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The Relation of Three-dimensional Knee Kinematics between Walking and Squatting for Healthy Young and Elderly Adults

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Abstract. [Purpose] The purpose of this study was to study the correlation of knee range of motion between walking and squatting for young and elderly populations. [Subjects] Sixteen young and eight elderly healthy subjects were recruited for this study. [Methods] Three-dimensional joint motions of each subject were captured while they performed walking and squatting exercises. [Results] Significant differences in the non-sagittal plane knee motions (peak adduction, and peak external and internal rotation) were revealed between the young and the elderly during squatting. Correlations of three-dimensional knee range of motion between walking and squatting were positive and high in all three planes for the young subjects (R^2=0.70, 0.52, and 0.45, respectively), but not for the elderly subjects (R^2=0.23, 0.0004, and 0.05, respectively). [Conclusion] We suggest that changes in secondary knee kinematics and poor correlations between walking and squatting for the elderly may result from degeneration of the sensory and neuromuscular systems. It could be injurious for the elderly to perform high flexion activities.
Key words: Knee kinematics, Squat exercise, Age-related degeneration

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INTRODUCTION

Aging is often related to degeneration of the sensory and neuromuscular systems[1)]. Numerous studies have investigated aging effects on human movement patterns, especially on walking[2–4)]. The elderly tend to use a slower gait and shorter step length during gait[1, 2)]. The changes in joint angles mainly involve lower peak plantar flexion[2, 4)], ankle range of motion (ROM)[5)], and peak hip extension[3, 4)]. However, in other studies no age-related kinematic changes were found[4, 6, 7)]. Thus, it remains controversial whether joint kinematics during gait are age-related. Furthermore, previous studies have mostly focused on the sagittal plane motion, but no study has reported the frontal and transverse plane motions, particularly those of the knee joint.

Due to the differences in lifestyle, in most Asian countries the elderly usually perform activities that involve high flexion angles (>120°), for instance, squatting[8)]. The joint patterns during high flexion activities might be related to patterns during gait. To our knowledge, no study has yet assessed the correlation of joint kinematics between walking and squatting. Therefore, the objective of this study was to investigate the correlations of different age-groups, thereby providing data for age-associated kinematics changes, and contributing to our understanding of joint biomechanics.

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SUBJECTS AND METHODS

A sample of 16 healthy young subjects (8 females and 8 males) and 8 healthy elderly subjects (5 males and 3 females) were recruited for this study. All subjects had a traditional lifestyle involving squatting or other high flexion activities on a daily basis. The subjects' characteristics are listed in Table 1. None of the subjects had a history of injury or pain in the lower limbs, or balance problems. This study was approved by the ethics committee of China University of Mining and Technology, and all participants signed a consent form before participating.

The Optotrak® Certus™ 3020 dynamic tracking system (Northern Digital Inc., Canada) was employed to capture the kinematic data at a frequency of 100 Hz. All subjects wore shorts while performing walking and squatting. The subjects performed the squatting exercise from an initial upright position with their feet shoulder width apart. The subjects were instructed to deeply lower their body, hold the position for 3 s and then ascend back to the upright position, without moving their feet. For each subject, six successful trials were recorded for each activity.

The raw kinematic data were processed using Visual 3D (C-Motion Inc., USA), and filtered using an integrated digital filter. Local coordinate systems were defined for each lower limb segment through bony landmarks[8]. Then, 3D knee joint angles were calculated based on the coordinate systems. To generate ensemble graphs, the data of one movement cycle were normalized to 100%. The average measures of each subject were obtained from the six trials, and then these individual means were averaged across the group of subjects. Analysis of variance (ANOVA) was performed to assess statistical differences. Statistical significance was accepted for values of $p<0.05$. Additionally, the relationships of 3D knee ROMs between walking and squatting were evaluated by testing the correlation using a linear regression model.

RESULTS

A comparison of 3D knee joint angles between the young and elderly subjects is presented in Table 2. During walking, no significant difference was demonstrated between the young and the elderly group ($p>0.05$), although the elderly displayed increased minimum knee flexion and decreased maximum knee flexion compared to the young subjects. Conversely, there were significant age-associated differences during squatting: the elderly demonstrated higher maximal adduction, maximal internal rotation and external rotation than the young subjects ($p<0.05$). Table 3 shows the correlation of knee ROM between walking and squatting within each group. Positive correlations were detected for the young subjects in all three planes (R^2=0.70, 0.52, and 0.45, respectively). Interestingly, it was observed that the knee ROM during walking was not strongly correlated to that during squatting in the elderly group (R^2=0.23, 0.0004, and 0.05, respectively).

DISCUSSION

The objective of the present study was to investigate the correlation of knee kinematics between walking and squatting for both the young and the elderly. To the best of our knowledge, this is the first attempt to investigate the relationship of 3D knee kinematics between walking and squatting. The findings would not only enable therapists and clinicians to develop diagnostic measures and rehabilitation programs for the elderly individuals, but also guide the design of prosthetics and rehabilitation protocols for Asian populations.

The results of the present study demonstrated that the elderly displayed increased knee flexion at mid-stance and decreased knee flexion during the swing phase; however, the differences were not significant between the age groups. This result is consistent with those of previous studies[1, 2, 6]. In the non-sagittal planes, the differences between the young and the elderly subjects were not significant either ($p>0.05$). Conversely, significant differences were observed in the frontal and transverse plane motions during squatting. Compared to the young subjects, the elderly demonstrated much higher peak adduction angle and peak rotation angle. Although the knee motions in the sagittal plane were almost identical in the two age groups, the age-related differences in non-sagittal plane motions may indicate subtle alterations in the sensory and nervous systems, or physiological changes in the elderly. Besides, due to much higher adduction and rotation of the knee, mechanical changes would accelerate degeneration of articular cartilage; thus, it might be injurious for the elderly to perform the squatting exercise.

The most interesting finding of this study was that positive correlations of knee ROM between walking and squatting were demonstrated by the young subjects, but not by the elderly subjects. This could be attributed to decreased muscle strength[2, 4] and joint laxity[1] in the elderly. During walking, the demands on muscle activities and joint ROM were relatively small, so the elderly were able to exhibit a normal gait similar to the young. However, with increasing demands, the limited joint laxity of the elderly would interfere with joint ROM, while the young would still be able

Table 1. Demographic data of the recruited subjects

Group	Age (year)	Height (cm)	Weight (kg)
Young	22.2±2.4	171.4±8.3	65.1±10.6
Elderly	63.6±4.5	170.3±6.7	70.3±8.8

Table 3. Correlation of knee ROM between walking and squatting for the young and elderly subjects

Motion planes	Young	Elderly
Sagittal	0.70	0.23
Frontal	0.52	0.0004
Transverse	0.45	0.05

Table 2. Mean (±SD) three-dimensional knee angles during walking and squatting of the young and elderly subjects

Angles (degree)	Walking		Squatting	
	Young	Elderly	Young	Elderly
Max. flexion	71.3±5.11	68.2±6.2	145.3±11.5	142.8±10.7
Min. flexion	5.1±4.1	8.6±4.0	2.9±5.5	5.4±5.6
Max. adduction	11.1±6.8	9.1±2.6	7.2±4.7*	11.9±3.7*
Min. adduction	1.5±5.9	−1.2±4.1	1.0±1.8	1.1±4.8
Max. external rotation	10.9±3.1	13.0±7.6	2.5±1.0*	5.2±5.8*
Max. internal rotation	4.8±3.9	5.8±7.3	7.6±4.7*	21.7±12.8*

* Significant age-related difference ($p<0.05$) (Unit: °)

to control their performances. As a consequence, the joint ROM during squatting would be less related to that during walking in the elderly group. On the other hand, the secondary movements of the knee are mostly constrained by the periarticular connective tissue (e.g. ligaments, joint capsule and tendon etc.). It has been reported that the mechanical properties of these tissues appear to change with advanced age[1]. This might also be a factor influencing gait patterns of the elderly. Besides, degeneration of articular cartilage might also influence joint ROM during deep squatting[9]. Irrespective of the mechanisms behind them, the results of this study suggest that the elderly should avoid performing high flexion activities.

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