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Comparison of Scapular Kinematics During Active Shoulder Horizontal Adduction Between Subjects With and Without Limited Range of Motion of Shoulder Horizontal Adduction

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Abstract

Background: Shoulder horizontal adduction (HA) is performed in many activities of daily living. The limited range of motion (LROM) of HA is affected by the tightness of the posterior deltoid, infraspinatus, teres major, and posterior capsule of glenohumeral joint. The LROM of shoulder HA contributes to excessive scapular abduction.

Objects: The aim of this study is to compare the scapular abduction distance and three-dimensional displacement of the scapula during shoulder horizontal adduction between subjects with and without the LROM of shoulder HA.

Methods: 24 subjects (12 people in LROM group and 12 people in normal ROM group) participated. Subjects with less than 115° of HA ROM were included in LROM group. Shoulder HA was performed 3 times for measuring scapular abduction distance and three-dimensional displacement of the scapula. Tape measure was used for measuring scapular abduction distance. Scapular abduction distance was normalized by dividing the scapular size. Polhemus Liberty was used for measuring the three-dimensional displacement of the scapula.

Results: Normalized scapular abduction distance was significantly greater in LROM group than normal ROM group ($p<.001$). Three-dimensional displacement of the scapula during shoulder HA was greater in LROM group than normal ROM group ($p<.05$).

Conclusion: LROM group had a greater scapular abduction and three-dimensional displacement of the scapula during shoulder HA compared to normal ROM group.

Key Words: Scapular abduction; Scapular kinematics; Shoulder horizontal adduction.

Introduction

Shoulder horizontal adduction (HA) involves many activities of daily living (ADL) such as brushing teeth, washing face, and combing hair (Sheikhzadeh et al, 2008). Namdari et al (2012) demonstrated that complete ADL requires 115° of HA. HA involves not only ADL, but sports activities such as baseball, football, golf, tennis, and rugby (Fleisig et al, 1996; Helgeson and Stoneman, 2014; Mitchell et al, 2003; Silva et al, 2006). HA occurs in the glenohumeral (GH) joint and scapulothoracic joint. The range of motion (ROM) of HA is measured at 90° shoulder abduction and 90° elbow flexion and then the subjects horizontally adduct their shoulder (Hislop and Montgomery, 2007).

Dashottar et al (2014) mentioned that the limited range of motion (LROM) of HA in the GH joint may

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be affected by the tightness of posterior deltoid, infraspinatus, teres major, latissimus dorsi, and posterior capsule of GH joint. The extensibility of the shoulder's external muscles also affects HA. Laudner et al (2012) mentioned that the accumulation of forces at the posterior shoulder causes posterior shoulder tightness which appeared in the LROM of the GH joint internal rotation and HA. Sahrmann (2002) mentioned that the LROM of HA contributes to excessive scapular abduction. Excessive scapular abduction induces pain at the anterior or posterior shoulder or deltoid area and pain during overhead activities and reaching forward, not being able to lie on the painful side (Sahrmann, 2002). When throwers horizontally adduct their arm, the throwing shoulder has less ROM than the non-throwing shoulder (Borsa et al, 2008). Borsa et al (2008) mentioned that throwers with posterior shoulder tightness might be associated with reactive scarring or contracture of the periscapular soft tissue structures. Because excessive posterior shoulder tightness causes various shoulder problems, previous studies have investigated the effects of posterior shoulder stretching exercise (Laudner et al, 2012; Salamh et al, 2015; McClure et al, 2007).

Scapular kinematics has been investigated in various ways. Lin et al (2006) compared scapular kinematics between subjects with posterior shoulder tightness and anterior shoulder tightness during arm elevation. They found that subjects with anterior shoulder tightness had more anterior tipped scapular position and more excessive scapular upward rotation. Karduna et al (2001) investigated scapular kinematics during shoulder flexion in the scapular plane and sagittal plane, and internal to external shoulder rotation. They found errors between (1) tracker method which is a bone-based receiver and (2) acromial method which is a skin-based receiver. Yang et al (2009) investigated scapular kinematics during active shoulder abduction in the scapular plane between subjects with anterior shoulder tightness and with posterior shoulder tightness. They found that subjects with anterior shoulder tightness had significant correlation with scapular tipping.

In previous studies, scapular kinematics was researched during shoulder flexion in the scapular plane and sagittal plane, and during shoulder abduction. However, no studies have investigated about scapular kinematics during shoulder HA, although shoulder HA happens a lot in ADL and sport. The purpose of this study is to compare the scapular kinematics during active shoulder HA between subjects with and without LROM of shoulder HA. We hypothesized that (1) normalized scapular abduction distance would be greater in subjects with LROM of shoulder HA compared with those without LROM and (2) three-dimensional displacement of the scapula would be greater in subjects with LROM of shoulder HA compared with those without LROM.

Methods

Subjects

24 subjects (12 subjects in LROM group, 12 subjects in normal ROM group; 14 males and 10 females) were recruited from Yonsei University (Table 1). The inclusion criterion of LROM group is less than 115° of HA ROM (Namdari et al, 2012). People

Table 1. Characteristics of the subjects (N=24)

Characteristics	Normal ROM[a] group (n_1=12)	LROM[b] group (n_2=12)
Age (year)	21.8±1.1[c]	21.8±2.2
Height (㎝)	168.0±7.7	169.4±8.3
Weight (㎏)	66.2±11.2	67.5±13.4
BMI[d] (㎏/㎡)	23.3±2.9	23.4±3.5

[a]range of motion, [b]limited range of motion, [c]mean±standard deviation, [d]body mass index.

who had a history of shoulder surgery and shoulder symptoms needed medical treatment in the last year, or shoulder pain at the time of study were excluded (Manske et al, 2010). Before this study, procedures were explained in detail, and all subjects signed the consent form. The study was approved by the Yonsei University Wonju Institutional Review Board (approval number: 1041849-201511-BM-073-02).

Tape measure

To measure the distance between 3rd thoracic spinous process and root of the scapular spine, and the distance between the root of the scapular spine and posterolateral acromion, the 3rd thoracic spinous process and acromion were marked by a water-based marker. Tape measure was used for measuring the distance between markers.

Polhemus Liberty™

The Polhemus Liberty™ (Polhemus Navigation Science Division, Kaiser Aerospace, Vermont, USA) is an electromagnetic motion-tracking device. It was used to collect the three-dimensional kinematic data of scapula during active HA. Liberty consists of a transmitter that creates electromagnetic field, and sensors that detect its position and orientation. Data were stored on a personal computer and scapular kinematic data were collected at a sampling rate of 120 ㎐. The orientation of the transmitter and sensors was represented using Euler angle sequence with X axis-left, Y axis-forward, Z axis-up (Karduna et al, 2001). Liberty had an accuracy of .3° to .7° for rotation and .4 ㎝ for translation, and repeatability for the scapular kinematics was between .68 to .91 (Shih and Kao, 2011). This device was used for measuring the three-dimensional displacement of the scapula in this study.

Procedure

Subjects wore a sleeveless shirt and sat on an adjustable chair with 90° hip and knee flexion and feet on the ground (Ahn et al, 2014). The subject's arm was lying freely at the side of the body. To prevent the compensatory motion of trunk, straps were applied on the rib (Ahn et al, 2014). To measure the scapular size for normalizing scapular abduction distance, the distance between the 3rd thoracic spinous process and root of the scapular spine, and the distance between the 3rd thoracic spinous process and posterolateral acromion were measured (DiVeta et al, 1990). Liberty sensors were attached to the 3rd thoracic spinous process and flat surface on the posterolateral acromion with double-sided tape (Karduna et al, 2001; Ludewig and Cook, 2000; Hsu et al, 2009). The wooden target bar was set to 130° HA measured by goniometer. The subjects abducted their arm to 90° for 5 seconds, moved toward the target bar, and maintained an end position in 5 seconds using metronome for collecting the data of Liberty (Figure 1). At the end position of each trial, the distance between the 3rd thoracic spinous process and root of the scapula was measured by tape measure. Shoulder HA was repeated 3 times with 10 seconds resting time during the trials.

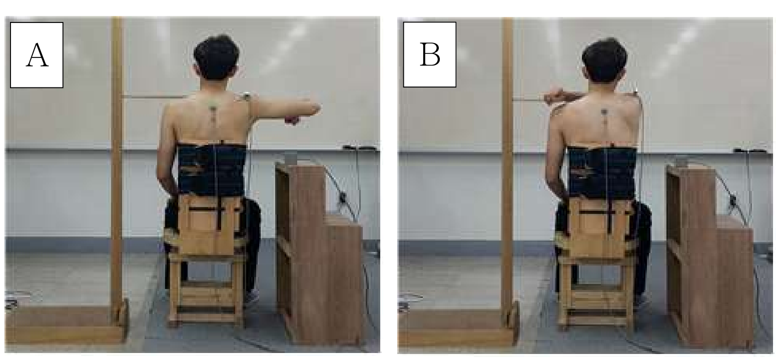

Figure 1. Shoulder horizontal adduction (A: start position, B: end position).

Data collection

To measure the differences between the pre-test and post-test of the normalized scapular abduction distance and three-dimensional displacement of the scapula, post-test value subtracted from pre-test value was calculated.

Normalized scapular abduction distance

The distance of the scapular abduction was needed for normalization because even though the distance from the 3rd spinous process to the root of the scapular spine was the same, the value of the scapular abduction could be different depending on the scapular size (DiVeta et al, 1990). Scapular abduction was normalized to scapular size by dividing the distance from the 3rd thoracic spinous process to posterolateral acromion by the scapular size (DiVeta et al, 1990). To measure the scapular size for normalizing scapular abduction distance, the distance between the 3rd thoracic spinous process and root of the scapular spine subtracted from the distance between the 3rd thoracic spinous process and posterolateral acromion (DiVeta et al, 1990). The total scapular abduction distance at end position was calculated by adding the scapular size and the distance between the 3rd spinous process and root of the scapular spine. Normalized scapular abduction distance was calculated by dividing the total scapular distance at end position into the scapular size (DiVeta et al, 1990) (Figure 2). Normalized scapular abduction distance was measured 3 times at end position. The data were averaged and calculated.

Figure 2. Scapular size was measured by the distance difference value between (A) from the 3rd thoracic spinous process to posterolateral acromion and (B) from the 3rd thoracic spinous process to root of the scapular spine. Normalized scapular abduction distance=[scapular size+(B)]/scapular size.

Three-dimensional displacement of the scapula

Liberty was used for collecting three-dimensional displacement data; however, the tape measure was two-dimensional. The tape measure was used to measure scapular abduction and protraction although scapular movement might result not only to abduction and protraction but also to other movements. Thus, Liberty was used to measure overall scapular movement, namely the three-dimensional displacement of the scapula. Three-dimensional displacement of the scapula was described as the relative orientation between the thoracic spine and scapula, which were measured by Liberty. It was scapular displacement on the basis of the 3rd thoracic spinous process displacement. To calculate the three-dimensional displacement of the scapula, Euler angle was used. The subjects maintained their start position and end position for 5 seconds to save Liberty data. The data during the middle 3 seconds were used and averaged.

Statistical Analysis

For statistical analyses, SPSS ver. 21.0 (SPSS Inc., Chicago, IL, USA) was used. Normal distribution was examined using Kolmogorov-Smirnov Z-test, and an independent t-test was used to compare normalized scapular abduction distance and the distance of scapular movement between groups with LROM and normal ROM. The level of significance was set to .05.

Results

Normalized scapular abduction distance

The results indicate the difference value between the pre-test and post-test of the normalized scapular abduction distance. The change of normalized scapular abduction distance was significantly greater in LROM group compared to normal ROM group ($p<.001$) (Table 2). The ratio of LROM group to normal ROM group was 2.55.

Three-dimensional displacement of the scapula

The three-dimensional displacement of the scapula was expressed as a relative orientation between the thoracic spine movement and scapular movement. The results indicated the difference value between the pre-test and post-test of the three-dimensional displacement of the scapula. The change of three-dimensional displacement of the scapula was significantly greater in LROM group compared to normal ROM group ($p<.05$) (Table 3). The ratio of LROM group to normal ROM group was 1.33.

Discussion

In this study, normalized scapular abduction distance and three-dimensional displacement of the scapula during shoulder HA was investigated in subjects with and without LROM of shoulder HA. Normalized scapular abduction distance was significantly greater in LROM group than normal ROM group. LROM group was 2.55 times as big as normal ROM group. Three-dimensional displacement of the scapula was significantly greater in LROM group than normal ROM group. LROM group was 1.33 times as big as normal ROM group.

LROM group had significantly greater normalized scapular abduction distance than normal ROM group. This can be explained by shortened/dominant posterior deltoid (Sahrmann, 2002). If posterior shoulder is shortened, humeral movement would be followed by the scapula during shoulder HA because the dominance of the posterior deltoid leads to progress of shortness of the posterior deltoid muscle (Sahrmann, 2002). Relative muscle stiffness is defined as a series of springs of diverse stiffness (Sahrmann, 2002). This can be explained by shoulder horizontal abductors being stiffer than shoulder horizontal adductors, so the spring of shoulder horizontal abductor is stronger than the spring of shoulder horizontal adductors. The more flexible the spring is, the easier to move. This means that relative stiffness on posterior deltoid muscle influences this result. Another study indicated that scapula moves and cannot isolate the soft tissue surrounding the posterior GH joint when the horizontal adduction is performed without scapular stabilization (Salamh et al, 2015). This means that if the soft tissue of the posterior GH joint could not be isolated, then scapula would follow the humeral movement. Thus, normalized

Table 2. Comparison of normalized scapular abduction distance between normal ROM group and LROM group

Scapular abduction	Mean±SD[a]	p value
Normal ROM[b] group	.05±.02	<.001
LROM[c] group	.13±.05	

[a]standard deviation, [b]range of motion, [c]limited range of motion.

Table 3. Comparison of the three-dimensional displacement of the scapula between normal ROM group and LROM group (Unit: ㎝)

Displacement of the scapula	Mean±SD[a]	p value
Normal ROM[b] group	2.52±.50	.005
LROM[c] group	3.36±.78	

[a]standard deviation, [b]range of motion, [c]limited range of motion.

scapular abduction distance is more increased in LROM group because of the tightness of the posterior deltoid. Further, LROM group might require scapular stabilization during HA motion for normal scapular position.

Hsu et al (2009) investigated scapular lateral displacement by Liberty during shoulder flexion in scapular plane in subjects with shoulder impingement syndrome. They found that applying kinesiotape in lower trapezius had less lateral displacement of the scapula than not applying kinesiotape. However, scapular abduction occurred in the horizontal plane (Nijs et al, 2007). In Liberty data, LROM group had significantly greater movement distance in the XY plane than normal ROM group (normal ROM group average=2.34, LROM group average=3.15, p=.018). We identified in two ways that when LROM group performed shoulder HA, scapula was more abducted than normal ROM group. Thus, in comparison with the research of Hsu et al (2009), the current study is superior in subjects. Hsu et al (2009) compared the scapular kinematics in subjects with impingement syndrome. But this study compared subjects with and without LROM of HA. In this study, scapular abduction was significantly greater in LROM group compared to normal ROM group (p=.018).

Three-dimensional displacement of the scapula was significantly large in LROM group compared to normal ROM group. The difference between normalized scapular abduction distance and three-dimensional displacement of the scapula was dimensional expression. Two-dimensional data couldn't get the movement of the sagittal and/or coronal plane, but three-dimensional data could get that movement. In three-dimension, scapular displacement can be explained by the tightness of posterior deltoid, infraspinatus, teres minor, and posterior capsule (Dashottar et al, 2014; Lin et al, 2006). Tightness of posterior deltoid, infraspinatus, and teres minor muscle alters the ROM and rotational force (Laudner et al, 2008). Thomas et al (2011) found that the more the posterior capsule was thick, the less was the ROM of GH joint. Our results agree with the results of posterior shoulder tightness in this previous study. Thus scapular stabilization is needed because of the tightness of the muscles and capsule.

Yang et al (2009) demonstrated that posterior shoulder tightness had moderate relationships with humeral internal and external rotation, but it did not investigate the relationship with shoulder horizontal adduction. Other previous studies tried to measure scapular motion during horizontal adduction, but the data were lost because of a computer problem (Karduna et al, 2001). However, Karduna et al (2001) investigated cadaveric study. In this study, we investigated scapular kinematics during active shoulder HA on humans. Muscle tension and skin resistance were not the same in cadaver and human. This study is useful for human scapular kinematics, and individuals with shoulder HA LROM can help explain the scapular stabilization during shoulder HA.

The limitations of the current study should be noted. First, we attached two Liberty sensors at the 3rd thoracic spinous process and posterolateral acromion but previous study used invasive Liberty sensor (Karduna et al, 2001). Second, internal and external shoulder rotation ROM could influence the cause of HA LROM but this study did not investigate. Third, this study didn't distinguish muscles which were causes of LROM. This study investigated shoulder horizontal adductor group. Further study require scapular stabilization during shoulder HA stretching among individuals with shoulder HA LROM based on this study.

Conclusion

This study investigated scapular kinematics during active HA. Our results demonstrate that normalized scapular abduction distance and three-dimensional displacement of the scapula moved more in LROM group. In clinical intervention, stretching exercise of the posterior deltoid, infraspinatus, teres major, latissimus dorsi, and posterior capsule of GH joint, and strengthening exercise of the rhomboid, and lower trapezius could be useful scapular stabilization in the cases of HA LROM patients.

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