J Shoulder Elbow Surg (2018) 27, 1214–1220

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Scapular kinematic alterations during arm elevation with decrease in pectoralis minor stiffness after stretching in healthy individuals

Jun Umehara, MS, PT[a,*], Masatoshi Nakamura, PhD, PT[b], Satoru Nishishita, MS, PT[a], Hiroki Tanaka, MS, PT[c], Ken Kusano, MS, PT[d], Noriaki Ichihashi, PhD, PT[a]

[a]*Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, Japan*
[b]*Institute for Human Movement and Medical Sciences, Niigata University of Health and Welfare, Niigata, Japan*
[c]*Rehabilitation Unit, Kyoto University Hospital, Kyoto, Japan*
[d]*Institute of Sports Science, ASICS Corporation, Kobe, Japan*

Background: Pectoralis minor tightness may be seen in individuals with scapular dyskinesis, and stretching is used for the treatment of altered scapular motion in sports and clinical fields. However, few researchers have reported on the effects of pectoralis minor stiffness on scapular motion during arm elevation. This study investigated whether an acute decrease of pectoralis minor stiffness after stretching changes the scapular motion during arm elevation.
Methods: The study allocated 15 dominant and 15 nondominant upper limbs in healthy men as control and interventional limbs, respectively. In the intervention limb group, the shoulder was passively and horizontally abducted at 150° of elevation for 5 minutes to stretch the pectoralis minor muscle. Before and after stretching, an electromagnetic sensor was used to examine 3-dimensional scapular motion during abduction and scaption. Ultrasonic shear wave elastography was used to measure pectoralis minor stiffness before and immediately after stretching and after arm elevation.
Results: In the interventional limb, pectoralis minor stiffness decreased by 3.2 kPa immediately after stretching and by 2.5 kPa after arm elevation. The maximal changes in scapular kinematics after stretching were 4.8° of external rotation and 3.3° of posterior tilt in abduction, and 4.5° of external rotation and 3.7° of posterior tilt in scaption. Upward rotation in abduction or scaption did not change.
Conclusions: Stretching for the pectoralis minor muscle increases external rotation and posterior tilt of the scapula during arm elevation.
Level of evidence: Basic Science Study; Kinesiology

Keywords: Shoulder; physical therapy; biomechanics; stretching; muscle stiffness; elastography; pectoralis minor muscle

The study design was approved by the Kyoto University Graduate School and the Faculty of Medicine Ethics Committee (R0233) and conformed to the principles of the Declaration of Helsinki.

*Reprint requests: Jun Umehara, MS, Human Health Sciences, Graduate School of Medicine, Kyoto University, 53 Shogoin-Kawahawa-cho, Kyoto 606-8507, Japan.

E-mail address: umehara.jun.77z@st.kyoto-u.ac.jp (J. Umehara).

The shoulder joint consists of the scapula, humerus, and clavicle and is one of the largest and most complex joints in humans. The coordinated movement of these bones is important for optimal shoulder motion. Early authors investigating scapula motion in healthy individuals defined scapulohumeral

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2018.02.037

rhythm,[10] and it has been established that the scapula rotates upward, externally, and tilts posteriorly during arm elevation in healthy individuals.[11,19,22] Additional researchers reported that scapular motion of patients with impingement syndrome or glenohumeral instability was decreased in external and upward rotation and posterior tilt compared with that of healthy individuals.[4,17,21] Scapular dyskinesis has been defined as the set of abnormal motions and positions of the scapula,[13] and the evaluation and treatment for scapular dyskinesis may be essential for shoulder rehabilitation.

Studies have shown that the onset of scapular dyskinesis is related to the tightness of soft tissue surrounding the scapula.[7,14] The tightness of the pectoralis minor muscle (PMi),[7,14] the short head of the biceps brachii,[14] the levator scapula,[7] or the rhomboid[7] has been speculated to cause scapular dyskinesis. Of these shoulder muscles, the PMi is the only muscle whose relationship between tightness and scapular dyskinesis has been verified by experimental study. Borstad et al[3] examined 3-dimensional (3D) scapular motion during elevation in healthy individuals with and without a shortened PMi and showed that a decrease in external rotation and posterior tilt are seen in individuals with a shortened PMi. The altered scapular kinematics, which is found in individuals with shortened PMi, seen in this previous study[3] was similar to that observed in many patients with shoulder disease.[15,17] PMi tension may therefore be an important factor in scapular dyskinesis.

Stretching is applied as an approach to scapular dyskinesis caused by the PMi tightness. Borstad et al[2] recommended a unilateral corner stretch as one self-stretch method for the PMi. Umehara et al[31] also showed that shoulder horizontal abduction at an elevation of 150° was the most effective stretching technique for the PMi. Considering that there is a correlation between PMi stiffness and scapular dyskinesis, investigating not only the stretching maneuver but also the change in the PMi stiffness and scapular motion after stretching is obviously important. However, few studies have examined this relationship.

The present study investigated whether the acute decrease in PMi stiffness after stretching alters the 3D scapular motion during arm elevation. Borstad et al[3] reported a decrease in external rotation and posterior tilt of scapula in individuals with a shortened PMi compared with healthy individuals. We therefore hypothesized that the decrease in PMi stiffness after stretching augments the external rotation and posterior tilt of the scapula during arm elevation.

Materials and methods

Participants

This study was a controlled experimental study with 20 men (age, 25.4 ± 3.1 years; height, 171.5 ± 5.3 cm; weight, 67.6 ± 8.5 kg) as participants. Dominant and nondominant upper limbs were allocated as control and interventional limbs, respectively. The volunteers were randomly recruited from the students at our institution. Upon selection, the participants orally confirmed that they did not meet the exclusion criteria, which included female gender, designation as an athlete, performance of any extensive exercise, or a history of orthopedic or nervous system disease in the upper limb. Considering that the low body mass index minimized skin motion artifacts in the measurement of scapular motion during arm elevation, we also excluded those with a body mass index >25 kg/m^2, calculated using the height and weight. Before the experiment, 4 men—1 with a daily extensive exercise regimen, 1 with a history of shoulder pain, and 2 with a high body mass index—were excluded. The aim and procedures of the study were explained to all volunteers, and informed consent was obtained.

Experimental procedures

The participants, while sitting on a wooden stool, performed shoulder abduction (elevation in the coronal plane) and scaption (elevation in the scapular plane) before and after the PMi stretching. The stretching procedure of the PMi is described in detail in our previous study (Fig. 1).[31] The participants underwent stretching to the point of discomfort (but not pain) for 5 minutes (30 seconds, 10 repetitions, 10-second intervals). Each elevation plane was marked on the floor using sections of elastic tape. In the starting posture, keeping the upper limb aside the body with the elbow fully extended, the palm facing the body, and the eyes looking straight forward on the target at eye height, the participant was asked to raise his arm to full elevation in 4 seconds and then lower it to starting position in 4 seconds 3 times consecutively to the rhythm of a metronome with 60 beats/

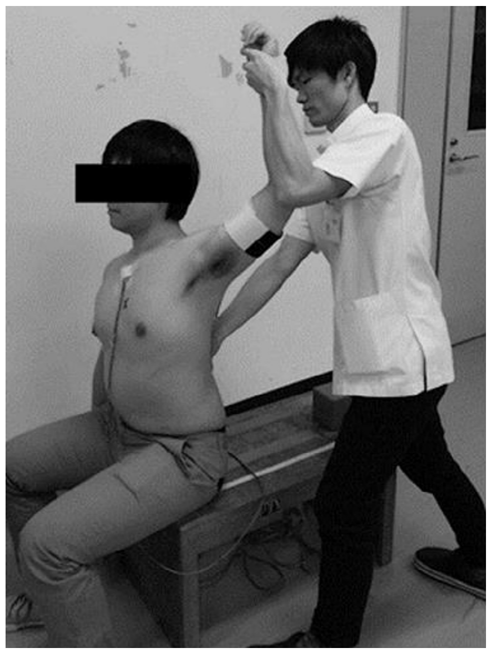

Figure 1 Stretching of the pectoralis minor muscle. As directed, the participant sat on the wooden stool. The interventional limb was brought to maximal horizontal abduction and external rotation at an arm elevation of 150° with the elbow in 90° flexion and was subsequently maximally externally rotated by the investigator. During the stretching, the participants was instructed to remain relaxed. The investigator used 1 hand to move the participant's upper limb and used the other hand to hold the trunk.

min. The participant underwent sufficient familiarization to the abduction and scaption before the assessment.

Instrumentation

Scapular kinematics

The 3D motion of the shoulder complex during arm elevation before and after stretching was measured using a Liberty electromagnetic tracking device (Polhemus, Colchester, VT, USA) at 120 Hz. This system consists of a transmitter, 5 sensors, and a digitizing stylus operated by an electronic unit. The transmitter was fixed on a rigid wooden board at a height of 40 cm from the floor and 30 cm behind the participants. An electromagnetic field generated by the transmitter was sensed by these sensors and the stylus. This electromagnetic field represented the global coordinate system, with the *x*-axis pointing forward, the *y*-axis pointing upward, the *z*-axis pointing to the right, and the origin located at the transmitter.

Next, the sensors were attached to the bony landmarks of the participants with adhesive tape. The thoracic sensor was placed on the sternum just inferior to the jugular notch, the humeral sensor was placed on the middle point of the humerus with a thermoplastic cuff, and the scapular sensor was placed on the flat surface of the acromion. The placement of these sensors was used to establish the local coordinate system of the thorax, humerus, and scapula by digitizing each bony landmark. All definitions of the local coordinate system were in accordance with the shoulder standardization proposal of the International Society of Biomechanics,[33] and the glenohumeral rotation center in the humeral segment was defined with reference to the previous study.[23]

The rotation of the distal coordinate system was described with respect to the proximal coordinate system, according to the Euler angles of the International Society of Biomechanics.[33] To describe the joint motion in correspondence with human kinesiology, the motion of the scapula around the *y*s-axis was defined as internal rotation (positive) and external rotation (negative), the motion around the *x*s-axis was defined as downward rotation (positive) and upward rotation (negative), the motion around *z*s-axis was defined as posterior tilt (positive) and anterior tilt (negative), and the motion of the humerus around *x*h-axis was defined as elevation (positive; Fig. 2). These motions were calculated using MATLAB software (The Math Works, Natick, MA, USA).

The scapular rotation was measured in every 10° of humeral elevation relative to the thorax, from 30° to 120° of humeral elevation. These angles were selected because the previous study[12] reported that there was little influence of the artifact of soft tissue on measuring the scapular motion in humeral elevations of less than 120° using a surface method. The elevation was examined 3 times, and the mean value was used for analysis.

Muscle stiffness

PMi stiffness was measured before stretching, immediately after stretching, and after arm elevation using ultrasonic shear wave elastography (Aixplorer; SuperSonic Imagine, Aix-en-Provence, France) with an ultrasound transducer (SL15-4: 4 to 15 MHz linear probe; Fig. 3). The ultrasonic shear wave elastography uses acoustic radiation forces to monitor the propagation of shear waves generated in tissue and is able to evaluate the tissue elasticity of individual muscles.[28] The shear elastic modulus of the muscle represents muscle stiffness and has been used as a quantitative indicator of the stretching effect in many previous studies.[24,29,34] The shear elastic

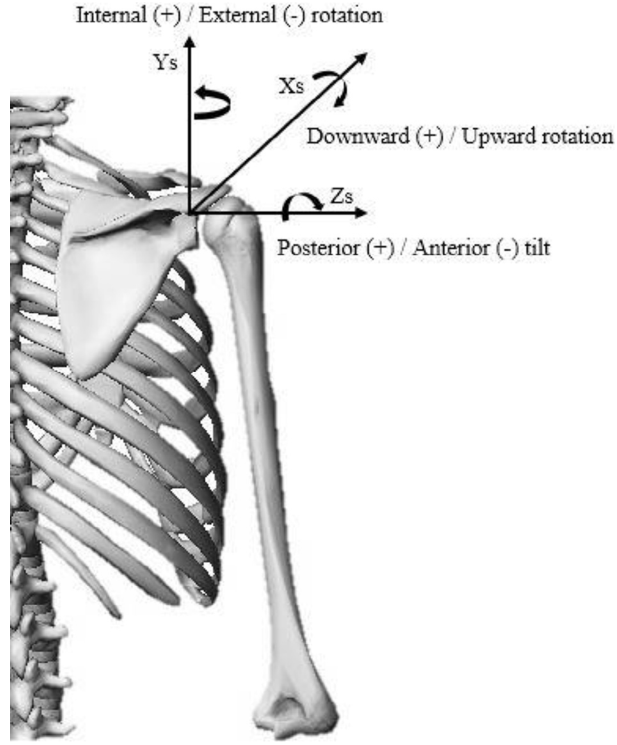

Figure 2 The definition of coordinate systems and motions relative to the thorax for the scapula. The scapulae are seen in the posterior view of the right shoulder.

modulus (G) was calculated from the shear wave propagation speed (V) generated by the transducer using the formula of $G = \rho V^2$, in which ρ is the muscle density (1000 kg/m^3). The validity of applying the shear wave elastography to evaluate the skeletal muscle was reported in a previous study.[8] The stiffness was measured 3 times in each session, and the mean value was used for analysis. Calculation of the stiffness was blinded by anonymizing the ultrasound image, and a region of interest of the shear modulus was carefully chosen as large as possible with exclusion of subcutaneous adipose tissues and aponeuroses.

For the reliability study, PMi stiffness was measured in 10 healthy men (age, 24.9 ± 1.5 years; height, 171.7 ± 6.5 cm; weight, 70.4 ± 7.8 kg) before this study. After the above-mentioned measurement method was completed, stiffness was measured 3 times with a sufficient rest interval. The intraobserver reliability of the ultrasound measurement was confirmed using the intraclass correlation coefficient (1,3) ($ICC_{1,3}$) with the 95% confidence interval (95% CI). $ICC_{1,3}$ was 0.99 (95% CI, 0.97-0.99). A previous study investigating the reliability coefficient reported that a range from 0.81 to 1.00 was "almost perfect" reproducibility.[16] The measurement of PMi stiffness in our study, therefore, was considered to be reproducible.

Data analysis

Only those participants whose decrease in muscle stiffness remained until after arm elevation were analyzed in this study. We focused on the effect of the decrease in PMi stiffness on the scapular motion but not PMi stretching so that we could examine the direct relationship between PMi stiffness and scapular motion.

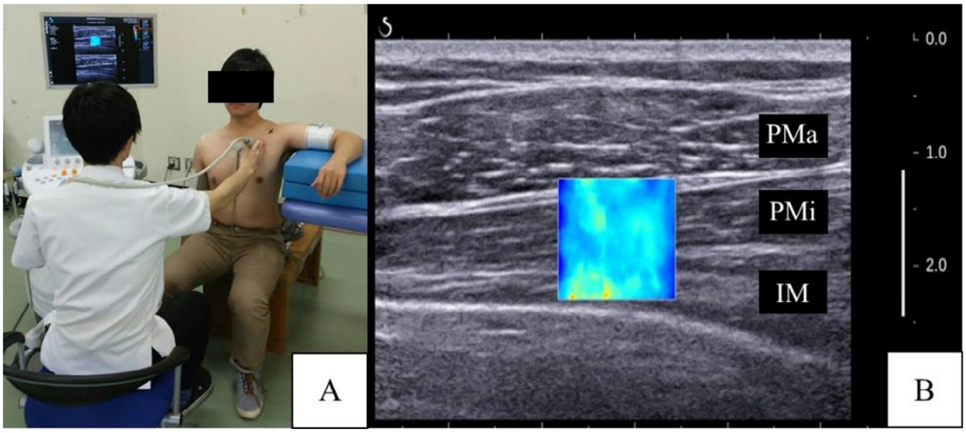

Figure 3 (**A**) Posture and measurement site of pectoralis minor stiffness. The participant sat on a wooden stool with his arm relaxed on a platform in a position with 90° of shoulder abduction and 90° of elbow flexion. The measurement site was defined as the midpoint between the coracoid process and the fourth rib and sternum junction. (**B**) The probe was placed parallel to the muscle fascicle of the pectoralis minor muscle (*PMi*) on the ultrasound image. The participant was instructed to hold his breath during the measurement to prevent elongation of the PMi caused by motion of the rib cage. *PMa*, pectoralis major muscle; *IM*, intercostal muscle.

Statistical analysis was performed with IBM SPSS Statistical 22 software (IBM, Armonk, NY, USA).

A paired *t* test was performed to compare the stiffness in raw data before stretching in the interventional and the control limbs. The amount of change in the stiffness was calculated by subtracting the value of the stiffness before stretching from that present immediately after stretching or after elevation. For the change in stiffness, a 2-way analysis of variance (ANOVA) with repeated measures on 2 factors [limb (2 levels, interventional limb; control limb) × time (2 levels, immediately after stretching – before stretching; after arm elevation – before stretching)] was used to demonstrate that the stretching decreased PMi stiffness. If a significant main effect was found, then a Bonferroni post hoc test was performed. A confidence level of .05 was used in all statistics tests. Cohen *d* values were also reported as the effect size, with the values of 0.2, 0.5, and 0.8 considered to elicit small, moderate, and large effects, respectively.[6]

The amount of change in scapular motion was calculated by subtracting the value of scapular motion before stretching from the value after stretching. For the change in each scapular motion (ie, internal/external rotation, downward/upward rotation, or posterior/anterior tilt), a 2-way ANOVA with repeated measures on 2 factors [limb (2 levels, interventional limb; control limb) × angle (10 levels, every 10° from 30° to 120°)] was used to determine the effects of the change in PMi stiffness on scapular motion during elevation. If a significant interaction was found, then a paired *t* test for post hoc test was performed to compare the interventional limb with the control limb with respect to each angle. If a significant main effect of the side was also found, then a Bonferroni post hoc test was performed to compare the interventional limb with the control limb. The significant main effect of the angle was ignored because the present study was interested in the comparison between the interventional limb and the control limb.

Results

In the dominant limb, the decrease in the PMi stiffness immediately after stretching and after arm elevation occurred in 15 men (age, 24.9 ± 3.3 years; height, 171.9 ± 5.9 cm; weight, 67.2 ± 8.4 kg); therefore, the results of these 15 men (30 shoulders) are shown below.

The paired *t* test showed no significant differences between the interventional limb and the control limb in stiffness before stretching (95% CI, –0.24 to 7.98; $P = .063$,). For the amount of change in the stiffness, a 2-way ANOVA indicated a significant main effect of the limb but not the time, with no significant interaction between the limb and the time (Table I).

The raw value and the amount of change in scapular motion for abduction are reported in Table S1. For the amount of change in the internal/external rotation of scapula, a 2-way ANOVA showed a significant interaction between the limb and the angle ($F = 4.519$, $P = .029$). Then, a post hoc test indicated that the change in the interventional limb was significantly greater than that in the control limb from 40° to 120° abduction ($P = .001$-.014), and an increase in external rotation in the interventional limb was found after stretching. For the amount of change in the downward/upward rotation of the scapula, there were no significant interactions between the limb and the angle ($F = 0.345$, $P = .726$) and no significant main effect in the limb ($F = 0.129$, $P = .725$). For the amount of change in the posterior/anterior tilt of scapula, a 2-way ANOVA showed no significant interaction between the limb and the angle ($F = 0.891$, $P = .378$), but a significant main effect in the limb was seen ($F = 4.966$, $P = .043$). A post hoc test indicated that the change in the interventional limb was significantly greater than that in the control limb ($P = .043$) and that the posterior tilt in the interventional limb increased after stretching throughout the full evaluated range.

The raw value and the amount of change in scapular motion for scaption are reported in Table S2. For the amount of change in the internal/external rotation of scapula, a 2-way ANOVA showed a significant interaction between the limb and the angle ($F = 6.655$, $P = .004$). Then, a post hoc test

Table I Pectoralis minor muscle stiffness before and after the assessment

Variable	Pectoralis minor stiffness (kPa)		Statistical significance	
	Interventional limb	Control limb	Interaction	Main effect
Before stretching			$F = 1.935$; $P = .186$	Limb: $F = 14.140$; $P = .002$
Raw value	12.7 ± 3.6	11.4 ± 3.8		Time: $F = 0.869$; $P = .367$
Change	–	–		
Effect size (*d*)	–			
Immediately after stretching				
Raw value	9.4 ± 2.2	11.0 ± 3.4		
Change	−3.2 ± 2.0	−0.4 ± 2.4		
Effect size (*d*)	1.2			
After arm elevation				
Raw value	10.2 ± 2.5	10.8 ± 3.6		
Change	−2.5 ± 1.9	−0.6 ± 2.0		
Effect size (*d*)	0.9			

Change, amount of change between before and after stretching, and before and after arm elevation.
Data are shown as the mean ± standard deviation.

indicated that the amount of change from 40° to 120° in the interventional limb was significantly greater than that in the control limb ($P = .001$-$.034$) and that the external rotation in the interventional limb increased after stretching. For the amount of change in the downward/upward rotation of the scapula, there were no significant interactions between the limb and the angle ($F = 0.295$, $P = .750$) and no significant main effect in the limb ($F = 0.006$, $P = .940$). For the amount of change in the posterior/anterior tilt of the scapula, a 2-way ANOVA showed a significant interaction between the limb and the angle ($F = 4.397$, $P = .032$). Then, a post hoc test indicated that the amount of change from 50° to 120° in the interventional limb was significantly greater than in the control limb ($P = .006$-$.035$) and that the posterior tilt in the interventional limb increased after stretching.

Discussion

The present study investigated the effects of PMi stiffness on 3D scapular motion during arm elevation and found a decrease in PMi stiffness and an increase in external rotation and posterior tilt of the scapula after stretching. These results indicate that the alteration in scapular motion in combination with decrease in PMi stiffness occurred after stretching and accorded with our hypothesis. To the best of our knowledge, this is the first study to demonstrate that an acute decrease in PMi stiffness after stretching changes the 3D scapular motion during arm elevation.

The decrease in the PMi stiffness occurred immediately after stretching and lasted until after arm elevation. The previous study[24] showed a positive correlation between the rate of change in the shear elastic modulus and the rate of change in muscle stiffness, and therefore, the decrease seen in the shear elastic modulus after stretching indicates a decrease in muscle stiffness (a so-called increase in the muscle flexibility).[1,9,30,34] Therefore, the decrease in PMi stiffness immediately after stretching and after arm elevation confirmed that the stretching used in the current study was sufficient in decreasing PMi stiffness until the end of the evaluation.

To the best of our knowledge, only 1 study has investigated the relationship between the acute change in the flexibility of the PMi and 3D scapular motion. Williams et al[32] measured PMi length (coracoid process to fourth rib) and scapular kinematics before and after 2 types of stretching, focused stretch or gross stretch, for 1 minute (30 seconds, 2 repetitions, 30-second intervals). They[32] concluded that no changes occurred in the scapular kinematics after either form of stretching, which was inconsistent with our results, which noted that a change in scapular motion occurred after PMi stretching. This discrepancy between the previous study and our results could be attributed to the duration time and the index of stretching effect.

Among various studies on stretching duration, a study by Nakamura et al[25] examined the minimum time required for stretching to change the passive property. They concluded that stretching for more than 2 minutes was recommended to decrease the passive property of the gastrocnemius muscle.[25] Therefore, although it is necessary to consider the difference in the muscles studied, the stretching duration of the PMi was possibly insufficient to elicit a change in scapular kinematics in the study by Williams et al.[32] Furthermore, there is also a possibility the length of the PMi may not be sufficient to represent PMi flexibility due to the bias of skin, soft tissues, or posture. In contrast, we measured the PMi stiffness quantitatively using the shear elastic modulus measured by ultrasonic shear wave elastography. Our study might therefore be more valid than their study in investigating the relation of PMi stiffness and scapular motion.

These results mean that the decrease in PMi stiffness after stretching induced the external rotation and posterior tilt of scapula. The scapula generally rotates upward and externally and tilts posteriorly during arm elevation in healthy individuals.[12,18,22] PMi tightness might cause the internal and downward rotation and anterior tilt of scapula from an anatomic perspective.[5,20,26] Borstad et al[3] showed that external rotation and posterior tilt in individuals with shortened PMi muscles were decreased compared with individuals with a long PMi during arm elevation. Therefore, considering these studies, our results suggested that the scapular external rotation and posterior tilt increased in abduction and scaption with a decrease in PMi stiffness. For the posterior tilt in the interventional limb group after stretching, there were differences in the amount of change between abduction and scaption. These differences in behavior, in which the increase in posterior tilt occurred from 30° to 120° in abduction and from 50° to 120° in scaption, might depend on the difference in the plane of elevation. Compared with scaption, abduction needs a slightly greater posterior tilt of the scapula, due to the difference of the plane, although there are no significant differences.[19] Therefore, it is rational that the posterior tilt of the scapula may arise from the early phase of abduction by the decrease in PMi stiffness.

The maximum amount of change in external rotation and the posterior tilt were 4.8° and 3.3° in abduction and 4.5° and 3.7° in scaption. Ludewig and Cook[17] reported that individuals with shoulder impingement had increased internal rotation, decreased upward rotation, and decreased posterior tilt during arm elevation. Their previous[17] study suggested that 4° to 6° of change in scapular motion is important in narrowing of the subacromial space and the occurrence of impingement, because individuals with impingement syndrome showed increased internal rotation of 5.2°, decreased upward rotation of 4.1°, and increased anterior tilt of 5.8° compared with healthy individuals.

We believe our findings are of clinical relevance because the change in scapular motion after stretching shown in the present study approximately corresponded with the range of changes seen in scapular motion between healthy individuals and those with impingement syndrome indicated in Ludewig and Cook's study.[17] The change in the scapular motion after the stretching observed in the current study may be of clinical significance; however, further research is warranted to validate these theories within individuals with shoulder pathology.

However, one should note some limitations when interpreting our findings. First, the participants were all healthy men, as prescribed by the exclusion criteria. Therefore, whether the findings can be generalized to individuals with impingement syndrome is unclear.

Second, the stiffness of only the PMi was measured among the shoulder girdle muscles. Therefore, this study does not exactly promise that only a decrease in the PMi stiffness changed the scapular kinematics, and it is possible that other muscles, such as the pectoralis major muscle, the subscapularis muscle, or glenohumeral ligaments and capsules, were also stretched and thus had an effect. This is the limitation of an in vivo study.

Third, the current study investigated only the acute effect of PMi stretching on scapular motion, so its long-term effect is unknown. The recent study examining the effects of self-stretching of the PMi for 6 weeks on scapular kinematics concluded that stretching did not change PMi length and scapular kinematics in individuals with and without shoulder pain.[27] Therefore, future study should evaluate the long-term effects of the therapist-applied PMi stretching on muscle stiffness and scapular motion.

Conclusion

We investigated the effects of PMi stiffness after stretching on the change in scapular motion during arm elevation. Our results indicated a decrease in PMi stiffness, increased external rotation, and posterior tilt of the scapula occurred during arm elevation after stretching. These findings might be relevant knowledge for the approach to scapular dyskinesis and in further studies.

Disclaimer

This study was supported by the Grant-in-Aid for Scientific Research (B) 15H03043.

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2018.02.037.

References

1. Akagi R, Takahashi H. Acute effect of static stretching on hardness of the gastrocnemius muscle. Med Sci Sports Exerc 2013;45:1348-54. http://dx.doi.org/10.1249/MSS.0b013e3182850e17
2. Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. J Shoulder Elbow Surg 2006;15:324-30. http://dx.doi.org/10.1016/j.jse.2005.08.011
3. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. J Orthop Sports Phys Ther 2005;35:227-38. http://dx.doi.org/10.2519/jospt.2005.35.4.227
4. Borstad JD, Ludewig PM. Comparison of scapular kinematics between elevation and lowering of the arm in the scapular plane. Clin Biomech (Bristol, Avon) 2002;17:650-9. http://dx.doi.org/10.1016/S0268-0033(02)00136-5
5. Burkhart SS, Morgan CD, Ben Kibler W. The disabled throwing shoulder: spectrum of pathology part I: pathoanatomy and biomechanics. Arthroscopy 2003;19:404-20. http://dx.doi.org/10.1053/jars.2003.50128
6. Cohen J. Statistical power analysis. Curr Dir Psychol Sci 1992;1:98-101.
7. Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Cagnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite

overhead athlete. Br J Sports Med 2014;48:692-7. http://dx.doi.org/10.1136/bjsports-2013-092148
8. Eby SF, Song P, Chen S, Chen Q, Greenleaf JF, An KN. Validation of shear wave elastography in skeletal muscle. J Biomech 2013;46:2381-7. http://dx.doi.org/10.1016/j.jbiomech.2013.07.033
9. Ichihashi N, Umegaki H, Ikezoe T, Nakamura M, Nishishita S, Fujita K, et al. The effects of a 4-week static stretching programme on the individual muscles comprising the hamstrings. J Sports Sci 2016;34:2155-9. http://dx.doi.org/10.1080/02640414.2016.1172725
10. Inman VT, Saunders FR, Abbott LC. Observations on the function of the shoulder joint. J Bone Joint Surg Am 1944;26:1-30.
11. Johnson GR, Stuart PR, Mitchell S. A method for the measurement of three-dimensional scapular movement. Clin Biomech (Bristol, Avon) 1993;8:269-73.
12. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurements of three-dimensional scapular kinematics: a validation study. J Biomech Eng 2001;123:184-90.
13. Kibler WB. The role of the scapula in athletic shoulder function. Am J Sports Med 1998;26:325-37.
14. Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the "Scapular Summit". Br J Sports Med 2013;47:877-85. http://dx.doi.org/10.1136/bjsports-2013-092425
15. Kijima T, Matsuki K, Ochiai N, Yamaguchi T, Sasaki Y, Hashimoto E, et al. In vivo 3-dimensional analysis of scapular and glenohumeral kinematics: comparison of symptomatic or asymptomatic shoulders with rotator cuff tears and healthy shoulders. J Shoulder Elbow Surg 2015;24:1817-26. http://dx.doi.org/10.1016/j.jse.2015.06.003
16. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
17. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. Phys Ther 2000;80:276-91.
18. Ludewig PM, Cook TM, Nawoczenski DA. Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation. J Orthop Sports Phys Ther 1996;24:57-65.
19. Ludewig PM, Phadke V, Braman JP, Hassett DR, Cieminski CJ, LaPrade RF. Motion of the shoulder complex during multiplanar humeral elevation. J Bone Joint Surg Am 2009;91:378-89. http://dx.doi.org/10.2106/JBJS.G.01483
20. Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. J Orthop Sports Phys Ther 2009;39:90-104. http://dx.doi.org/10.2519/jospt.2009.2808
21. Matias R, Pascoal AG. The unstable shoulder in arm elevation: a three-dimensional and electromyographic study in subjects with glenohumeral instability. Clin Biomech (Bristol, Avon) 2006;21:S52-8. http://dx.doi.org/10.1016/j.clinbiomech.2005.09.014
22. McClure PW, Michener LA, Sennett BJ, Karduna AR. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. J Shoulder Elbow Surg 2001;10:269-77.
23. Murray IA. Determining upper limb kinematics and dynamics during everyday tasks [PhD thesis]. Newcastle upon Tyne: Department of Mechanical, Materials and Manufacturing Engineering, University of Newcastle upon Tyne; 1999. <https://theses.ncl.ac.uk/dspace/bitstream/10443/185/1/murray99.pdf> accessed March 10, 2018.
24. Nakamura M, Ikezoe T, Kobayashi T, Umegaki H, Takeno Y, Nishishita S, et al. Acute effects of static stretching on muscle hardness of the medial gastrocnemius muscle belly in humans: an ultrasonic shear-wave elastography study. Ultrasound Med Biol 2014;40:1991-7. http://dx.doi.org/10.1016/j.ultrasmedbio.2014.03.024
25. Nakamura M, Ikezoe T, Takeno Y, Ichihashi N. Time course of changes in passive properties of the gastrocnemius muscle-tendon unit during 5 min of static stretching. Man Ther 2013;18:211-5. http://dx.doi.org/10.1016/j.math.2012.09.010
26. Novak CB, Mackinnon SE. Repetitive use and static postures: a source of nerve compression and pain. J Hand Ther 1997;10:151-9.
27. Rosa DP, Borstad JD, Pogetti LS, Camargo PR. Effects of a stretching protocol for the pectoralis minor on muscle length, function, and scapular kinematics in individuals with and without shoulder pain. J Hand Ther 2017;30:20-9. http://dx.doi.org/10.1016/j.jht.2016.06.006
28. Shiina T, Nightingale KR, Palmeri ML, Hall TJ, Bamber JC, Barr RG, et al. WFUMB guidelines and recommendations for clinical use of ultrasound elastography: part 1: basic principles and terminology. Ultrasound Med Biol 2015;41:1126-47. http://dx.doi.org/10.1016/j.ultrasmedbio.2015.03.009
29. Taniguchi K, Shinohara M, Nozaki S, Katayose M. Acute decrease in the stiffness of resting muscle belly due to static stretching. Scand J Med Sci Sports 2015;25:32-40. http://dx.doi.org/10.1111/sms.12146
30. Umehara J, Hasegawa S, Nakamura M, Nishishita S, Umegaki H, Tanaka H, et al. Effect of scapular stabilization during cross-body stretch on the hardness of infraspinatus, teres minor, and deltoid muscles: an ultrasonic shear wave elastography study. Musculoskelet Sci Pract 2017;27:91-6. http://dx.doi.org/10.1016/j.math.2016.10.004
31. Umehara J, Nakamura M, Fujita K, Kusano K, Nishishita S, Araki K, et al. Shoulder horizontal abduction stretching effectively increases shear elastic modulus of pectoralis minor muscle. J Shoulder Elbow Surg 2017;26:1159-65. http://dx.doi.org/10.1016/j.jse.2016.12.074
32. Williams JG, Laudner KG, McLoda T. The acute effects of two passive stretch maneuvers on pectoralis minor length and scapular kinematics among collegiate swimmers. Int J Sports Phys Ther 2013;8:25-33.
33. Wu G, van der Helm FC, Veeger HE, Makhsous M, Van Roy P, Anglin C, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion—part II: shoulder, elbow, wrist and hand. J Biomech 2005;38:981-92. http://dx.doi.org/10.1016/j.jbiomech.2004.05.042
34. Yamauchi T, Hasegawa S, Nakamura M, Nishishita S, Yanase K, Fujita K, et al. Effects of two stretching methods on shoulder range of motion and muscle stiffness in baseball players with posterior shoulder tightness: a randomized controlled trial. J Shoulder Elbow Surg 2016;25:1395-403. http://dx.doi.org/10.1016/j.jse.2016.04.025