Critical Reviews™ in Physical & Rehabilitation Medicine, 31(1):23–34 (2019)

Influence of Varying Squat Exposure on Knee Pain and Function among People with Knee Osteoarthritis

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ABSTRACT: Knee osteoarthritis (OA) is a leading cause of pain and functional disability globally. Knowledge about the influence of high-flexion postures on knee function among people with knee OA is limited. Sustained occupational squatting is assumed to increase tibio-femoral and patella-femoral compressive force and knee osteoarthritis. Additionally, people spend varying amounts of time in deep squat for performing self-care, activities of daily living (ADL), and leisure. Hence, a study was conducted to explore the influence of varying squat exposure on knee pain and function. An interview-based survey was conducted inclusive of 300 participants, following institutional ethical approval and informed consent. Participants were classified based on daily squat exposure using a validated tool: the MGM Ground Level Activity Exposure Questionnaire. Knee pain and function were assessed using the Numeric Rating Scale and the Modified Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), respectively. Thirty-three people from the study cohort (Nonsquatters n = 13, ADL squatters n = 10, occupational squatters n = 10) were evaluated for knee motion, muscle strength, and balance using 2D motion analysis, 30-second chair-stand test, calf-raise test, 30-second deep-squat test, single-leg stance test, and star excursion test, respectively. Prevalence of knee pain was 27% in squatters and 21% in nonsquatters. People with higher squat exposure demonstrated greater knee motion, muscle strength, and balance compared with nonsquatters. Occupational squatters continued to work on a higher level of function despite pain and difficulty. Deep-squat activity performed in moderation is a potentially beneficial activity to maintain knee range, muscle strength, and balance.

KEYWORDS: knee pain, osteoarthritis, occupational knee pain, sustained knee posture, high-flexion posture, squat

ABBREVIATIONS: OA, osteoarthritis; **KCF**, knee contact force; **ADL**, activities of daily living; **IPAQ**, International Physical Activity Questionnaire; **WOMAC**, Western Ontario and McMaster Universities Osteoarthritis Index; **BMI**, body mass index

I. INTRODUCTION

Knee osteoarthritis, a highly prevalent musculoskeletal disorder, leads to pain and loss of function.[1,2] Prevalence of knee osteoarthritis (OA) varies from 2.6% to 10.5% globally.[3–6] Risk factors associated with development of OA include advancing age, female gender, high BMI, involvement in high levels of physical activity, and occupations involving sustained high-flexion postures like squatting or kneeling for more than 30 minutes for 2 hours daily.[7]

Extensive literature is available on the influence of factors associated with development and progression of knee OA. Nonmodifiable risk factor such as increase in age after 50 years, increases the likelihood of developing knee OA.[8,9] Females are predisposed to higher prevalence and severity of OA. Loss of the protective effect of estrogen following menopause increases sensitivity to pain.[10] Overweight contributes to progression of cartilage degeneration due to high compressive stresses placed on the medial compartment of the knee.[11] Injury to the knee is known to accelerate biochemical changes in the articular cartilage with progressive loss of proteoglycans, and exposure of subchondral bone contributes to loss of cartilage volume and symptoms of knee OA.

Heavy physical occupational load is considered a major risk factor for development of knee OA.[12] Biomechanical risk factors like lifting weight, jumping, exposure to vibrations, standing for prolonged duration, frequent exposure to activities involving bending of the knee in kneeling, crawling, and squatting also predispose toward OA.[13] Occupational exposure to high knee flexion in carpet layers, tile layers, and compositors reveal increased risk of knee OA in workers above 50 years of age.[14] Although the risk of developing OA increases with excessive engagement in high-flexion occupational activity, there is little or no information available on individuals having high squat exposure for activities other than occupational. Across continents, particularly south Asia and Africa, people adopt squat postures for self-care activities such as toileting, bathing, and eating. Squat is used while performing household chores such as washing clothes and utensils, sweeping and mopping floors, cooking, leisure activities, and sports. Occupational squatting is observed in farmers, carpet layers, plumbers, painters, fish and vegetable vendors, house maids, and manual laborers. One study from China, where people squat habitually for activities of daily living (ADL), reported increased prevalence and risk of tibio-femoral OA with increasing squat exposure from 30 minutes to more than 120 minutes.[15]

Although the etiology of knee OA is still not completely understood, biomechanical factors are known to exert substantial influence. Knee loading on the medial compartment is considered a biomarker for OA onset and progression. Biomechanical loading on the knee joint during walking is estimated to exceed 2–3 times body weight. Patients with established knee OA demonstrate significantly greater total knee contact force (KCF) during standing, stair- ascent and high-flexion activities.[16–19] Knee contact force is estimated to be three times body during deep squat. However, the effect of thigh-calf contact of approximately 34% at knee flexion angles of 150 during deep squats and soft-tissue adaptation leading to enhanced load distribution and force transfer, remains unaccounted for.[20]

Although high-flexion activities like squat exert high joint loading; they confer benefits of maintaining joint mobility and strength. Squat recruits multiple muscles of the lower extremity and trunk, thereby increasing muscle strength known to influence bone density.[21]Additionally, being a weight-bearing activity, squats place a natural weight-bearing stimulus on lower-extremity bones and the spine. Increased exposure and mechanical influences lead to adaptations in intra-articular structures such as menisci and cartilage and extra-articular soft tissues—namely, muscles and bones. [22]

Changing life styles and mechanization have resulted in waning engagement in activities demanding adoption of high-flexion postures for ADL, self-care, and leisure activities.[7,23,24] Lack of clarity regarding the quantum of squat exposure required to maintain beneficial effects on knee joints has led to the current study, which explores the influence of varying squat exposure on knee pain and function among nonsquatters and ADL and occupational squatters.

II. MATERIALS AND METHODS

This descriptive cross-sectional study was approved by the Institutional Review Board of Mahatma Gandhi Mission Institute of Health Sciences, Navi Mumbai. Three hundred adults (160 females, mean age 48.8 ± 8.0 years; 140 males, mean age 54.6 ± 9.5 years) were recruited for a survey from rural and urban areas near Mumbai and Navi Mumbai, Maharashtra. Written informed consent as per the Declaration of Helsinki was sought from all participants. People with major surgeries; acute infections of hip, knee, and spine; congenital disorders of lower limbs or spine; lower-limb amputations; and cognitive issues were excluded from the study. Demographic and anthropometric data were recorded and survey questionnaires were administered by two field administrators. Socioeconomic status was assessed using the Modified Kuppuswamy Scale 2017.[25] Magnitude of knee pain was assessed using the Numeric Rating Scale (NRS), where 0 represents no pain and 10 represents the worst pain imaginable.[26] Severity of pain, stiffness, and functional performance was assessed using the Modified Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).[27] The MGM Ground Level Activities Questionnaire, a validated and reliable tool, was used to quantify exposure to various ground-level activities (Cronbach's alpha for reliability: 0.89).[28] Subjects were categorized based on daily squat exposure into three groups: nonsquatters (no squats for any ADL, $n = 139$), ADL squatters (squats for self-care, household chores, and leisure activities, $n = 75$), and occupational squatters(more than 60 minutes per day in squats for occupation-related activity, $n = 86$). The International Physical Activity Questionnaire (IPAQ) Short Version was used to assess levels of habitual physical activity in low, moderate, and vigorous categories.[29]

Further, knee function in 33 subjects with knee pain from the survey cohort (nonsquatters $n = 13$, ADL squatters $n = 10$, occupational squatters $n = 10$), was evaluated clinically, at the MGM Physiotherapy Outpatient Department. Knee range of motion was evaluated using 2D motion capture. Markers were placed over the greater trochanter, the lateral joint line of the knee, and the lateral malleolus to enable computation of knee flexion angle. Prone knee bend was videorecorded using a camera placed laterally at pelvic level for capturing sagittal knee movement. Videos were imported into Kinovea software version 0.8.15 (https://www.kinovea.org/), a freely downloadable program for capturing and measuring human motion.[30,31]

Muscle strength/endurance was evaluated using the 30-second chair-stand test, the calf-raise test, and the 30-second deep-squat test; balance was evaluated using the star excursion test following standard reported methods.[32–35]

III. STATISTICAL ANALYSIS

Data analysis was carried out using IBM SPSS version 24.0. Measures of central tendency, including mean and standard deviation, were calculated. Comparison of the three occupational groups was carried out using one-way ANOVA and post hoc analysis, with statistical significance set at $p \leq 0.05$. Most outcome variables did not fulfil the requirement of normality, so nonparametric tests were used for inferential analysis. Spearman's rho correlation coefficient was used to measure association between squat exposure time and outcome measures of functional test.

IV. RESULTS

The body mass of nonsquatters was higher than that of ADL and occupational squatters. Scores on the Kuppuswamy scale were significantly lower for occupational squatters, with the maximum number of subjects (68%) belonging to the upper-lower class (Modified Kuppuswamy score 5–10) whereas nonsquatters and ADL squatters belonged to the upper (Modified Kuppuswamy score 26–29) and upper-middle classes (Modified Kuppuswamy score 16–25).

Daily, recent and previous squat exposure was highest in occupational squatters, followed by ADL squatters while nonsquatters had no daily and recent squat exposure. However, nonsquatters reported previous squat exposure, indicating that they had given up performing ADL in squat in recent times. Demographic characteristics of the three groups are presented in Table 1.

Out of 300 participants, 75 were classified as knee OA on basis of American College of Rheumatology clinical criteria.[36]Thirty-one people reporting knee pain were nonsquatters, 21 were ADL squatters and 23 were occupational squatters. Prevalence of knee pain was 22% in nonsquatters (31/139), 27% in ADL squatters (21/76), and 27% in occupational squatters (23/85). The Odds ratio for knee pain in the three groups was 1.00, 1.00, and 1.003, respectively, indicating similar risk of developing knee pain in all groups.

The WOMAC score, reflecting difficulty in performing functions, was highest in occupational squatters followed by ADL squatters and was lowest in nonsquatters ($p <$ 0.001). Similarly, score on Numeric Rating Scale was highest in occupational squatters and lowest in nonsquatters. Habitual physical activity was highest in occupational squatters (2348.4 ± 2090.8 MET minutes/week) whereas nonsquatters reported lowest amount of physical activity (576.3 ± 3029.1 MET minutes/week) ($p < 0.001$). High standard deviation in IPAQ scores indicates large variability in physical activity profiles. Table 2 outlines knee pain and function in the OA cohort.

Daily squat exposure demonstrated mild positive correlation with WOMAC and Numeric Rating Scale scores (Spearman's rho 0.413 and 0.300, respectively).Moderate positive correlation was observed between daily squat exposure and IPAQ score (Spearman's rho 0.604).

Of the 75 subjects presenting with clinical signs of knee OA, 33 who could visit the Physiotherapy Outpatient Department of MGM Hospital were evaluated clinically for functional performance. They were considered representative of the knee OA cohort.

TABLE 1: Demographic characteristics, squat exposure, and physical activity of study population (n = 300) with varying squat exposure

Variable	**Nonsquatters (n = 139) mean (SD)**	**ADL squatters (n = 76) mean (SD)**	**Occupational squatters (n = 85) mean (SD)**	***p* value (one-way ANOVA)**
Age (years)	51.5 (9.4)	49.0 (8.8)	53.5 (8.8)	—
Height (cm)	165.0 (9.1)	160.0 (6.7)	160.3 (8.4)	—
Weight (kg)	65.7 (10.1)	64.0 (9.4)	60.1 (10.1)	< 0.001*
BMI (kg/m^2)	24.3 (3.9)	25.4 (3.8)	24.8 (16.0)	0.698
Kuppuswamy total score	25.5 (3.7)	21.5 (5.7)	8.9 (3.8)	< 0.001*
Daily squat exposure (min/day)	0.0	47.5 (79.2)	304.8 (122.8)	< 0.001*
Recent squat exposure (h/year)	0.0	265.5 (614.9)	2340.5 (3766.3)	< 0.001*
Previous squat exposure (h)	45.3 (534.3	3237.9 (614.9)	166270.1 (742929.4)	0.005*
IPAQ walking MET (min/week)	271.88 (321.6)	511.95 (896.4)	1172.34 (1040.1)	< 0.001*
IPAQ moderate MET (min/week)	284.89 (2916.5)	1200.41 (4141.6)	1072.21 (1062.6)	0.044*
IPAQ vigorous MET (min/week)	18.83 (92)	104.83 (406.7)	102.05 (156.6)	0.007*
Total IPAQ MET (min/week)	576.3 (3029.1)	1815.74 (4378.9)	2348.44 (2090.8)	< 0.001*

*Level of significance: ≤ 0.05

TABLE 2: Knee pain and function in subjects with knee OA

Variable	Nonsquatters (*n* = 31/139) mean (SD)	ADL squatters (*n* = 21/76) mean (SD)	Occupational squatters (*n* = 23/85) mean (SD)	*p* value (one-way ANOVA)
WOMAC pain	2.35 (3.5)	5.67 (4.3)	5.14 (3.7)	< 0.001*
WOMAC stiffness	0.87 (1.5)	1.8 (1.7)	2.31 (1.8)	< 0.001*
WOMAC difficulty	7.27 (10.5)	20.22 (15.3)	21.79 (15.1)	< 0.001*
WOMAC optional	0.0	0.12 (1.0)	0.32 (1.5)	.051
WOMAC total	10.3 (15.0)	27.2 (20.9)	29.6 (20.7)	< 0.001*
NRS score on activity right	1.01 (2.1)	1.89 (2.7)	3.04 (2.9)	< 0.001*
NRS score on activity left	1.1 (2.1)	3.1 (2.8)	1.5 (2.1)	< 0.001*

*Level of significance: $p \leq 0.05$

Knee range of motion (ROM) was the highest in occupational squatters (124.1 degrees) and lowest in nonsquatters (111.1 degrees). Muscle strength/endurance was 126% higher in occupational squatters compared with nonsquatters, with more repetitions performed during the 30-second deep-squat test ($p < 0.05$). The 30-second chair-stand test showed a nonsignificant difference of 13% in repetitions, which may indicate the 30-second deep-squat test's greater sensitivity to the reduced lower-limb muscle endurance unidentified by the 30-second chair-stand test. Although higher NRS scores were elicited on the deep-squat test compared with the chair-stand test, no participant reported long-lasting discomfort after either. Balance in postero-medial and postero-lateral directions was significantly better in occupational squatters. Table 3 outlines knee ROM, muscle strength, and balance in subjects diagnosed with knee OA.

Weak to moderate negative correlations were observed between deep-squat exposure time and the 30-second chair-stand test (rho −0.36, $p < 0.05$), the 30-second deep-squat test (rho − 0.41, $p < 0.05$), and the star excursion balance test (rho −0.44, $p < 0.01$), which may indicate that increasing sustained occupational exposure adversely affects functional performance.

V. DISCUSSION

This study explored the influence of squat exposure on knee pain and function. The prevalence of knee pain was similar in squatters (27%) and nonsquatters (22%) (Table 2). Functional impairment varied with squat exposure. Although subjects with high squat exposure reported greater difficulty in walking, stair climbing, ascending and descending to deep squat, prolonged standing, and rising from a sitting position, as revealed by the WOMAC scores, they presented with greater knee joint motion, muscle strength/endurance, and balance.

TABLE 3: Knee ROM, muscle strength, and balance in 33 subjects with knee OA

Variable	**Nonsquatters (*n* = 13) Mean (SD)**	**ADL squatters (*n* = 10) Mean (SD)**	**Occupational squatters (*n* = 10) Mean (SD)**	***p* value (one-way ANOVA)**
Age (years)	57.4 (7.4)	55.5 (10.40)	57.8 (8.0)	0.810
Height (cm)	161.2 (10.0)	158.4 (8.2)	160.6 (6.4)	0.723
Weight (kg)	70.8 (14.70	62.7 (11.9)	65.6 (13.7)	0.329
BMI (kg/m^2)	27.3 (5.8)	24.9 (4.3)	25.3 (4.4)	0.485
Kuppuswamy score	22.3 (6.7)	19.7 (8.2)	13.5 (6.2)	0.019*
Daily squat exposure (minutes)	0	10.7 (11.8)	164.7 (52.3)	< 0.00*
Modified WOMAC total score	27.6 (16.8)	41.3 (10.4)	45.5 (8.3)	0.006*
NRS on activity				
Right	1.7 (2.2)	3.1 (3.40	2.8 (3.2)	0.530
Left	3.5 (2.8)	2.4 (2.4)	4.8 (2.8)	0.183
Knee flexion (°)				
Right	112.6 (8.5)	123.1 (11.1)	124.1 (9.7)	0.065
Left	111.1 (8.6)	121.3 (9.7)	124.1 (9.7)	0.004*
30-s chair-stand test				
Repetitions	9.3 (2.0)	8.5 (0.97)	10.6 (2.4)	0.066
NRS score	2.4 (2.1)	2.5 (1.3)	2.6 (1.7)	0.983
30-s deep-squat test				
Repetitions	1.9 (0.9)	2.9 (1.6)	4.3 (2.2)	0.007*
NRS score	7.2 (1.1)	6.4 (1.0)	6.8 (1.0)	0.178
Star excursion balance test anterior (cm)				
Right	60.6 (10.7)	76.9 (22.1)	74.4 (8.1)	0.325
Left	63.3 (12.2)	68.8(17.9)	76.4 (10.4)	0.096
Posteromedial (cm)				
Right	52.6 (12.3)	59.5 (14.3)	69.6 (7.1)	0.007*
Left	54.8 (12.5)	61.5 (16.6)	69.9 (9.1)	0.034*
Posterolateral (cm)				
Right	60.3 (12.4)	68.5 (14.4)	80.2 (5.3)	0.001*
Left	64.0 (13.1)	69.0 (15.9)	80.0(10.7)	0.026*

The following paragraphs discuss factors that influence knee pain and function in addition to varying squat exposure.

The body mass of nonsquatters was greater than that of ADL and occupational squatters. Sedentary life style and low engagement in physical activity may contribute to higher body mass in nonsquatters most of whom in the study cohort (62%) were engaged in desk jobs involving prolonged sitting. Previous studies reported lower hazard ratios (HR 0.63, 95% CI 0.48 ± 0.83) for people spending more than seven hours sitting at work due to unloading of the knee in a sitting position.[36] However, prolonged sitting, added to a sedentary lifestyle, may lead to increased BMI, eventually predisposing to knee pain.[37]

As per socioeconomic status, nonsquatters were predominantly from class 1 (upper), ADL squatters were from classes 1 and 2 (upper-middle), and occupational squatters were from class 4 (lower). Nonsquatters were engaged in white-collar jobs, whereas occupational squatters were involved in lower-skilled jobs and manual labor.[38] The low monthly family income of occupational squatters may influence nutritional status, health status awareness, access to healthcare facilities, and coping stretegies. Occupational squatters cope with pain and continue to perform at the higher levels of physical activity demanded by their occupation, despite pain and difficulty, because they cannot do without their daily wages. Moreover, they do not discontinue or modify any activities of daily living despite knee pain.

A sustained squat posture adopted for occupation places unique biomechanical demands on the body. Prolonged squatting leads to sustained static/dynamic loading on the knee articular cartilage. Static loading decreases diffusivity with increasing articular cartilage compression and results in focal defects of articular cartilage in people with knee OA.[12,39] Conversely, dynamic loading is reported to increase diffusivity and enhance transport of large solutes in articular cartilage, thus enhancing nutrition. A judicious balance of weight-bearing stimulus and physical activity may determine joint loading and emergence of symptoms of cartilage degeneration.

Nonsquatters reported lower scores on the WOMAC and the NRS compared with ADL and occupational squatters. Lower engagement in physical activity and subsequent evocation of pain due to joint loading may elicit lower NRS scores on activity and lower WOMAC scores for pain, stiffness, and difficulty in functioning. Sustained occupational squatting is assumed to increases tibio-femoral and patella-femoral compressive forces when the knee is flexed to approximately 150 degrees.[18] Although increased compressive forces associated with increased squat depth neutralizes shear forces, excessive and sustained compression may lead to breakdown of articular cartilage due to reduced nutrition transport to the cartilage in this position. Occupational squatters engage in long-duration deep squats in their occupational activities as well as in their ADL and leisure activities.

Functional evaluation revealed greater knee mobility, lower-limb muscle strength/endurance, and balance in people with high squat exposure despite pain. Deep squats demand complete range of motion at the knee. Engaging in them may prevent loss of terminal knee flexion observed in knee OA. Loss of terminal knee extension ROM impacts the loading mechanics of the knee during standing and walking.[40,41] Engagement in a minimum 10 minutes of squat activity has been associated with an increase in knee ROM of 10 degrees in ADL squatters compared with nonsquatters. No observable difference was noted in knee ROM between ADL and occupational squatters, suggesting that short-duration deep-squat activity of 10.7 ± 11.8 min is adequate to maintain knee ROM. Engaging in regular deep-squat activity may provide the necessary stimulus for maintaining the soft-tissue length of knee joint structures required to perform high-flexion activities.

Occupational squatters demonstrated greater muscle strength/endurance with more repetitions in the 30-second chair-stand and 30-second deep-squat tests. Deep squats are known to strengthen hip and knee musculature.[42] Moreover, they activate quadriceps, hamstring, and gastrocnemius muscles.[43,44] People with knee pain exhibit reduced quadriceps activation.[45] Autogenic inhibition of muscles along with reduction in overall physical activity may further induce muscle weakness.[46,47] Deep squats can be a potential strengthening exercise for people with knee pain to bring about activation of knee and hip muscles.

Standing balance was observed to be better in people with greater deep-squat exposure. Decreased proprioceptive awareness in the lower extremities leads to postural instability; deficits in balance control and in the placement of lower extremities during walking, stair climbing, and other physical activities adversely affect function and quality of life in people with knee OA. Impaired balance is associated with increased risk of fall and decreased mobility.[48]

VI. CONCLUSION

In this study, squatters presented with similar prevalence of knee pain in comparison with nonsquatters. Occupational squatters must meet greater physical demands of occupation despite pain and difficulty. People with higher squat exposure demonstrated greater knee ROM, muscle strength/endurance, and balance compared with nonsquatters. A minimal exposure of 10 minutes/day in ADL squatters was shown to be adequate to maintain knee ROM and provide better balance. Deep-squat activity performed in moderation may be beneficial in maintaining knee range, muscle strength, and balance.

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APPENDIX

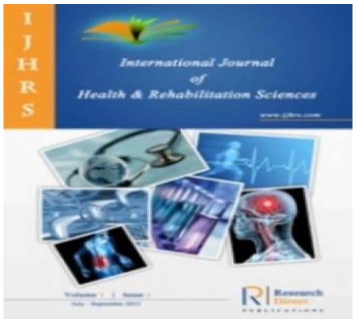
The Modified Kuppuswamy scale measures socioeconomic status based on education and profession of head of household and total per capita family income per month [see Tabassum N, Lakshman Rao RL. An updated Kuppuswamy's socio-economic classification for 2017. Int J Health Sci Res. 2017;7(5):365–367; also see Sharma R. Indian pediatrics. Available from: https://www.indianpediatrics.net/oct2017/oct-867-870.htm].

The Numeric Rating Scale is a unidimensional measure of pain intensity in adults on a scale of 0 to 10 where 0 represents no pain and 10 represents the worst pain imaginable. It can be used as a semiquantitative measure of pain in all types of musculoskeletal, neurological, and postsurgical disorders in both children and adults [see Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. J Clin Nurs. 2005;14(7):798–804; also see 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].

The MGM Ground Level Activities Questionnaire is a validated and reliable tool, developed by researchers at the MGM Institute of Health Sciences, Navi Mumbai, India. It was designed to quantify exposure to various ground-level activities using high-flexion postures such as squat, cross-leg sit, kneel, and combinations. It provides daily recent exposure in the past year and previous exposure throughout the life span (see Agarwal B, Mullerpatan R. MGM Ground Level Activities Questionnaire© 2018. Available by request).

The International Physical Activity Questionnaire (IPAQ) Short Version provides information regarding health-related physical activity classified as vigorous, moderate, walking, sitting [see 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; also see https://snaped.fns.usda.gov/library/.../international-physical-activity-questionnaire-ipa.

ORIGINAL RESEARCH



Influence of habitual deep squatting on kinematics of lower extremity, pelvis and trunk

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DOI: 10.5455/ijhrs.0000000139

ABSTRACT

Background: Deep squatting is traditionally adopted for self-care, activities of daily living (ADL), leisure and occupation in India and other parts of the world. However western life style is gradually replacing squatting with sitting postures. Given the fact that there is now huge variation in the use of deep squatting in people's daily lives in India.

Purpose: The aim of this study is to explore differences in adaptations in lower limb kinematics among people with varying levels of exposure to deep squatting.

Method and Materials: Kinematic analysis of deep squat was performed in 8 adults 30-45yr of age who don't squat daily(non-squatters), 10 adults who squat on a daily basis(ADL-squatters) and 8 adults who use squatting very regularly for long durations of time (occupational-squatters). Five trials of deep squat were captured using. Vicon Nexus software at 100 Hz. Full body plug-in-gait model was used with 4 additional markers on left-right iliac crests and medial femoral-condyle to allow for reconstruction of marker trajectories lost during parts of the movement

Results: BMI was used as a covariate to account for differences in the lifestyle characteristics. There were significant differences between groups in maximum knee flexion (p<0.05). Occupational-squatters had greatest knee flexion followed by ADL-squatters and least knee flexion was seen in non-squatters'.

Conclusion: Longer squat exposure appears to influence maximum knee flexion during deep squat which may be indicative of soft tissue adaptation at the knee. Reduction in joint range of motion if not used during habitual activities indicates specific adaptation of the body to the daily stresses it is exposed to.

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Key Words: biomechanics; motion analysis; deep squatting

INTRODUCTION

Deep squatting, is an exercise activity that uses the persons own body weight and gravity to strengthen muscles, train balance, exert load bearing stimulus and evoke full flexion at hip, knee and ankle joints[1,2,3]. In many parts of the globe particularly in south-east Asian and African countries, deep squatting is habitually adopted for self-care activities, activities of daily living (ADL), occupational and leisure tasks[4,5,6]. It has been proposed that there is a potentially protective effect of deep squat against development of knee arthritis in Asians and Indians who adopt these postures as a part of their cultural practices[7].

However, modernization of life style across the world has influenced Asian and African continents resulting in reduction in traditional ground level activities in these countries. In India, there is now a large variation in the use of squatting; on the one hand people have given up squatting completely while on other hand people spend long hours squatting for activities of daily living and occupational activities[7]. However, between the two ends of the spectrum lies a large portion of population that squats for moderate duration to perform self-care activities like toileting and household chores.

Although, abundant literature is available on kinematics and kinetics of partial squat[8, 9, 10, 11] deep squat has been studied predominantly as a sport activity and as a posture adopted while performing occupational activities. While partial squat and deep squat have been attributed to offer beneficial effects to musculoskeletal structures around the knee[1,9-14], squatting for prolonged duration of time has also been propounded as a risk factor predisposing towards osteoarthritis (OA) of knee[15-19]. Currently, there is no consensus on how varying squatting exposure affects the knee joint. Literature search reveals that knee kinematics during squat are affected by increasing age[20,21]. They are reported to vary between male/female genders[22,23] and with varus/valgus foot position and depth of squat[24]. However, the effect of varying duration of squatting exposure on joint kinematics remain unexplored.

Currently lifestyle modification for people with knee dysfunction includes recommendation to forgo high flexion activities like squatting[25-28] although these activities are an integral component of ADL[7]. Therefore understanding the kinematic demands of ankle, knee, hip and trunk in people with varying squat exposure is justified.

Hence the current study was undertaken to explore the hypothesis that high daily exposure to deep squatting influences kinematics of lower extremity, spine, and trunk.

Method and Materials

Subjects characteristics and general experimental design

Study subjects

Ethical approval was sought from Ethical Committee for Research on Human Subjects, MGM Institute of Health Sciences. A consecutive consenting sample of 28 healthy adults (30-50 years) was recruited for the study following informed consent as per Declaration of Helsinki guidelines. Participants were screened for presence of musculoskeletal conditions like back pain, pain in joints of lower extremity due to degenerative or autoimmune disorders, bony or soft tissue injury, previous surgery, developmental disorders, neurological conditions, cardiopulmonary conditions and cognitive issues prior to recruitment. Participants were grouped on the basis of daily squat exposure. People who did not have any daily squatting exposure in the past year were grouped as non-squatters. People who adopted deep squat for self-care and ADL like washing clothes, cooking, mopping, sweeping and leisure activities were grouped as ADL squatters while occupational squatter group included people who adopted deep squat daily when performing occupational activity (laborers, house maids and gardeners).

Daily Squat exposure was quantified using a validated MGM Ground Level Activity Exposure Questionnaire-interview based (MGMGLAE; Cronbach alpha for reliability 0.89). Squatting exposure was categorized into self-care, instrumental activities of daily living and occupational, sport and leisure activities. Self-care was further sub divided into squatting for toileting, bathing and eating, instrumental activities of daily living (IADL) category was sub divided into washing clothes, cleaning utensils, sweeping, mopping, and cooking. Self-reported time spent in squat on a daily basis for the above activities was recorded. Exposure duration to squatting for occupation, sport and leisure activities was also noted. Daily exposure in each category was summated to quantify total daily squat exposure (Refer Table 1, 2).

Demographic details such as age, height, weight, body mass index (BMI) were noted. Participants were scored on modified Kuppuswamy Socioeconomic Status Scale applicable to the Mumbai population which ranked and classified them on an ordinal scale into upper, middle–upper, middle, lower-upper and lower class on the basis of monthly family income, educational qualification and occupation[29].

3D movement analysis of deep squat was performed at MGM Center 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. Forty two retro reflective spherical markers were applied to anatomical landmarks using plug-in-gait full body marker set with four additional markers at right-left/bilateral iliac crest and medial femoral condyles in order to aid reconstruction of body segments[30]. 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 captured and was used to align joint axis. This was followed by six dynamic deep squat trials. Data were filtered with a Butterworth filter at a cut off frequency of 6 Hz for marker trajectories and 10Hz for analog data.

Participants were instructed to descend into deep squat keeping hands forward throughout the trial to prevent loss of markers. Deep squat was sustained for 10 seconds followed by ascend to standing position. No instruction regarding foot placement was provided except to place one foot on each force plate in an attempt to obtain a natural squat performance.

The trials were processed within Vicon Nexus 2.5. Gaps in marker trajectories were filled using standard gap filling techniques. ASIS marker trajectory interrupted during deep squat was filled using the rigid body technique in Vicon Nexus with use of the additional iliac crest markers. Outcome variables computed were joint angles at hip, knee, ankle, pelvic tilt and thorax inclination. All joint positions were reported at peak knee flexion.

Statistical Analysis

Data were analyzed using SPSS version 24(SPSS IBM, New York, USA). Normality of distribution was ascertained, measures of central tendency and dispersion were calculated and reported as means and standard deviation. Comparison for symmetry of motion between sides was performed using paired t test. Comparison among groups for squat exposure and joint angles was performed using a one way ANCOVA with BMI as covariate and post-hoc contrasts using Bonferroni adjustment. Level of significance was considered at $p<0.05$ for the ANOVA and $p<0.025$ for the contrasts. Associations between joint angles, BMI and Kuppuswamy score were analyzed using Pearson's /Spearman's correlation coefficient as appropriate.

RESULTS

Demographic characteristics, daily deep squat exposure and joint angles of non-squatters, ADL squatters and occupational squatters are presented in Table 1,2&3, Figure1-3.

Body mass index was significantly different among the three groups (P =.024) with occupational squatters having lowest BMI 20.3

(4.4) $kg.m^{-2}$ and non-squatters having the highest 25.9 (3.1) $kg.m^{-2}$. Among non-squatters, 50% people were overweight and 50% were obese. 70% of ADL squatters had a BMI within normal range, 20% were overweight and 10% were obese. Occupational squatters had the least BMI with 37% of people having below normal BMI, 50% having normal category and 13% were obese.

Total daily squatting exposure was nil in non-squatters while ADL squatters had a total daily squatting exposure of 41.0 (22.5) min/day spent for self care and IADL living like washing clothes, sweeping, mopping, cooking and other household chores. Occupational squatters had a total daily squat exposure of 229.37 (67.1) min/day. These differences were found to be statistically significant ($P < .001$). The high cumulative score in occupational squatters was divided between 147.5 (54.4) min/day in deep squat for occupational activity and 81.8 (19.9) min/day for self-care, IADL and leisure activity.

All occupational squatters were categorized as upper-lower socioeconomic class, 60% ADL squatters were people from upper class and 40% were from upper middle class. All non-squatters were categorized as upper class as defined by the Kuppuswamy Socioeconomic Status Scale.

Deep squat symmetry was analyzed by comparing left and right joint angles. With the exception of asymmetry in hip rotation in non-squatters (Right $_{\text{Hip Internal Rotation}}$ 19.2 (13.7^0) and Left $_{\text{Hip Internal Rotation}}$ 46.5 (20.6^0), Left >Right by 142 %), hip, knee and ankle joint angles were symmetrical on both sides in occupational squatters, ADL squatters and non-squatters. Hence, only data from right ankle, knee, and hip joint were considered for further analysis.

Ankle dorsiflexion motion during deep squat was largest in ADL squatters 45.2 (6.2^0), followed by occupational squatters 41.7 (7.7^0) and least in non-squatters 31.6 (30.5^0). However the difference was not statistically significant (P = .277). It was also observed that 40% of non-squatters could not perform a foot flat deep squat and a high standard deviation was seen in ankle dorsiflexion angle (Refer Table3, Figure1).

With respect to knee sagittal plane motion, a statistically significant difference was observed in maximum knee flexion during deep squat among the three groups even after adjusting BMI as a covariate ($P < .05$). Occupational squatters had the greatest knee flexion angle 164.6 (4.5^0) followed by ADL squatters 158.1 (4.7^0) and lowest knee flexion was seen in non-squatters 155 (7.3^0).With respect to coupled motion, knee

Table 1: Demographic characteristics of non-squatters, ADL squatters and occupational squatters

Variable	Non Squatters n=8 mean(SD)	ADL Squatters n=10 mean(SD)	Occupational Squatters n=8 mean(SD)	*P*-value
Age yrs	35.6 (4.6)	34.2 (4.1)	39.8 (5.7)	.057
Height m	1.58 (0.11)	1.62 (0.12)	1.54 (0.10)	.331
Mass kg	64.8 (7.7)	57.9 (16.9)	49.0 (13.9)	.086
BMI kg/m^2	25.9 (3.1)	21.7 (4.2)	20.3 (4.4)	.024*
Total Squat exposure min	0.0	41.0 (22.5)	229.3 (67.1)	<.001*
Kuppuswamy Scale Score	29.1 (9.5)	20.4 (12.5)	7.25 (1.0)	<.001*

Table 2: Daily squat exposure of non-squatters, ADL squatters and occupational squatters

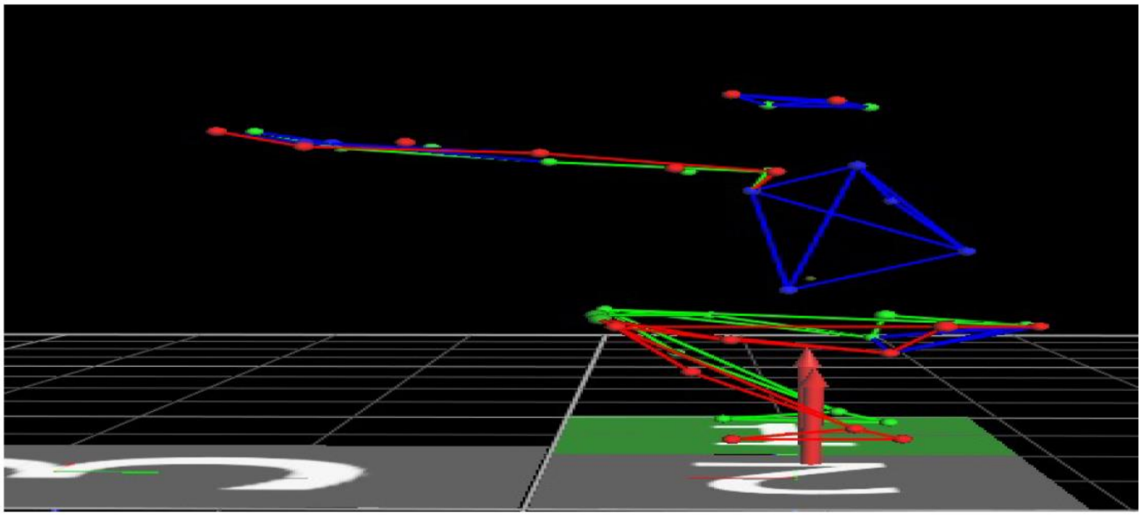
Squat exposure categories	Non Squatters min/day mean(SD)	ADL Squatters min/day mean(SD)	Occupational Squatters min/day mean(SD)	p value using one way ANOVA
Self care	0	12.5 (3.5)	14.3 (7.2)	<.001
Instrumental Activities of Daily Living	0	21.0 (14.4)	28.7 (13.5)	<.001
Occupation	0	0	147.5 (54.4)	<.001
Leisure	0	7.5 (12.7)	38.7 (13.5)	<.001
Total squat exposure	0	41.0 (22.58)	229.3 (67.1)	<.001

* Level of significance at $p \leq 0.05$

Table 3: Kinematics during deep squat in non-squatters, ADL squatters and occupational squatters at peak knee flexion

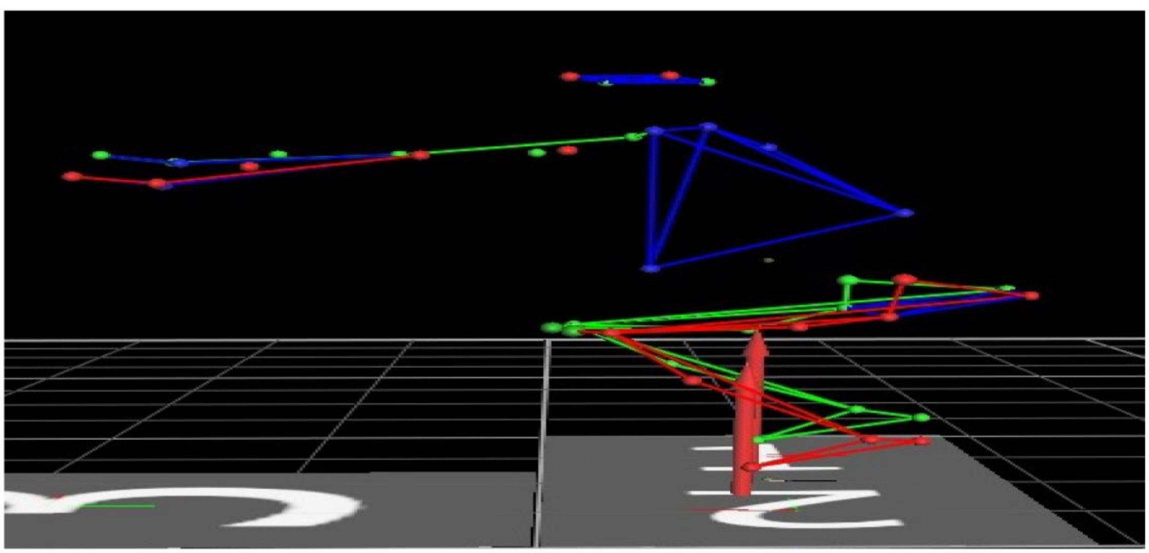
Variable	Non Squatters n=8 mean(SD)	ADL Squatters n=10 mean(SD)	Occupational Squatters n=8 mean(SD)	*P*-value
Thorax ^{0}	29.1 (19.6)	22.4 (8.4)	22.7 (5.5)	.485
Ant Pelvic tilt ^{0}	4.9 (26.0)	-9.3 (21.7)	-12.4 (18.5)	.266
Hip Flexion ^{0}	111.0 (13.0)	106.3 (19.5)	108.7 (18.7)	.856
Hip Abd^0	13.2 (4.6)	13.9 (8.6)	16.7 (9.1)	.707
Hip IR ^{0} R L	19.2 (13.7) 46.5 (20.6)	18.1 (16.7) 33.7 (11.3)	31.9 (24.5) 30.4 (19.0)	NS .017* ADLS .092 OS .779
Knee Flexion^0	155.0 (7.3))	158.1 (4.7)	164.6 (4.5)	.008*
Knee Adduction^0	12.6 (16.3)	1.5 (10.9)	4.6 (10.2)	.190
Knee Internal Rotation^0	35.5 (15.5)	33.6 (18.5)	37.8 (19.0)	.887
Ankle Dorsiflexion^0	31.6 (30.5)	45.2 (6.2)	41.7 (7.7)	.227

* Level of significance at $p \leq 0.05$

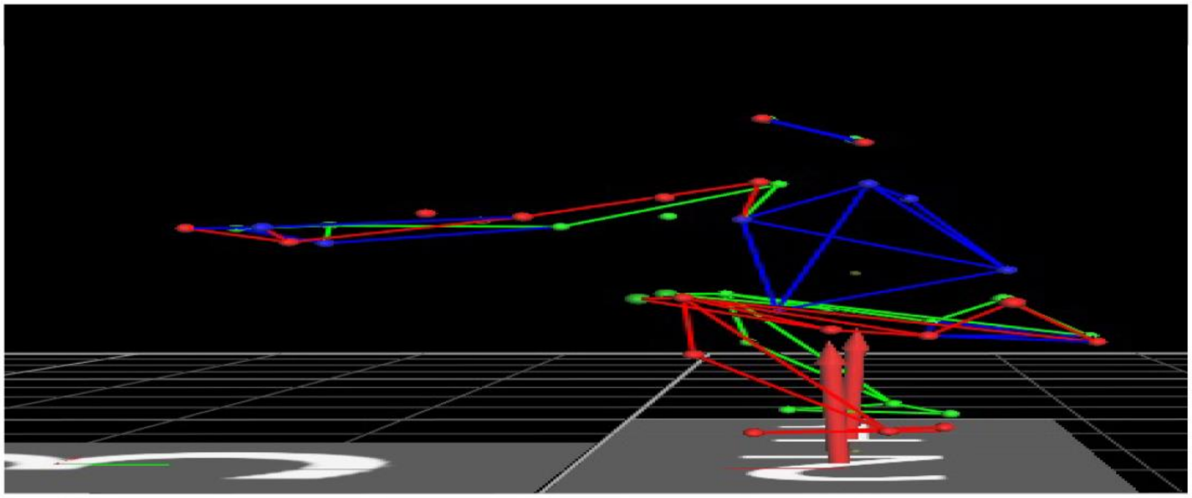


ADL Squatter

Figure 1: Deep squat position adopted by non-squatters, ADL squatters and occupational squatters



Non Squatter



Occupational Squatter

Discussion

The objective of the study was to explore the influence of varying duration of daily squatting exposure on kinematics of the lower extremity, spine and pelvis during deep squat. It was observed that daily squat exposure had a significant influence on knee kinematics. Longer squatting exposure led to increased maximum knee flexion during deep squat. Various factors associated with squatting exposure likely to influence joint motion are discussed below.

Firstly, joint motion could likely have been influenced by BMI. Leaner people could have demonstrated higher joint angles due to lower girth of thigh and calf. Therefore BMI was used as a covariate to study its influence on joint angles. However, difference in knee joint angles amongst the groups remained significant even after BMI was adjusted as a covariate and therefore the difference is not fully explained by this factor. This suggests that inherent changes in soft tissues of knee joint occur with daily squat exposure. Soft tissues of knee like menisci, cartilage, ligaments, anterior knee capsule and bones are believed to be amenable to anabolic metabolic processes and possess an ability to adapt to increased activity and mechanical influences. This could render a protective influence on the joints structures[31]. It could be possible that as occupational squatters and ADL squatters squatted for a prolonged time their tissues adapted to these stresses and contributed to the greater flexion observed at the knee joint. High correlations between knee flexion angle and total squat exposure are consistent with this interpretation. Furthermore, increased thigh-calf contact area may lead to greater distribution of compressive force, thus providing a protective effect on the knee joint.

Secondly, influence of socioeconomic status on knee kinematics was explored with the objective of understanding lifestyle activity patterns adopted by people for daily living. All occupational squatters were from upper-lower socioeconomic class, 60% of ADL squatters were from upper class and 40% from upper middle class whereas all non-squatters were people from upper class with higher monthly family incomes and better education. Non squatters demonstrated high BMI which correlated negatively with time spent in squat for ADL, leisure activities and total squat exposure thus establishing a link between economic progression, adoption of modernized lifestyle, reduction in time spent in habitual ground level activities using squatting and joint motion.

Thirdly, total daily deep squat exposure time was highest in occupational squatters who spent 147.5 (54.4) min/day in deep squat for occupational activity in addition to 81.8 (19.9) min/day for self-care, IADL and leisure activity which leads to a high cumulative score of 229.3 (67.1) min/day. In India, people from low socioeconomic class continue to adopt squat not only for occupational activities but also for IADL which increases the habitual, repetitive loading experienced by soft tissues of and around the knee and lead to greater adaptations as seen by the greatest knee flexion angle in this group during deep squat. ADL squatters had a moderate deep squatting exposure of 41 (22.5) min/day spent in squatting predominantly for self-care and IADL thus providing the habitual, repetitive loading in moderation sufficient to bring about soft tissue adaptation at the knee. Since BMI was not influenced by socioeconomic status and differences in joint angles remained significant in spite of adjusting for BMI, it would seem reasonable to assume that difference in knee joint kinematics can be attributed to soft tissue adaptations to the habitual, repetitive loading of daily squat exposure.

Fourthly, knee motion in the sagittal plane during deep squat, increased from non-squatters to occupational squatters. Higher values of knee flexion recorded in occupational squatters 163 (4.5^0) were greater than values reported previously in Indians[25] [153.7 (10.4^0)] which may be attributed to the grouping of participants on the basis of daily squat exposure or methodological differences of using electromagnetic tracking systems versus the Vicon system. Knee flexion coupled with internal rotation has been reported earlier [20, 24,25,32,33]. Interestingly, in the current study a greater percentage of non-squatters used knee-flexion-internal rotation-adduction coupling as compared to ADL squatters or occupational squatters. Although no relationship could be established among knee motions in the three planes, this does demonstrate that different knee movement patterns existed within the group studied. Studies using 4D fluoroscopic modeling in conjunction with CT scans demonstrated a strong coupling of posterior translation of femoral condyle along with internal rotation of tibia is reported during deep flexion activity of kneeling[34]. However, it has also been described that longitudinal rotation of the knee may be influenced to a great extent by passive soft tissue structures and dynamic forces rather than bony anatomy thus changing the axis of rotation for each activity[35]. Therefore in our study of squatting as a deep flexion activity, variation in the superincumbent weight, greater degree of knee flexion, rotation and adduction during squatting appear to affect forces and movement at the joint[36,37]. It may be interesting to study in future whether greater knee flexion coupled with internal rotation-adduction along with a high BMI contributes to higher compressive forces encountered by medial compartment of knee as high correlation was observed between BMI and knee adduction.

With respect to ankle motion, although differences in sagittal plane motion were not significant, it was observed that 40% of non-squatters were unable to perform foot flat deep squat which may indicate that lack of habitual repetitive loading on soft tissues like gastrocnemius and soleus could lead to shortening of these structures which restricts the ability of tibia to move over the talus during deep squat. Similar findings are reported previously in western populations who do not adopt deep squat routinely[8]. Reduction in joint range of motion if not used during habitual activities further demonstrates specific adaptations of the body to daily stresses exemplifying the principle of ‘use it or lose it”.

Hip motion in the sagittal and frontal plane during deep squat was similar in the three groups. However greater asymmetry between right and left sides in transverse plane motion in non-squatters may be a compensatory mechanism for lack of plantar flexor muscle length and knee flexion required to maintain deep squat effectively. Occupational squatters demonstrated highest symmetry between sides and low standard deviations indicating that habitual squatting may lead to greater stretching ability of musculo-tendinous structures of knee and ankle. Additionally, habitual squatting for prolonged time durations may contribute to increased ability to sustain squat with lesser trunk flexion and posterior pelvic tilt. Although this was not significant, our data suggests that non-squatters appear to tilt their trunk further forwards to maintain their center of mass within the base of support. However, a study using a larger sample will be required to confirm this. Results from other studies suggested that restriction of forward knee displacement during squat results in changes in knee-hip coordination[36] with increase in internal angle between knee and ankle, greater forward lean at the thorax and excessive transfer of force from hips to low back thereby contributing to musculoskeletal dysfunction[31,37,38].

With respect to study limitations, a prime concern in generating inferences from motion analysis is skin artifact consisting of movement of skin markers relative to underlying bone position. Thigh segment movement artifact in transverse and frontal plane motion create kinematic noise due to shifting of markers, muscle movement and inertial impact. Current techniques are unable to nullify the effect of skin movement artifact thus the reported frontal and transverse plane motion analysis should be interpreted with caution[39-42].In addition , studies on a larger number of individuals with varying squat exposure would make it easier to confirm that differences are significant.

Conclusions

In conclusion, varying durations of deep squat exposure influences knee kinematics. Lack of deep squat exposure led to reduction in maximum knee flexion angle which increased correspondingly with squat exposure. Moderate daily squat exposure of 20-45 minutes was sufficient to demonstrate improvement in knee range of motion thereby indicating that incorporation of deep squat in activities of daily living or as an exercise may help promote or maintain mobility at the knee.

Additionally, kinematic findings from this study may help in the design of better indigenous tailor made artificial joints, prostheses and orthoses that can mimic demands of traditional lifestyle activities of Indian and Asian culture and increase acceptance of knee replacement surgeries.

Authorship and Acknowledgement

All authors have contributed substantially towards conception of design, data acquisition, data analysis, interpretation and manuscript content. Bela Agarwal contributed to data acquisition, analysis, interpretation and manuscript content, Dr Rajani Mullerpatan and Dr Robert van Deursen provided consultation and guidance for data interpretation and manuscript content. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Dr Rajani Mullerpatan will be responsible as the guarantor for the work as a whole.

The autours would like to acknowledge internal support provided by MGM Center of Human Movement Science and MGM Institute of Health Sciences. We would like to thank all participants of the study and Dr Triveni Shetty(PT) for assistance in data capture.

Conflict of interest: None

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