Original Article
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Comparison of *In Vivo* Three-Dimensional Glenohumeral Positions and Scapular Kinematics between Young and Older Male Groups

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Background: Many researchers have questioned whether shoulder kinematics such as the glenohumeral position and scapular kinematics would be different in different age groups. However, studies comparing shoulder kinematics between different age groups have been rare. The aim of this study was to analyze and compare the three-dimensional (3D) glenohumeral position, scapular kinematics, and scapulohumeral rhythm (SHR) during scapular plane arm abduction between a normal young male group and a normal older male group.

Methods: Twenty normal men (10 young and 10 older) were enrolled in this controlled laboratory study. Fluoroscopic images were obtained using a single plane X-ray system. Bilateral computed tomography scans were taken to create a 3D model. A 3D-2D registration technique was used to determine the 3D position and orientation of the bones of the shoulder.

Results: During scapular plane arm abduction, there were significant differences in scapular kinematics between the groups. The older male group showed more upward rotation, posterior tilt, and external rotation than the young male group. On the other hand, the glenohumeral position such as superior inferior translation, anterior posterior translation, and external rotation of the humeral head did not show significant difference between the groups. The mean value of SHR for the overall arm elevation range from start to maximum elevation angle for the older group and young group was 2.298 ± 0.964 and 2.622 ± 0.931, respectively, showing a significant difference between the two groups ($p = 0.035$).

Conclusions: Scapular kinematics and SHR were significantly different between the older male group and the young male group. Our study could provide reference values of shoulder kinematics for older men aged 55–65 years.

Keywords: *Shoulder, Glenohumeral joint, Scapula, Kinematics*

Normal and abnormal shoulder kinematics described in the literature are mainly based on the observation of young adults.[1-4] Analysis of normal shoulder kinematics has been usually conducted in young adults, whereas research on normal shoulder kinematics of older people above 55 years old has been scarce. However, degenerative diseases and sports injuries have become more common in older people with increasing average life expectancy and participation in sports activities. For this reason, a question has been raised whether shoulder kinematics data obtained from young people could be used as reference values in studies that focus on the shoulder kinematics of older people. We conjecture that older people would have different shoulder kinematics compared to young people because they have used their shoulders more during daily life activities, work, or sports activities for at least 30 years after complete physical development.

In previous studies on rotator cuff tears, researchers usually used contralateral shoulders for comparison.

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We also considered in the past that contralateral shoulders would be healthy if there was no symptom. But there have been reports of older patients with rotator cuff tears in whom they actually had rotator cuff lesions on the contralateral shoulder that had been assumed normal. Therefore, it could be unreliable for researchers to use contralateral shoulders for comparison with the affected shoulders in the older patients, and we need reference values of normal shoulder kinematics of the older people.

Hence, the purpose of this study was to analyze and compare the three-dimensional (3D) glenohumeral position, scapular kinematics, and scapulohumeral rhythm (SHR) during scapular plane arm abduction between a normal young male group and a normal older male group. We hypothesized that there would be differences in shoulder kinematics during scapular plane arm abduction between the young male and older male groups.

METHODS

Subjects

In this study, volunteers were recruited and divided into two groups: young men in their 20s–30s and older men in their 50s–60s. Those who had symptoms or disease of the shoulder were excluded from the study. Subjects underwent physical examination, plain X-ray, and ultrasound, and those who showed abnormal results were also excluded. Furthermore, we excluded people working in harsh conditions such as those who used their shoulders regularly to lift heavy load or throw objects like a baseball player. A total of 20 people were involved in the experiment, 10 people in each group, and the dominant shoulder was tested. All of our subjects provided informed consents and the protocol of research was approved by the Institutional Review Board of Yonsei University (IRB No. CR318092).

Acquisition of Fluoroscopic Images and 3D Bone Modeling

Participants sat on a stool and were guided to position their normal shoulder toward a single plane X-ray system (Infinix Activ; Toshiba, Tochigi, Japan). Fluoroscopy images were obtained at 30 Hz while people raised their arm in the scapular plane direction at a rate of approximately three seconds per cycle.[5-8] According to the arm movement, along the longitudinal axis of the humeral shaft, the rotation of the humerus could be measured. One cycle meant completion of full elevation and lowering of arms. To correct geometric image distortion and to permit computation of the radiographic projection parameters, we obtained fluoroscopic images of the calibration object. Bilateral computed tomography (CT) scans (SOMATON Sensation 16; Siemens Medical Solutions, Malvern, PA, USA) of the entire humerus and scapula were obtained with a 1-mm slice pitch (image matrix 512 × 512; pixel size, 0.9765625 × 0.9765625 mm). The 3D bone models of the proximal humerus and scapula were acquired through segmentation of CT images (ITK-SNAP; Penn Image Computing and Science Laboratory, Philadelphia, PA, USA). Referring to the report of a typical anatomic coordinate system (Geomagic studio; Geomagic, Morrisville, NC, USA), anatomic coordinate systems were embedded to each bone model (Fig. 1).[9]

Image registration was performed by using open-source software Joint Track (https://sourceforge.net/projects/jointtrack/) developed by our laboratory.[10,11] The bone models of the humerus and scapula were projected onto undistorted fluoroscopic images. From shape matching, position and orientation of each bone were determined (Fig. 2).

The outcome of Joint Track software consists of

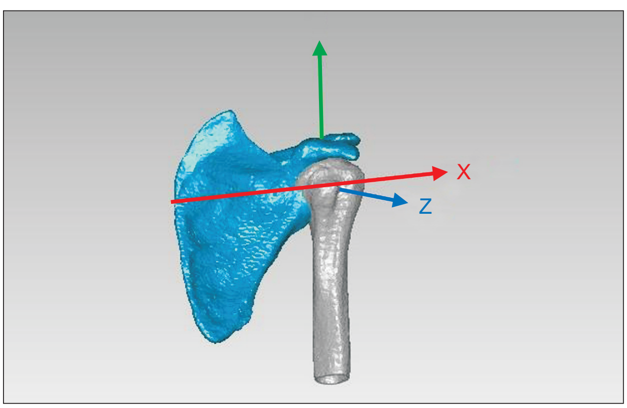

Fig. 1. Anatomic coordinate systems were set in each bone model with use of commercial software (Geomagic Studio; Raindrop Geomagic, Research Triangle Park, NC, USA).

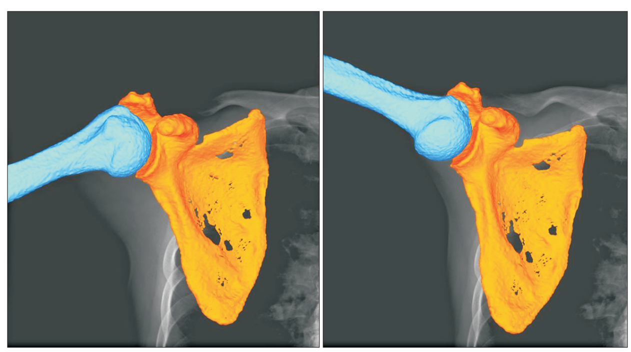

Fig. 2. Three-dimensional-two-dimensional model registration techniques were used to determine the three-dimensional position and orientation of the shoulder bones using Joint Track.

three-way translations and three-way rotations. In this study, Z-rotation of the humerus was defined as the arm abduction angle, and superior/inferior and anterior/posterior translation were defined as the motion of the humeral origin relative to the glenoid center along the Y-axis of the scapula.[7] The scapular kinematics and external rotation of the humerus relative to the X-ray coordinate system were determined using Euler and Cardan angles.[12] Each scapular rotation Z, X, and Y means upward rotation, posterior tilt, and external rotation, respectively. The abduction angle, which is Z-rotation of the humerus, was used as the X axis for each graph. Scapular kinematics values were plotted as a function of the arm elevation angle, and custom MATLAB (Mathworks, Natick, MA, USA) code was used to interpolate scapular rotation values in 10° increments of the humeral elevation angle and to get data of kinematics. SHR was defined as (ΔH–ΔS)/ΔS. ΔH is an interval of humerus elevation angle and ΔS is an interval of scapular upward rotation angle. To compute SHR, we set ΔH=10° as we measured scapular rotation at every 10° of humerus elevation, which is a method that has been used in previous research.[13]

Statistical Analysis

We used two-way repeated analysis of variance (ANOVA) to compare the incremental data of the glenohumeral

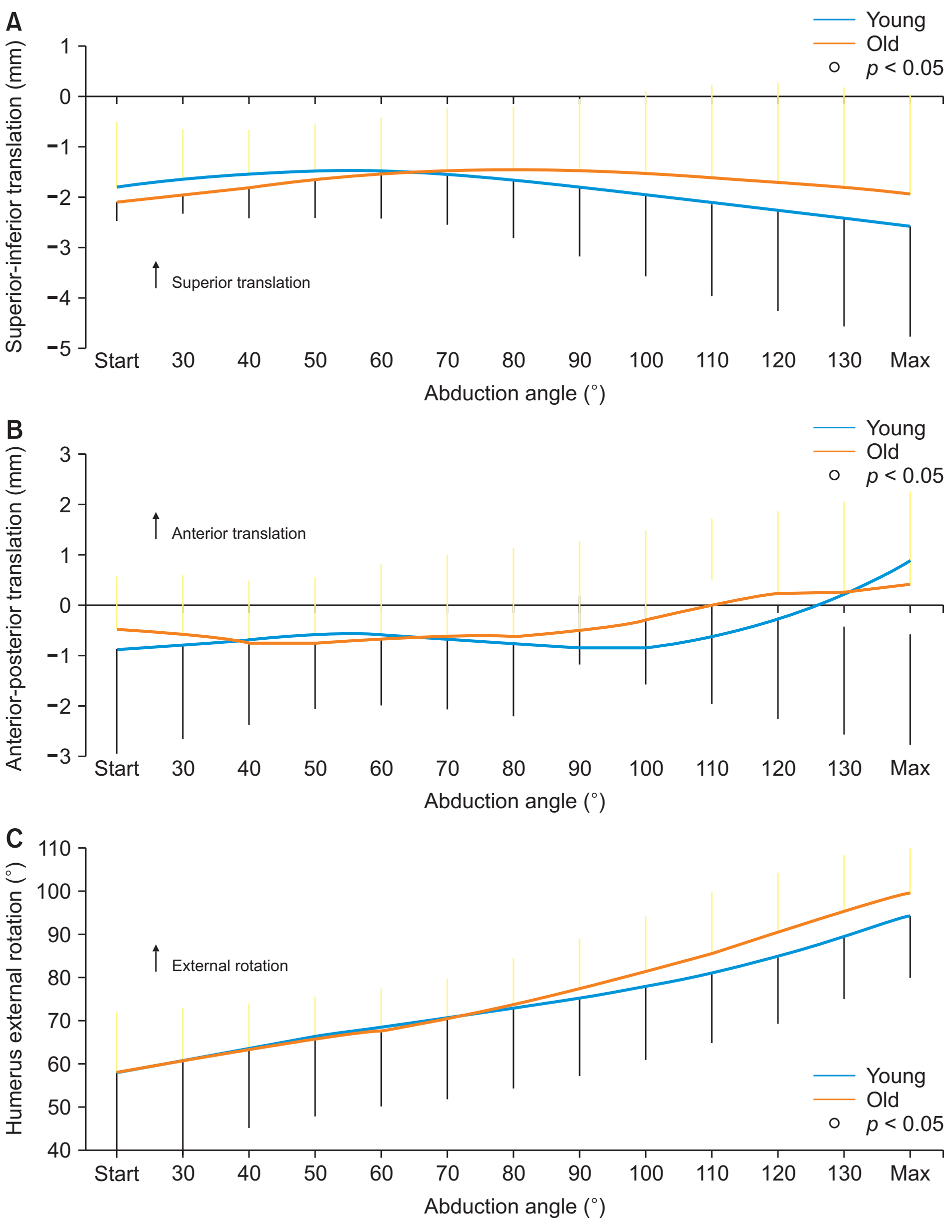

Fig. 3. (A) Superior-inferior translation of the humeral head. (B) Anterior-posterior translation of the humeral head. (C) External rotation of the humerus.

positions, scapular angles, and SHR between two groups. Tukey-test was performed as a post-hoc test if significant difference was detected in ANOVA. The level of significance was set at $p < 0.05$.

RESULTS

Ten young male subjects with a mean age of 27 years (range, 20–32 years) and 10 older male subjects with a mean age of 61.2 years (range, 55–65 years) were enrolled in this study. No significant difference was observed for glenohumeral joint kinematics: external to internal rotation of the humerus ($p = 0.365$) and superior-inferior ($p = 0.38$) and anterior-posterior translation ($p = 0.367$) of the humeral head relative to the glenoid center during scapular plane arm abduction. For scapular kinematics (upward rotation, posterior tilt, and external to internal rotation), however, there were significant differences between two groups during scapular plane arm elevation ($p < 0.05$).

Glenohumeral Joint Kinematics

Superior-inferior translation

There was no significant difference in superior-inferior translation of the humeral head relative to the glenoid center between the young group and older group during arm elevation ($p = 0.38$). Both groups did not have significant difference in humeral head position by arm elevation angle ($p = 0.989$). At resting position, the position of the humeral head relative to the glenoid center showed a negative value in both groups. In the early stage of elevation,

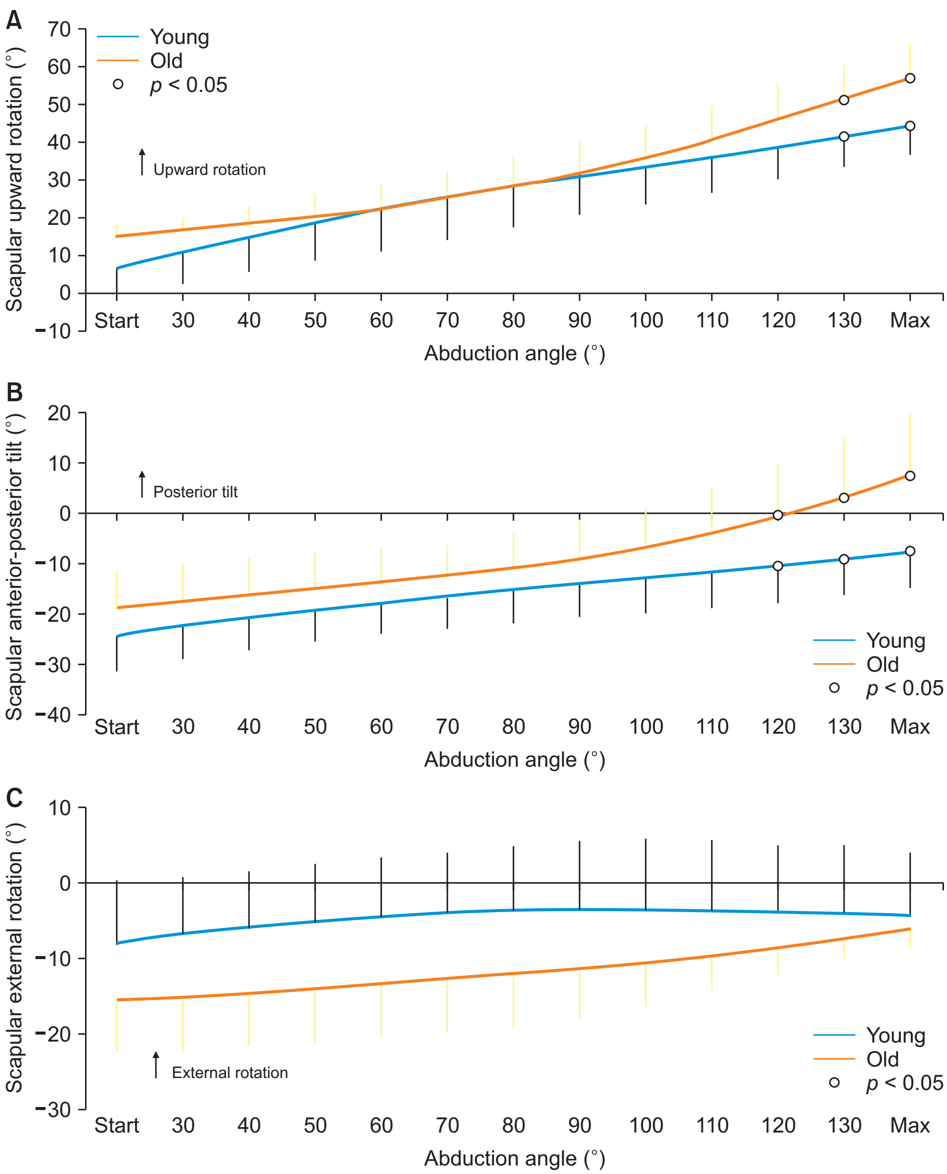

Fig. 4. (A) Scapular upward rotation. (B) Scapular anterior-posterior tilt. (C) Scapular external-internal rotation.

the humeral head position gradually went up, whereas in the middle and end stages of elevation, it had a tendency to fall slightly. The total variation was within 1–2 mm. The humeral head of the older group was higher than that of the young group at 120° to maximum elevation angle, but the difference was within 0.5 mm (Fig. 3A).

Anterior-posterior translation

There was no significant difference in anterior-posterior translation of the humeral head relative to the glenoid center between two groups ($p = 0.367$). No significance difference of the humeral head position was observed by arm abduction angle ($p = 0.66$). Both groups showed similar moving tendency: the humeral head was located approximately 0.5–1.0 mm posterior to the glenoid center at the starting point. In the older group, the humeral head was located 0.5 mm more anterior than that of the young group at abduction angle of 100° to 120° (Fig. 3B).

Humerus external rotation

In both groups, external rotation of the humerus relative to the ground increased according to the increment of arm abduction angle ($p < 0.01$). But there was no significant difference between the two groups ($p = 0.365$). At a higher arm abduction angle, which is from 120° to maximum, the humerus of the older group showed 5° more external rotation than that of the young group (Fig. 3C).

Scapular Kinematics

Scapular upward rotation

Scapular upward rotation relative to the ground increased following the increment of arm elevation angle and also showed significant difference ($p < 0.01$) by arm elevation angle in both groups. There was a statistical difference between the two groups by more than 130° ($p < 0.05$). The mean change in upward rotation from the starting point to maximum elevation was 41.44° for the older people and 37.74° for the young people. In resting position, the older group showed 8.3° more upward rotation than the young group although there was no significant difference. At 130° to maximum elevation angle, significance difference was observed between the groups; the older group showed more upward rotation (Fig. 4A).

Scapular posterior tilt

Posterior tilt of the scapula relative to the ground slowly increased according to the increment of arm abduction angle and showed significant difference by arm abduction angle ($p < 0.01$). There was a significant difference between the two groups by more than 120° ($p < 0.01$). The mean change in posterior tilt from the starting point to maximum elevation for the older and young group was 26.68° and 16.79°, respectively. At resting position, the older group showed approximately 5° more posterior tilt than the young group, but there was no significance difference. The older group showed more significant posterior tilt than the young group at 120° to the maximum abduction angle (Fig. 4B).

Scapular external to internal rotation

In both groups, no significance difference was detected for scapular external rotation relative to the ground according to the increase of arm abduction angle ($p = 0.446$). However, there was a statistical difference between two groups between 30° and 80° ($p < 0.01$). At resting position, the older group showed approximately 7.6° more internal rotation than the young group but there was no significant difference ($p > 0.05$). The scapula of the older group was rotated externally according to the increase of abduction angle (Fig. 4C).

Scapulohumeral Rhythm

The mean values of SHR for the overall arm elevation range from the starting point to maximum elevation angle for the older group and young group were 2.298 ± 0.964 and 2.622 ± 0.931, respectively. There was a significant difference between two groups ($p = 0.035$). Especially at 100°–110° and 110°–120° arm elevation angle, there was a significant difference between two groups. The SHR value (mean, 5.16) of the older group showed a higher value at a lower elevation angle (30°–60°) but showed a decreasing tendency according to the increase of arm abduction angle. In contrast, the young group showed a much lower SHR value (mean, 2.237) at a lower arm abduction angle (30°–60°) and showed a tendency of increasing until 90°–110° and decreasing after 110°.

DISCUSSION

As far as we know, this study is the first research comparing normal shoulder kinematics, such as glenohumeral kinematics and scapular kinematics, during scapular plane arm abduction between young male and older male groups. Our results showed no significant difference in glenohumeral kinematics, but significant differences were detected in scapular kinematics and SHR.

The results of this study could provide physical therapists and shoulder surgeons with reference values for treatment and rehabilitation and improve their understanding of glenohumeral kinematics and scapular kinematics for relatively old people between 55 to 65 years of age. It is not an easy task to set reference values for recovering normal shoulder kinematics of older people with rotator cuff tears. This is because in older people there is a high possibility of the presence of a rotator cuff tear even in the contralateral shoulder that is considered normal. Therefore, using the value of the contralateral shoulder as a reference does not make sense.

This study revealed the difference in the shoulder kinematics values between the older and young people. Therefore, using shoulder kinematics values of young people as a reference value for older people or vice versa would not be ideal. In the near future, we need to verify the differences with a more detailed and controlled experiment design.

Many authors have focused only on scapular kinematics of healthy and pathologic shoulders of adults.[1-4) For adults, it has been known that abnormal scapular movements cause shoulder pain and pathologies, and the understanding of typical shoulder kinematics patterns has played an important role in shoulder pathology research.[2) Recently, as diverse age groups of people participate in sports activities, the need to know normal shoulder kinematics as a reference value from children to old people has emerged. Although most patients with shoulder pathologies are not young people but older people aged 55 to 70 years, the kinematics values obtained from relatively young adults have been used as reference values to treat older people.

Dayanidhi et al.[14) recently reported that although children had generally similar shoulder kinematics to adults, the scapulothoracic joint made more effect on shoulder movement during arm elevation (especially significant difference was detected at scapular upward rotation). There were some studies[14,15) revealing shoulder kinematics differences between children and adults aged 20 to 30 years. However, few studies compared normal shoulder kinematics between young adults aged 20 to 30 years and older people aged 55 and 65 years.

In both young and older groups in this study, scapular upward rotation increased according to the increment of arm abduction angle and also showed very high alteration. There was no significant difference at the resting position between the groups, but the older group displayed 8.3° more upward rotation than the young group did. It was not clear whether the age difference between the groups was attributable to such difference. There have been two studies[14,15) comparing scapular kinematics between children and adults. Even though they performed an analogous experiment and targeted similar age groups, they reported totally contradictory results about scapular upward rotation: in one study, upward rotation of children showed higher values than that of adults, but in the other study, the adult group had higher scapular upward rotation than children did. We conjecture that it might be wrong to attribute the difference in scapular kinematics between children and adults only to the age difference.

Of note is the interpretation of the results of scapular external rotation. We minimized the effect of resting position through the process of result modification and analyzed the influence of the shifted position on scapular external rotation. At the shifted position, the older group tended to more externally rotate than the young group, and statistically significant difference between two groups disappeared (Fig. 4C). Even though the scapula of the young group was more rotated externally than the older group at resting position, we could say that the scapula of the older group had a more external rotation tendency depending on the increment of arm abduction angle.

As well as the increased upward rotation, the older group also showed a tendency to tilt posteriorly and rotate externally. Many previous studies have reported that normal healthy young adults show increased scapular upward rotation, posterior tilt, and external rotation during arm abduction. Interestingly, we noticed that the older group in this study had an increased tendency of upward rotation, posterior tilt, and external rotation according to the increment of abduction angle. Even though the mechanism of the scapular movements has not been fully elucidated, it has been thought that the position and orientation of the scapula in resting position would be determined by the condition of scapulothoracic muscles such as the tone and length of these muscles in resting position. Therefore, many authors have tried to explain the changes of scapular behavior with changes of scapulothoracic muscles. Matsuki et al.[7) reported that dominant shoulders were downwardly rotated compared to nondominant shoulders at resting position in a recent research of *in vivo* 3D kinematic analysis between the dominant shoulder and the nondominant shoulder. This situation could be elucidated by tightness or shortening of levator scapulae or rhomboids that have the ability to control the scapula to rotate downwards. In describing differences in scapular kinematics between children and adults, Dayanidhi et al.[14) explained that throughout the adolescence, children go through muscle and strength development. This has an effect on scapular stabilization and could change scapular motions as scapular musculature stabilizes the scapulothoracic joint of the scapula on the thoracic wall, which enables elevation.[14,16) We think that all of our older subjects experienced more repeated shoulder elevation in a routine day than the young group. And all data were obtained from dominant shoulders in this study. Dominant shoulders have been more frequently used than nondominant shoulders. This means that dominant shoulders in the older group might have relatively big difference in scapulothoracic muscles compared to dominant shoulders in the young group. Having different scapulothoracic muscle activities could be considered as one of the reasons causing a different resting position in scapular kinematics between the two groups. This can be understood as it was mentioned previously that levator scapulae or rhomboid muscles enable the scapula to rotate downwards (Matsuki et al.[7]) and the infraspinatus and teres minor allow posterior tilting of the scapula (Tsai et al.[17]). Hence, the imbalance of muscles surrounding the scapula is thought to influence the position and motion of the scapula. We surmise that the resting position of the scapula in the older male group was changed to lift the arm in a more proper and easier way.

Wang et al.[18] and McQuade et al.[19] explained that scapular motion was changed because of muscular strengthening and muscle fatigue, respectively. Although the older group did not have preexisting diseases and show any symptoms, repetitive overhead motions for decades would induce considerable muscle fatigue. Many authors broadly agree that muscle fatigue near the scapula would have influence on shoulder kinematics, especially the scapular upward rotation. However, there were some differences between studies using muscle fatigue protocols in terms of scapular kinematics. Although Tsai et al.[17] reported that the scapula showed less upward rotation after shoulder muscles had been fatigued, Ebaugh et al.[20] insisted that upward rotation was rather increased. Both studies used a muscle fatigue protocol but there were differences in magnitude and duration for load. Tsai et al.[17] caused localized muscle fatigue to external rotator muscles that are infraspinatus and teres minor and performed a fatigue protocol for a relatively short time. On the other hand, Ebaugh et al.[20] designed their experiment to cause global shoulder muscle fatigue for a much longer time. The results of our study showed that the older group have more significant scapular upward and external rotation. This could be interpreted to indicate that the scapulothoracic muscle of the older group, compared to the young group, seems to follow the global shoulder muscle fatigue protocol for a long time and the local muscles fatigue protocol in shorter time when compared to the study of Ebaugh et al.[20] It was not clear whether the alteration of position and orientation of the scapula was mainly affected by muscle fatigue or secondary changes of compensation by changes of other muscles. The experiment with muscle fatigue protocol caused temporary fatigue to muscles during limited time so it is not sure if following alterations of scapular kinematics could induce pathologic changes. So it is hard to say the muscle fatigue theory could better explain our results. That is why more well-designed studies will be needed.

Endo et al.[21] said that older people had decreased scapular posterior tilt and upward rotation angle with aging. They also insisted that those changes of scapula could be a predisposing factor for impingement syndrome especially in old people. Ludewig and Cook[5] asserted that scapular internal rotation was discovered from the subjects with impingement syndrome. Our results showed different shoulder kinematics with them. With the increase in arm abduction angle, scapular behavior in the older group showed more upward rotation, posterior tilt, and external rotation than those in the young group in this study; particularly significantly higher values were observed at a higher angle of elevation such as 120° to maximum angle. Such alterations were directly opposed to Endo's research. Scapular upward rotation and external rotation play a key role in maintaining the subacromial space properly and optimal relationship between the humeral head and glenoid fossa.[5,19,22] Increased scapular upward rotation and external rotation make the acromion rotate upwardly away from the greater tuberosity of the humeral head. Moreover, scapular posterior tilt during arm abduction has an important role in providing proper space under the anterior aspect of the acromion to make it easy to give optimal motion between the humeral head and cuff tendons.[3] The older group showed significantly higher scapular upward rotation, posterior tilt, and external rotation than the young group at the late phase of arm elevation, having possibility of collision between the acromion and the rotator cuff. Some authors tried to find the reasons from the muscle fatigue theory but it has not been fully elucidated yet.

Physical therapists and shoulder surgeons should keep in mind that if old people in their clinics display more upward rotation, posterior tilt, and external rotation than usual, those changes of scapular kinematics might not be an abnormal behavior of the scapula. It is also of note that since our older normal male group showed increased values for three kinds of scapular motions, a decrease in scapular upward rotation, posterior tilt, and external rotation during arm elevation could not be a natural alteration with aging in old people.

Kibler and McMullen[22] described SHR was disrupted in patients having symptoms and signs of impingement, which could be a prelude to impingement syndrome. It means that shoulder dysfunction and disease would accompany a variation of SHR. SHR of the older group had a decreasing tendency with an increment of arm abduction angle in the current study. Particularly, at 100°–110° and 110°–120° arm abduction angle, SHR of the older group significantly dwindled than that of the young group, so it could be used as a basis to judge abnormal scapular movements in the older group.

The present study has some limitations. First, the number of subjects was not sufficient. Variations of scapular kinematics largely depend on each person. So, we need to include more subjects in further study. Second, all subjects were male and only dominant shoulders were used for this study; thus, our results could not be applied to the whole old people. We are planning to investigate differences in scapular kinematics between the dominant and nondominant shoulders in the older group to overcome such shortcoming in the near future. Third, we did not measure scapular muscle activities. If we investigate the difference in scapular muscle activities between the two age groups, we will be able to explain the difference between the groups more clearly. Fourth, we did not include the thorax in this study, thus there is a chance of variation in scapular position by the subject's posture during fluoroscopy; however, we instructed the subjects to maintain the position such as stretching the arm straight and lifting the arm along the constant path.

This study revealed there are differences in the 3D glenohumeral position, scapular kinematics, and SHR between the older group and young group during scapular plane arm abduction. The main results of this research are that the older male group showed a more significant increase in upward rotation, posterior tilt, and external rotation in scapular kinematics than the young male group. On the other hand, there was no significant difference in the glenohumeral position, which is superoinferior and anteroposterior translation of the humeral head relative to the glenoid center, between two groups. Our study could provide reference values for shoulder kinematics in older men aged 55–65 years.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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