 0.011$), uCTxII and left knee adductor moment ($r = 0.363$, $p = 0.008$), left knee adductor moment and BMI ($r^2 = 0.244$, $p = 0.034$). Further, strong positive correlation was observed between PLA_2 activity and

TABLE 3: Correlations between BMI, uCTxII, antioxidant activity, PLA_2 activity, knee flexion angles, and knee adductor moment during squat

Variables	BMI	PLA_2 activity knee	RKAM	LKAM	Antioxidant activity knee	R Knee flexion angle	L Knee flexion angle
uCTxII	0.336*	$p = 0.952$	$p = 0.350$	0.363*	$p = 0.332$	–0.300*	$p = 0.058$
BMI	—	$p = 0.689$	$p = 0.230$	0.244*	–0.399*	–0.502*	–0.486*
PLA_2 activity	$p = 0.689$	—	$p = 0.864$	$p = 0.619$	$p = 0.263$	0.293	0.246
Antioxidant activity (%)	–0.399*	$p = 0.263$	–0.917*	–0.767*	—	0.121	0.116
Daily squat exposure	–0.351*	$p = 0.983$	$p = 0.397$	$p = 0.294$	0.497*	0.522*	0.403*

*Correlation coefficients significant at $p < 0.05$.

age ($r = 0.819$, $p = 0.004$), moderate positive correlation between daily squat exposure and uCTxII ($r = 0.604$, $p = 0.013$), and a strong negative correlation was observed between antioxidant activity at knee and right knee adductor moment ($r = –0.917$, $p = 0.001$), antioxidant activity at knee and left knee adductor moment ($r = –0.767$, $p = 0.001$ (Table 3).

IV. DISCUSSION

The current study established the association between biomechanical and biochemical biomarkers related to cartilage degeneration in knee OA and explored the presence of PLA_2 activity in human sweat as an indicator of localized inflammatory activity in people with varying squat exposure.

Our study suggests that body mass and joint kinematics are influenced by varying quantum of daily squat exposure. People who do not squat and lead a sedentary lifestyle consequently gain body mass, which is a strong risk factor leading to progression of knee OA and functional deterioration. Positive correlations between daily squat exposure and anti-oxidant activity demonstrate beneficial effects of squatting. Therefore, inclusion of squatting activities into the daily lifestyle, in moderate dose, would seem prudent.

Further, positive correlations were observed among knee joint moment, knee flexion angles, knee function (WOMAC Score), BMI, and biochemical biomarker uCTxII, a sensitive biochemical biomarker related to knee articular damage. Similar observations are reported in various studies where weak correlations were demonstrated between MRI findings of knee OA and uCTxII.[34,35] In this study, similar values of uCTxII levels were observed in healthy people with low to high squat exposure, suggesting that squatting exposure may not be detrimental to knee articular cartilage health. However, higher sweat PLA_2 activity in people with high squat exposure suggests commencement of early degeneration and inflammation changes within the knee joint. Similar findings are reported in people with degenerative conditions of the knee on tissue histopathology.[36–38] Hence it may be safer to prescribe low–moderate squat exposure to healthy people.

Further, we observed strong negative correlation between superoxide scavenging activity at knee and right/left knee adductor moment, in people with knee OA. Thus, high joint loading associated with low antioxidant activity may serve as a precursor for progression of degeneration/inflammatory changes. In recent years, a substantial body of evidence has developed supporting the key role of free radicals in many fundamental cellular reactions. Previous studies suggest that oxidative stress might be important in the pathophysiology of common diseases including inflammatory diseases. Antioxidants reduce free radicals, stimulate growth of normal cells, protect cells against premature and abnormal aging, help fight age related molecular degeneration, and support the immune system.[36]

While high level of physical activity is associated with high risk of knee OA, on the other hand

restricted joint loading results in tendency to develop severe OA.[36,37] High BMI and KAM in healthy young non squatters may pose as a risk factor for development of early knee OA, thus substantiating the role of maintenance of a healthy BMI, high antioxidant status, and performing joint loading exercises such as squatting in preventive management of knee OA.

Group II PLA has been isolated from human synovial fluid and is characteristic of inflammatory exudates, with speculations on role of extracellular PLA_2 in inflammation. Investigators are looking at methods to explore PLA_2 inhibitors in acute and chronic diseases.[37,38] High PLA2G5 has been reported in articular cartilage and synovium of people with knee OA, attributed to overactivation of conversion of phosphatidylcholine to lysophosphatidylcholine catalyzed by PLA_2 and a greater risk of articular cartilage loss.[39] High circulating PLA_2 values have been reported by Leistad et al. in patients with arthritis with multiple PLA_2 isoforms expressed in chondrocytes in OA.[40] To the best of our knowledge this is the first study reporting associations between biomechanical variables and inflammatory activity. In this study, high PLA_2 activity was observed in occupational squatters, followed by people with OA, while lowest PLA_2 activity was observed in people with low–moderate squat exposure. These findings may indicate that sustained biomechanical load placed by squatting for prolonged duration of time leads to disruption of healthy cellular mechanisms, inflammatory response and potential degradation of articular cartilage and synovium. Constant loading pressure may alter the synovial fluid dynamics and subsequently nutrition to the articular cartilage thereby establishing the environment for cartilage damage.[41] People squatting in moderation may not exhibit this phenomenon and may receive positive benefits of deep squatting. Thus, the articular cartilage and synovium may demonstrate a dose-dependent response to specific quantum of physical activity. The fluid load support offered by interstitial fluid of cartilage may reduce friction under the transient and dynamic loading conditions while squatting.[42]

In summary, positive correlations were observed between daily squat exposure, biomechanical variables, and biochemical markers in the present study. High body mass, increase in uCTxII, decrease in knee flexion angle during deep squat, increase in knee adductor moment, and low antioxidant activity may serve as non-invasive biomarkers for identification of early knee osteoarthritis even before radiological signs of knee OA are observed and degeneration of articular cartilage is established.

A rise in PLA_2 activity in localized sweat from knee in healthy people with high squat exposure may indicate its ability to identify early inflammatory changes in the knee joint at a stage where cartilage damage may not be sufficiently high. Thus, early identification of risk factors using non-invasive methods and institution of early preventive therapeutic measures such as maintenance of ideal BMI, engaging in moderate level of squatting activities that optimally load the knee joint, correction of biomechanical factors that lead to excessive loading, and optimizing antioxidant status of the body may delay onset of symptomatic knee OA. PLA_2 activity in localized sweat from knee may be explored in a large scale study to establish it as a biochemical biomarker of early knee OA.

Limitations: A cross-sectional study design precludes establishment of a cause–effect relationship between biomechanical and biochemical markers of knee OA. In this study we recruited healthy people and people with grade 2–3 knee osteoarthritis. People with grade 1 knee OA with doubtful narrowing of joint space could not be recruited. The results from this study need to be explored in these patients to confirm our observations. This study reports a novel concept that inflammatory activity can be demonstrated in locally produced sweat and demonstrates correlations between biomechanical analysis and biochemical markers. Although the patients were rested prior to testing and sweat collection, it may not be possible to dissociate acute response to weight bearing activity from damage to articular cartilage. Sweat collection methods need to be standardized to obtain repeatable results. Interactions between squatting exposure and biomechanical and biochemical variables need to be explored in large population studies to prescribe squatting as a healthy lifestyle activity.

V. CONCLUSION

People with little or no squat exposure presented with reduced knee range of motion and lower joint moment during high flexion activity. People engaged in moderate dynamic squatting demonstrated greater knee range of motion and lower inflammatory markers. Hence, squatting in moderation can emerge as an effective lifestyle measure to maintain healthy joint loading and knee health. Thus, early identification of altered knee function, range of motion, loading characteristics and cartilage damage using established, valid non-invasive biomechanical methods and biochemical biomarkers may guide prescription of early therapeutic measures for prophylaxis.

REFERENCES

1. Eckstein F, Lemberger B, Gratzke C, Hudelmaier M, Glaser C, Englmeier KH, Reiser M. In vivo cartilage deformation after different types of activity and its dependence on physical training status. Ann Rheum Dis. 2005 Feb;64(2):291–5.
2. Vanwanseele B, Eckstein F, Knecht H, Spaepen A, Stüssi E. Longitudinal analysis of cartilage atrophy in the knees of patients with spinal cord injury. Arthritis Rheum. 2003 Dec;48(12):3377–81.
3. Jurvelin J, Kiviranta I, Säämänen AM, Tammi M, Helminen HJ. Partial restoration of immobilization-induced softening of canine articular cartilage after remobilization of the knee (stifle) joint. J Orthop Res. 1989 May;7(3):352–8.
4. Briggs AM, Woolf AD, Dreinhöfer K, Homb N, Hoy DG, Kopansky-Giles D, Åkesson K, March L. Reducing the global burden of musculoskeletal conditions. Bull World Health Organ. 2018 May;96(5):366.
5. Maly MR, Robbins SM, Stratford PW, Birmingham TB, Callaghan JP. Cumulative knee adductor load distinguishes between healthy and osteoarthritic knees—a proof of principle study. Gait Posture. 2013 Mar;37(3):397–401. doi: 10.1016/j.gaitpost.2012.08.013.
6. Birmingham TB, Hunt MA, Jones IC, Jenkyn TR, Giffin JR. Test-retest reliability of the peak knee adduction moment during walking in patients with medial compartment knee osteoarthritis. Arthritis Rheum. 2007 Aug 15;57(6):1012–7. doi: 10.1002/art.22899.
7. Jackson BD, Teichtahl AJ, Morris ME, Wluka AE, Davis SR, Cicuttini FM. The effect of the knee adduction moment on tibial cartilage volume and bone size in healthy women. Rheumatology. 2004 Mar;43(3):311–4. doi: 10.1093/rheumatology/keh002.
8. Collins JE, Losina E, Nevitt MC, Roemer FW Guermazi A, Lynch JA, Katz JN, Kwoh CK, Kraus VB, Hunter DJ. semiquantitative imaging biomarkers of knee osteoarthritis progression: Data from the foundation for the National Institutes of Health Osteoarthritis Biomarkers Consortium. Arthritis Rheumatol. 2016 Oct;68(10):2422–31.
9. Berenbaum F, Wallace IJ, Lieberman DE, Felson DT. Modern- day environmental factors in the pathogenesis of osteoarthritis. Nat Rev Rheumatol. 2018 Nov;14(11):674–81.
10. Wearing SC, Hennig EM, Byrne NM, Steele JR, Hills AP. Musculoskeletal disorders associated with obesity: A biomechanical perspective. Obes Rev. 2006 Aug;7(3):239–50. doi: 10.1111/j.1467-789X.2006.00251.x.
11. Ezzat AM, Li LC. Occupational physical loading tasks and knee osteoarthritis: A review of the evidence. Physiother Can. Winter 2014;66(1):91–107.
12. Jensen LK. Knee osteoarthritis: Influence of work involving heavy lifting, kneeling, climbing stairs or ladders, or kneeling/squatting combined with heavy lifting. Occup Environ Med. 2008 Feb;65(2):72–89.
13. Hunt MA, Pollock CL, Kraus VB, Saxne T, Peters S, Huebner JL, Sayre EC, Cibere J. Relationships amongst osteoarthritis biomarkers, dynamic knee joint load and exercise: Results from a randomized controlled pilot study. BMC Musculoskeletal Disord. 2013,14: 115.
14. Sanchez- Adams, J, Leddy HA, McNulty AL, O'Conor CJ, Guilak F. The mechanobiology of articular cartilage: Bearing the burden of osteoarthritis. Rev Curr Rheumatol Rep. 2014 Oct;16(10):451.
15. Joseph GB, Nevitt MC, McCulloch CE, Neumann J, Lynch JA, Heilmeier U, Lane NE, Link TM. Associations between molecular biomarkers and MR-based cartilage composition and knee joint morphology: Data from the osteoarthritis initiative. Osteoarthritis Cartilage. 2018 Aug;26(8):1070–7.
16. Garnero P, Aronstein WS, Cohen SB, Conaghan PG, Cline GA, Christiansen C, Beary JF, Meyer JM, Bingham CO 3rd. Relationships between biochemical markers of bone and cartilage degradation with radiological progression in patients with knee osteoarthritis receiving risedronate: The knee osteoarthritis structural arthritis randomized clinical trial. Osteoarthritis Cartilage. 2008;16:660e6.
17. Urso ML, Clarkson PM. Oxidative stress, exercise, and antioxidant supplementation. Toxicology. 2003 Jul 15;189(1-2):41–54.
18. Valko M, Leibfritz D, Moncol J, Cronin MT, Mazur M, Telser J. Free radicals and antioxidants in normal physiological functions and human disease. Int J Biochem Cell Biol. 2007;39(1):44–84.
19. Emery CA, Whittaker JL, Mahmoudian A, Lohmander LS, Roos EW, Bennell KL, Toomey CM, Reimer RA, Thompson D, Ronsky JL, Kuntze G, Lloyd DG, Andriacchi T, Englund M, Kraus VB, Losina E, Bierma-Zeinstra S, Runhaar J, Peat G, Luyten FP, Snyder-Mackler

L, Risberg MA, Mobasheri A, Guermazi A, Hunter DJ, Arden NK. Establishing outcome measures in early knee osteoarthritis. Nat Rev Rheumatol. 2019 Jul;15(7): 438–48.
20. Raiszadeh MM, Ross MM, Russo PS, Schaepper MA, Zhou W, Deng J, Ng D, Dickson A, Dickson C, Strom M, Osorio C. Proteomic analysis of eccrine sweat: Implications for the discovery of schizophrenia biomarker proteins. J Proteome Res. 2012 Apr;11(4):2127–39.
21. Halliwell B. Antioxidants in human health and disease. Annu Rev Nutr. 1996;16:33–50.
22. Agarwal B, Advani M, Deursen RV, Mullerpatan R. Influence of varying squat exposure on knee pain and function among people with knee osteoarthritis. Crit Rev Phys Rehabil Med. 2019;31(1):23–34.
23. Phan NQ, Blome C, Fritz F, Gerss J, Reich A, Toshi Ebata T, Augustin M, Szepietowski JC, Stander S. Assessment of pruritis intensity: Prospective study on validity and reliability of visual analogue scale, numeric rating scale and verbal rating sale in 471 patients with chronic pruritis. Acta Derm Venereol. 2012;92:502–7.
24. Craig C, Marshall AL, Sjostro M, Bauman AE, Booth ML, Ainsworth BE, Pratt M, Ekelund U, Yngve A, Sallis JF, Oja P. International physical activity questionnaire: 12-country reliability and validity. J Am Coll Sports Med. 2003;35(8):1381–95. doi: 10.1249/01.MSS.0000078924.61453.FB.
25. Reddy SV, Arumugam G, Kumar R, Jose N. Association of pain, physical function and radiographic features in knee osteoarthritis in Indian population. Int J Adv Res. 2013;1(10):339–42.
26. Christgau S, Garnero P, Fledelius C, Moniz C, Rosenquist C, Ensig M, Gineyts E, Christiansen C, Qvist P. Collagen type II degradation products in urine as an index of cartilage degradation. Bone. 2001 Sep;29(3): 209–15.
27. Baker LB, Stofan JR, Hamilton AA, Horswill CA. Comparison of regional patch collection vs. whole body washdown for measuring sweat sodium and potassium loss during exercise. J Appl Physiol. 2009;107(3): 887–95.
28. McInnis KJ, Balady GJ. Comparison of submaximal exercise responses using the Bruce vs. modified Bruce protocols. Clinical Trial Med Sci Sports Exerc. 1994 Jan;26(1):103–7.
29. Beauchamp C, Fridovich I. Superoxide dismutase: Improved assays and an assay applicable to acrylamide gels. Anal Biochem. 1971 Nov;44(1):276–87.
30. Bhagit AA, Mhatre SV, Yadav RP. Biofabrication of bifunctional cerium oxide nanoparticles using Phaseolus vulgaris with enhanced antioxidant and carbonic anhydrase class 1 inhibitory activity. MGM J Med Sci. 2016;3(4):161–6.
31. Petrovic N, Grove C, Langton PE, Misso NLA, Thompson PJ. A simple assay for a human serum phospholipase A2 that is associated with high-density lipoproteins. J Lipid Res. 2001;42:1706–13.
32. Agarwal BM, van Deursen R, Mullerpatan RP. Influence of habitual deep squatting on kinematics of lower extremity, pelvis and trunk. Int J Health Rehabil Sci. 2018;7(1): 1–19.
33. Vetter TR. Fundamentals of research data and variables: The devil is in the details. Anesth Analg. 2017 Oct;125(4):1375–80.
34. Vosyz JM, Welsingyx PMJ, deGroot J, Huisman AM, Oostveen JCM, Reijmanyy M, Damenzz J, Mastbergen SC, Lafeber FPJG. Skin pentosidine in very early hip/knee osteoarthritis (CHECK) is not a strong independent predictor of radiographic progression over 5 years follow-up P.A. Osteoarthritis Cartilage. 2013;21:823–30.
35. Dam EB, Loog M, Christiansen C, Byrjalsen I, Folkesson J, Nielsen M, Qazi AA, Pettersen PC, Garnero P, Karsdal MA. Identification of progressors in osteoarthritis by combining biochemical and MRI-based markers. Arthritis Res Ther. 2009;11:R115.
36. Mastbergen SC, Marijnissen AC, Vianen ME, Van Roermund PM, Bijlsma JW, Lafeber FP. The canine 'groove' model of osteoarthritis is more than simply the expression of surgically applied damage. Osteoarthritis Cartilage. 2006;14:39e46.
37. Vos PA, DeGroot J, Barten-van Rijbroek AD, Zuurmond AM, Bijlsma JW, Mastbergen SC, Lafeber FP. Elevation of cartilage AGEs does not accelerate initiation of canine experimental osteoarthritis upon mild surgical damage. J Orthop Res. 2012;30:1398e404.
38. Weiss J, Wright G. Mobilization and function of extracellular phospholipase A2 in inflammation. In: Wong PYK, Dennis EA, editors. Phospholipase A2. Advances in experimental medicine and biology. Vol 275. Boston, MA: Springer; 1990.
39. Zhai G Pelletier JP, Liu M, Aitken D, Randell E, Rahman P, Jones G, Martel-Pelletier J. Activation of the phosphatidylcholine to lysophosphatidylcholine pathway is associated with osteoarthritis knee cartilage volume loss over time. Sci Rep. 2019;9:9648.
40. Leistad L, Feuerherm AJ, Faxvaag A, Johansen B. Multiple phospholipase A2 enzymes participate in the inflammatory process in osteoarthritic cartilage. Scand J Rheumatol. 2011;40(4):308–16.
41. Furmann D, Nečas D, Rebenda D, Čípek P, Vrbka M, Křupka I, Hartl M. The effect of synovial fluid composition, speed and load on frictional behaviour of articular cartilage. Materials. 2020 Mar;13(6):1334.
42. Ateshian GA. The role of interstitial fluid pressurization in articular cartilage lubrication. J Biomech. 2009 Jun 19;42(9):1163–76.
43. Joseph GB, Nevitt MC, McCulloch CE, Neumann J, Lynch JA, Heilmeier U, Lane NE, Link TM. Associations between molecular biomarkers and MR-based cartilage composition and knee joint morphology: Data from the

osteoarthritis initiative. Osteoarthritis Cartilage. 2018 Aug;26(8):1070–7.
44. Leistad L, Feuerherm AJ, Faxvaag A, Johansen B. Multiple phospholipase A2 enzymes participate in the inflammatory process in osteoarthritic cartilage. Scand J Rheumatol. 2011;40(4):308–16.
45. Csősz E, Emri G, Kalló G, Tsaprailis G, Tőzsér J. Highly abundant defense proteins in human sweat as revealed by targeted proteomics and label free quantification mass spectrometry. J Eur Acad Dermatol Venereol. 2015 Oct;29(10):2024–31.

APPENDIX A. DETAILS OF BIOCHEMICAL MEASURES

A.1 Urinary Cartilage Telopeptide Type II (uCTxII)

Excessive compressive forces on the knee articular cartilage disrupts the balance between cellular regeneration and degeneration. The resultant fibrillation and degradation of collagen tissue releases biochemical metabolic by-products into body fluids. Urinary cartilage telopeptide type II is one such biomarker indicative of articular cartilage damage. Biochemical markers of protease degraded cartilage matrix constituents like levels of uCTxII also provide prognostic information of structural damage.[43]

A.2 Group II Phospholipase (PLA_2) Activity

PLA_2 has been isolated from human synovial fluid and is characteristic of inflammatory exudates. It is speculated that extracellular PLA_2 might play a role in the inflammatory pathogenesis of knee OA. Overactivation of conversion of phosphatidylcholine to lysophosphatidylcholine catalyzed by PLA_2 is associated with a greater risk of articular cartilage loss. To the best of our knowledge this is the first study reporting expression of PLA2 activity in localized sweat.[44]

A.3 Superoxide Scavenging Activity

Antioxidants support the body's immune system by reduction of free radicals, stimulation of growth of normal cells, protection of cells against premature and abnormal aging and age-related molecular degeneration. Formation of reactive oxygen species and decreased antioxidant defense activity are implicated as causative mechanisms that lead to cellular damage and act as a causative factor for development of inflammatory diseases like knee OA. Superoxide scavenging activity reflects on the protective antioxidant mechanisms present normally in body fluids. They are responsible for repairing oxidative damage and inhibiting production of free radicals.[45]

Hong Kong Physiotherapy Journal Published by World Scientific

Hong Kong Physiother J. 2021 Dec; 41(2): 139–146.
Published online 2021 May 19. doi: 10.1142/S101370252150013X

PMCID: PMC8221982
PMID: 34177202

Indian (Marathi) version of the Shoulder Pain and Disability Index (SPADI): Translation and validation in patients with adhesive capsulitis

Apeksha Javesh Pahade,[1] Surendra K. Wani,[1,*] Rajani P. Mullemalan,[2] and Kathryn Elizabeth Roach[3]

Abstract

Background:

The Shoulder Pain and Disability Index (SPADI) is the most commonly used self-administered questionnaire which is a valid and reliable instrument to assess the proportion of pain and disability in shoulder disorders. There is no evidence of SPADI questionnaire being translated into regional Indian language (Marathi).

Objective:

This study aims to translate and culturally adapt and validate the Marathi version of the SPADI questionnaire. This was done as per the AAOS outcomes committee guidelines.

Methods:

Cross-cultural adaptation and psychometric testing of SPADI was done in the Outpatient Physiotherapy Department of Tertiary Care Hospital, Ahmednagar, India.

Results:

The internal consistency was assessed by calculating Cronbach alpha value for the pain score (0.908), disability score (0.959), and total SPADI (0.969) which were all high. The Test–retest reliability was assessed using the intraclass correlation coefficient (ICC) values for the pain score (0.993), disability score (0.997), and total SPADI (0.997) which showed excellent reliability. The criterion validity was assessed using Pearson correlation coefficient. In Males, weak to strong negative correlation was observed except for shoulder extension and in females, moderate negative correlation was observed between baseline shoulder range of motion and initial total SPADI scores and individual pain and disability except for shoulder internal rotation. The internal consis-

tency of the Marathi SPADI (Cronbach's alpha >0.99) was higher than the original English version. The reliability of the total Marathi SPADI and its subscale (Intraclass correlation coefficient >0.90) were found to be higher than that of the English SPADI and were consistent with the German, Brazilian, Slovene and Greek versions.

Conclusion:

The translated and culturally adapted Marathi version of the SPADI questionnaire is a reliable and valid tool for the assessment of pain and disability in Marathi population.

Keywords: Cross cultural adaptation, Marathi version, psychometric, reliability, SPADI, validity

Introduction

Shoulder pain or dysfunction is the third most common musculoskeletal condition among the general population with a lifetime prevalence of 70%.[1,2] Periarthritis, subacromial impingement, rotator cuff injury, acromioclavicular arthritis, etc. are some of the common causes of shoulder pain and disability which interferes in the social & working aspects of living of patients, affecting the overall quality of life.[3,4]

Adhesive capsulitis is one of the common causes of shoulder pain & disability, with a prevalence of around 43.1% among the shoulder cases reported.[3] This condition is characterized by pain, stiffness and limited range of motion of glenohumeral joint due to chronic inflammation of capsule which affects the upper extremity function and performance.[5]

A comprehensive evaluation of the shoulder joint generally involves the assessment of pain, clinical evaluation of shoulder range of motion, strength and joint play using standard protocols. Besides, shoulder specific self-reported questionnaires or patient-reported outcome measures (PRO) and performance-based outcome measures are also some of the simplest ways to obtain information about musculoskeletal pain and were used to evaluate disability associated with it.[4] The appropriate selection of outcome parameter is essential to confirm the efficacy of specific treatment protocol for shoulder pain & disability.[6]

More than 30 different questionnaires are available in the literature to assess pain and function of shoulder.[7] The clinometric properties of the 16 shoulder questionnaires which were designed to measure physical functioning in individuals with shoulder problems were analyzed and its clinometric properties were identified and evaluated in a systemic review[8] and they found that the Shoulder Pain and Disability Index (SPADI),[9] Disability of the Arm, Shoulder and Hand Questionnaire (DASH),[10] and the American Shoulder and Elbow Surgeons Questionnaire (ASES)[11] were the most extensively used questionnaires to assess disability associated with shoulder dysfunction.

SPADI is the most commonly used instrument in research around the shoulder joint to assess the

tested in many clinical settings. It is self-administered and assesses both shoulder pain and disability during the important functional tasks of daily living.[9]

Roach and colleagues developed the original SPADI questionnaire in 1991. The initial validation of the questionnaire was done on 37 men with shoulder pain. They reported high internal consistency (0.86 to 0.95), and moderate test–retest reliability (interclass correlation coefficient (ICC = 0.65) on a subgroup of 23 patients. Principal components factor analysis was conducted which supported two subscales: pain and disability. The validity of the questionnaire was established by correlating SPADI total and subscale scores with shoulder ROM.[9]

Although enough evidence supports the reliability and the validity of the English language SPADI, these properties do not extend to a translated version used in a different cultural context.[12] The SPADI questionnaire has been translated and culturally adapted into many other languages but there very few published studies on its validity either in Asia or specifically in India.

Patients in India experience difficulties in understanding English questionnaires due to the language barrier. Before using any outcome measure, which quantifies the impact of shoulder pain and disability on patients and assesses the efficacy of treatments in Indian scenario, it should be validated for their use in the Indian socio-cultural context for more accurate interpretation. Therefore, cross-cultural adaptation, reliability testing and validation of the questionnaire, which is translated in Indian regional languages, is essential for the questionnaire to be used use in that particular region. Moreover, there is no evidence of the SPADI questionnaire being translated into Marathi, which is a widely used language in the Maharashtra state of India. Therefore, this study aimed to translate and culturally adapt the Marathi version of the SPADI questionnaire and to validate it in Indian patients with Adhesive capsulitis.

Materials and Methods

Shoulder Pain and Disability Index (SPADI) (English version)

The SPADI is a self-administered questionnaire that assesses shoulder pain and dysfunction.[10] It consists of 13 items. The first five items measure the pain, and the next eight items assess patients' disability.[14] This version of the SPADI questionnaire has a ten-point numerical rating scale (NRS).[15] The patient has to answer the questions according to the level that corresponds to their pain and difficulty in movement, on a numerical rating scale ranging from 0, i.e., no pain and difficulty to 10, i.e., maximum pain and such difficulty so that the patient needs help.[10,15] The calculation of final score was done by summing the individual responses and converting them into a percentage (%).[15]

Procedure

The commencement of study was done after obtaining approval by the Institutional Ethics Committee. The linguistic validation process was initiated after prior permission was obtained from the original developer of the questionnaire through the mail, to acquire their consent.

Steps Followed for Translation & Validation

As per the guidelines provided by the American Association of Orthopaedic Surgeons (AAOS) outcomes committee, translation and cross-cultural adaptation of the SPADI questionnaire was performed.[15]

(1) First, forward translation of the questionnaire from English to Marathi was done by an informed (T1) and uninformed translator (T2).
(2) In the second step, the two translations (T1 and T2) were taken into consideration and the discrepancies were resolved, and a final form of the Marathi questionnaire was made (version T-12).
(3) In the third step, Back-translation (Marathi to English) of the version T-12 was obtained from the two back-translators (BT1 and BT2).
(4) Then Expert committee consisting of all four translators (T1, T2, BT1, BT2), one methodologist (researcher), and one language professional (having a good knowledge of both English and Marathi languages) reviewed the two back translated questionnaire (BT1 & BT2) to find out any discrepancies in interpretation/meaning and established a prefinal Marathi version of the questionnaire.
(5) Pretesting of prefinal Marathi version of the questionnaire was done by administering in 31 patients with adhesive capsulitis selected with a purposive sampling method attending our physiotherapy outpatient department of Tertiary Care Hospital, Ahmednagar.

While testing the cross-culturally adapted version in Marathi for its validity, written informed consent was obtained from each patient who satisfied the inclusion criteria for this study. The patients of both the genders aged between 40–60 years and medically diagnosed with adhesive capsulitis were included in the study. Patients reported gradual onset and progressive worsening of pain (VAS ranging in between 3 and 8) and stiffness at shoulder at least from three months duration affecting functional activities related to shoulder. Patients having history of trauma, surgery or fracture of affected shoulder, Shoulder joint instability or dislocation, systemic illness like rheumatoid arthritis, Reiter's syndrome, osteoarthritis of the affected shoulder joint, Shoulder pain of cervical origin, patients with neurological diseases or other severe medical or psychiatric disorders, inability to read and understand Marathi were excluded from the study.

After a brief clinical examination, patients were explained about the procedure to fill the questionnaire before responding. The patients were seated comfortably and the questionnaire was given to them and they were asked to mark the point on the scoring system, which best represented their status of shoulder pain and disability.

The researcher noted the layout and wording of the questionnaire, its ease of understanding, and ease of completion of the questionnaire during the administration of questionnaire among patients. The patients stated no trouble in understanding and answering the questions effectively, therefore without making major alterations the SPADI questionnaire — Marathi version

(6) The documentation of the above steps was submitted to the developers of the original questionnaire so as to ensure that the process has been carried out properly and that a reasonable translation has been achieved.[16]

After the patients completed the Marathi version of the questionnaire (Step 5), the active ROM of the shoulder was measured using a standard universal goniometer in the standard test positions.[17] These ROM values were then used to analyze the criterion validity of the questionnaire. The test–retest reliability was also assessed by taking a second assessment session which was at least 24 hours after the first session (ICC).

Statistical analysis: Statistical analysis was done using SPSS version 20.0. Unpaired t-test was used for comparison of the baseline characteristics of males and females. The internal consistency was determined using Cronbach alpha value. The test–retest reliability of the Marathi total SPADI, pain and disability subscales were assessed using intraclass correlation coefficient (ICC). The criteria validity was assessed using Pearson correlation coefficient.

Results

The sample consisted of 17 male and 14 female participants with the right shoulder being affected in 16 participants and left shoulder being affected in 15 participants. The mean age of males and females was 46.29 and 50.5 years, respectively. There was no statistical significant difference between males and females at baseline ($p > 0.05$) (Tables 1 and 2).

Table 1.

Descriptive statistics.

Gender	Male	17 (54.83%)
	Female	14 (45.16%)
Affected side	Right	16 (51.61%)
	Left	15 (48.38%)
Comorbidities	Diabetes	10 (32.25%)
	Hypertension	8 (25.80%)
	Hypertension and diabetes	5 (16.12%)

Table 2.

Patient baseline characteristics.

	Male	Female	
Characteristics	**Mean ± SD**	**Mean ± SD**	***p*-value**
Age (Years)	46.29 ± 7.47	50.5 ± 5.57	0.092
Shoulder flexion (degree)	115.64 ± 27.38	116 ± 23.10	0.96
Shoulder extension (degree)	31.76 ± 5.76	33.21 ± 3.33	0.41
Shoulder abduction (degree)	91.11 ± 19.2	93.92 ± 15.67	0.66
Shoulder internal rotation (degree)	51.23 ± 11.46	53.64 ± 13.52	0.59
Shoulder external rotation (degree)	36 ± 8.73	33.71 ± 8.95	0.47
SPADI pain score (%)	63.64 ± 14.92	65.28 ± 14.79	0.76
SPADI disability score (%)	53.48 ± 19	58.77 ± 16.10	0.42
Total SPADI score (%)	57.36 ± 17.2	61.21 ± 15.22	0.51

Reliability

The ICC values for the pain score (0.993), disability score (0.997), and total SPADI (0.997) were all high, showing excellent reliability (Table 3).

Table 3.

Reliability of Marathi language SPADI.

		95%CI[a]	
SPADI[c] scale	**ICC[b] value**	**Lower bound**	**Upper bound**
Pain score			
average measure	0.993	0.985	0.996
Disability score			
average measure	0.997	0.995	0.999
Total score			
average measure	0.997	0.994	0.999

Notes: [a]CI = Confidence Interval; [b]ICC = Intraclass Correlation Coefficient; [c]SPADI = Shoulder Pain and Disability

Internal consistency

The Cronbach alpha value for the pain score (0.908), disability score (0.959), and total SPADI (0.969) was all high. Removal of any question except questions 1, 10 and 13 would lead to lower Cronbach alpha compared to that of the total SPADI score. Removal of questions 1, 10, 13 leads to small improvement in the Cronbach alpha (Table 4).

Table 4.

Redundancy of each individual item (by computing Cronbach alpha if item was deleted).

Questions	Cronbach alpha if item deleted
Question 1	0.972
Question 2	0.965
Question 3	0.965
Question 4	0.966
Question 5	0.965
Question 6	0.965
Question 7	0.963
Question 8	0.964
Question 9	0.965
Question 10	0.973
Question 11	0.964
Question 12	0.964
Question 13	0.972

Validity

The face validity of the questionnaire was established with the original English version of the SPADI and was considered adequate for the Marathi SPADI after discussions within the expert committee, i.e., the content of the translated items was understandable and could be used in the assessment of shoulder pain and function as they depict activities of the shoulder in daily living (stage 4).

Criterion validity between the initial total SPADI score, individual pain score, and individual disability score and the baseline active range of motion of shoulder for males and females was assessed using Pearson correlation (Tables 5 and 6). For males, there was a weak to strong negative correlation between shoulder range of motion and pain score (Correlations ranged from 0.309 to

0.850) except for shoulder extension; shoulder range of motion and disability score correlation ranged from 0.474 to 0.869 except for shoulder extension, indicating weak to strong negative correlation; shoulder range of motion and total SPADI correlation scores ranged from 0.426 to 0.874) except for shoulder extension indicating weak to strong negative correlation (Table 5). For females, there was a moderate to strong negative correlation between shoulder range of motion and pain score (Correlations ranged from 0.639 to 0.770), except for shoulder internal rotation; shoulder range of motion and disability score correlation ranged from 0.611 to 0.692 except for shoulder internal rotation, indicating negative correlation; shoulder range of motion and total SPADI correlation scores ranged from 0.648 to 0.697) except for shoulder internal rotation, indicating moderate negative correlation (Table 6).

Table 5.

Relationship between SPADI scale and shoulder ROM in males.

$N = 17$	Pain score	Disability score	Total score
Shoulder flexion	−0.851**	−0.869**	−0.874**
Shoulder extension	−0.263	−0.241	−0.251
Shoulder abduction	−0.832**	−0.814**	−0.829**
Shoulder internal rotation	−0.309	−0.475	−0.426
Shoulder external rotation	−0.777**	−0.820**	−0.816**

Notes: ROM = Range of motion; SPADI = Shoulder Pain and Disability Index. **Correlation is significant at 0.01 level (2-tailed). *Correlation is significant at 0.05 level (2-tailed).

Table 6.

Relationship between SPADI scale and shoulder ROM in females.

$N = 14$	Pain score	Disability score	Total score
Shoulder flexion	−0.675**	−0.611*	−0.649*
Shoulder extension	−0.718**	−0.646*	−0.684**
Shoulder abduction	−0.770**	−0.629*	−0.697**
Shoulder internal rotation	+0.015	−0.086	−0.042
Shoulder external rotation	−0.639*	−0.693**	−0.684**

Notes: ROM = Range of motion; SPADI = Shoulder Pain and Disability Index. **Correlation is significant at 0.01 level (2-tailed). *Correlation is significant at 0.05 level (2-tailed).

Discussion

The SPADI is a self-administered questionnaire that assesses shoulder pain and dysfunction. The reliability and validity of the English language SPADI were established earlier and had enough documented evidence.[9] But patients in Maharashtra (India) experience difficulties in understanding the English version of the questionnaire due to the language barrier. Therefore, this questionnaire was administered in patients by translating questions in the local language. So, there may be some variations in administration and interpretation of this questionnaire among different researchers in the Maharashtra region. Therefore, there is a need for translation of the SPADI questionnaire in the local language — Marathi in our set up.

Most widely used language in the Maharashtra state of India is Marathi, and hence we have translated the English version of SPADI questionnaire into Marathi version for ease in administration among patients. The SPADI questionnaire was Translated and culturally adapted into Marathi language according to the guidelines of the AAOS outcome committee for cross-cultural adaptations.[15] The pre-final version of the SPADI Marathi version was administered to 31 patients with Frozen shoulder. Most of the patients understood every item from the questionnaire except the 1st and the 9th item of the questionnaire, which was then reformulated accordingly. During translation, some words in the questionnaire were adapted, keeping in mind the clothing differences of the patients in India and also according to gender. For example, "Putting on a shirt that buttons down the front" and "Putting on your pants". In Indian culture, as women mostly wear sarees with a blouse piece that hooks in the front or at the back and instead of pant they wear underskirt under sarees, so the Marathi version of the questionnaire was slightly modified accordingly.

On comparing the internal consistency of Marathi version with the original English version of SPADI (Roach KE), we observed that the Cronbach alpha values for pain subscale (0.908) were higher than the pain subscale score for English version (0.86) and the Cronbach alpha value for disability (0.959) was almost similar to disability score (0.93) of English version and the Cronbach alpha value for the total SPADI score (0.969) was also similar to that of the original English version (0.95), and also previous literature reported that the values greater than 0.7 is considered reliable having good internal consistency.[17] Therefore, the Marathi version is considered a reliable tool. These results are also comparable to the previous study of translation in another Indian language — Tamil version.[24]

Further, the reliability of the Marathi version was also analysed and the intraclass correlation coefficient (ICCs) was > 0.90 for the pain score, disability score, and total SPADI showing excellent reliability indicating that the questionnaire is suitable for individual assessment of patients.[8] These results are similar to those which were obtained when the original English version of the questionnaire was tested for reliability.[14,18,19]

Additionally, when our results of reliability were compared with the original author's study (Roach E), the reliability of the total Marathi SPADI had an ICC value (0.997), which was higher than the total English SPADI (ICC = 0.6552).[9] Comparison of the ICC values for the pain and the disability subscale score and the total Marathi SPADI score with the values obtained by testing the

questionnaires in German, Brazilian, Slovene and Greek versions showed consistent results.[20,21,22,23] Our results also demonstrated a good face and criterion validity of the Marathi version of the SPADI questionnaire analysed by calculating the correlation between the initial total SPADI score, individual pain score, individual disability score and the baseline degree of active range of motion of shoulder using Pearson correlation.

There was gender difference observed in the correlation between the initial total SPADI score, individual pain, disability score and baseline shoulder range of motion. The hypothesized mechanism behind these findings may be as the pain threshold level and pain tolerance is lower in females than in males which would affect the achieved shoulder range of motion.[25]

This study demonstrated that the Marathi version of an SPADI Questionnaire had a satisfactory test–retest reliability, internal consistency, and face and criterion validity. Therefore, it is a reliable and valid tool to record the quality of life affected due to pain and disability in the Maharashtrian population.

Study Limitation

The main limitation of our study is that the sample size was small, and factor analysis of individual items of the questionnaire was not done.

Conclusion

The results of our study concluded that the translated and culturally adapted Marathi version of the SPADI questionnaire is a reliable and valid tool for the assessment of pain and disability in Marathi population.

Conflict of Interest

The author(s) have no conflicts of interest relevant to this paper.

Funding/Support

The authors declare that there is no funding or grant support provided for this paper.

Author Contributions

All the authors contributed to the conception and design of study and approval for the submission to publication. A J Pahade & Wani S K contributed to the data analysis and interpretation. Mullerpatan R P contributed to the manuscript drafting. Roach K E contributed to the manuscript revision.

1. Van der Heijden GJ. Shoulder disorders: A state-of-the-art review. *Best Pract Res Clin Rheumatol* 1999;13:287–309. [PubMed] [Google Scholar]

2. Luime JJ, Koes BW, Hendriksen IJ, Burdorf A, Verhagen AP, Miedema HS, Verhaar JA. Prevalence and incidence of shoulder pain in the general population; a systematic review. *Scand J Rheumatol* 2004;33:73–81. [PubMed] [Google Scholar]

3. Singh S, Gill S, Mohammad F, Kumar S, Kumar D, Kumar S. Prevalence of shoulder disorders in tertiary care centre. *Int J Res Med Sci* 2015; 3:917–20. [Google Scholar]

4. Pribicevic M. The epidemiology of shoulder pain: A narrative review of the literature. InPain in Perspective 2012.

5. Boyle-Walker KL, Gabard DL, Bietsch E, Masek-VanArsdale DM, Robinson BL. A profile of patients with adhesive capsulitis. *J Hand Ther* 1997;10:222–8. [PubMed] [Google Scholar]

6. Kirkley A, Griffin S, McLintock H, Ng L. The development and evaluation of a disease-specific quality of life measurement tool for shoulder instability. *Am J Sports Med* 1998;26:764–72. [PubMed] [Google Scholar]

7. Angst F, Schwyzer HK, Aeschlimann A et al.. Measures of adult shoulder function: Disabilities of the arm, shoulder, and hand questionnaire (DASH) and its short version (Quick DASH), Shoulder Pain And Disability Index (SPADI), American Shoulder and Elbow Surgeons (ASES) Society standardized shoulder assessment form, constant (Murley) score (CS), simple shoulder test (SST), Oxford shoulder score (OSS), shoulder disability questionnaire (SDQ), and Western Ontario shoulder instability index (WOSI). *Arthritis Care Res (Hoboken)* 2011;63(Suppl 11): S174–88. [PubMed] [Google Scholar]

8. Bot SDM, Terwee C, Windt Daan der, Bouter L, Dekker J, de Vet HCW. Clinimetric evaluation of shoulder disability questionnaires: A systemic review of literature. *Ann Rheum* 2004;63:335–41. [PMC free article] [PubMed] [Google Scholar]

9. Roach KE, Budiman-Mak E, Songsiridej N, Lertrantanakul Y. Development of a shoulder and pain disability index. *Arthritis Care Res* 1991;4:143–9. [PubMed] [Google Scholar]

10. McConnell S, Beaton DE, Bombardier C. *The DASH Outcome Measure: A User's Manual.* Toronto, Ontario: Institute for Work and Health, 1999. [Google Scholar]

11. King GJ, Richards RR, Zuckerman JD, Blasier R, Dillman C, Friedman RJ et al., A standardized method for assessment of elbow function. *Am Shoulder Elbow Surg J* 1999;8:351–4. [PubMed] [Google Scholar]

12. Portney LG, Watkins MP. Validity of Instruments. *Foundation of Clinical Research: Applications to Practice.* 2nd ed. New Jersey: Prentice Hall Health, 2000. pp. 79–110. [Google Scholar]

13. Jain NB, Wilcox RB III, Katz JN, Higgins LD. Clinical examination of the rotator cuff. *PM&R* 2013;5(1):45–56. [PMC free article] [PubMed] [Google Scholar]

14. Breckenridge JD, McAuley JH. Shoulder pain and disability index (SPADI). *J Physiotherapy* 2011;57:197. [PubMed] [Google Scholar]

15. Beaton DE, Bombardier C, Guillemin F, Ferraz MB. Guidelines for the process of cross-cultural adaptation of self-report measures. *Spine* 2000;25(24):3186–91. [PubMed] [Google Scholar]

16. Norkin CC, EdD PT. *Measurement of Joint Motion a Guide to Goniometry*. 3rd ed. Philadelphia: F.A Davis Company, 2003. [Google Scholar]

17. Terwee CB, Bot SD, de Boer MR, van der Windt DA, Knol DL, Dekker J, Bouter LM, de Vet HC. Quality criteria were proposed for measurement properties of health status questionnaires. *J Clin Epidemiol* 2007;60:34–42. [PubMed] [Google Scholar]

18. MacDermid JC, Solomon P, Prkachin K. The Shoulder Pain and Disability Index demonstrates factor, construct and longitudinal validity. *BMC Musculoskel Disord* 2006;7:12. [PMC free article] [PubMed] [Google Scholar]

19. Hill CL, Lester S, Taylor AW, Shanahan ME, Gill TK. Factor structure and validity of the shoulder pain and disability index in a population-based study of people with shoulder symptoms. *BMC Musculoskel Disord* 2011;12:8. [PMC free article] [PubMed] [Google Scholar]

20. Angst F, Goldhahn J, Pap G, Mannion AF, Roach KE, Siebertz D, Drerup S, Schwyzer HK, Simmen BR. Cross-cultural adaptation, reliability and validity of the German Shoulder Pain and Disability Index (SPADI). *Rheumatology* 2007;46:87–92. [PubMed] [Google Scholar]

21. Martins J, Napoles BV, Hoffman CB, Oliveira AS. The Brazilian version of Shoulder Pain and Disability Index: translation, cultural adaptation and reliability. *Rev Bras Fisioter* 2010;14:527–36. [PubMed] [Google Scholar]

22. Jamnik H, Spevak MK. Shoulder pain and disability index: validation of Slovene version. *Int J Rehabil Res* 2008;31:337–41. [PubMed] [Google Scholar]

23. Vrouva S, Batistaki C, Koutsioumpa E, Kostopoulos D, Stamoulis E, Kostopanagiotou G. The Greek version of Shoulder Pain and Disability Index (SPADI): Translation, cultural adaptation, and validation in patients with rotator cuff tear. *J Orthopaed Traumatol* 2016;17:315–26. [PMC free article] [PubMed] [Google Scholar]

24. Jeldi AJ, Aseer AL, Dhandapani AG, Roach KE. Cross-cultural adaption, reliability and validity of an Indian (Tamil) version for the Shoulder Pain and Disability Index. *Hong Kong Physiother J* 2012;30:99–104. [Google Scholar]

25. Nascimento MG, Kosminsky M, Chi M. Gender role in pain perception and expression: An integrative review. *Br JP* 2020;3:58–62. [Google Scholar]