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Original Article

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Comparisons of Shoulder Muscle Activity and Muscle Activity Ratio during Serratus Anterior Exercise between CrossFit Practitioners with/without Shoulder Impingement Syndrome

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Purpose: Due to the high incidence of shoulder injuries, including shoulder impingement syndrome (SIS), among CrossFit practitioners due to frequent overhead movements, serratus anterior exercises are considered crucial for scapular stabilization in both intervention and prevention.

Objective: The objective of this study is to compare the muscle activity and ratios of scapular stabilizing and shoulder girdle muscles between individuals with and without SIS during serratus punch and wall slide exercises, both targeting the serratus anterior muscle, in CrossFit training practitioners.

Methods: Surface electromyography was used to compare the muscle activity and activity ratio of scapular stabilizing muscles and shoulder muscles during serratus punch and wall slide exercises in two groups of 20 CrossFit practitioners: ten with SIS and ten without symptoms.

Results: The group with SIS showed higher activation of the pectoralis major, upper trapezius, and a higher pectoralis major/serratus anterior and upper trapezius/serratus anterior muscle activation ratio during the serratus punch exercise compared to the group without SIS. Similarly, during the wall slide exercise, the group with SIS exhibited higher activation of the upper trapezius and a higher upper trapezius/serratus anterior muscle activation ratio compared to the group without SIS. However, no significant difference in serratus anterior muscle activation was observed between the two groups.

Conclusions: This study highlights the higher activation of the pectoralis major and upper trapezius muscles in CrossFit practitioners with SIS during the serratus anterior exercise, suggesting the importance of minimizing the overactivation of these muscles to prevent impingement syndrome in this population.

Keywords: Crossfit, Shoulder impingement syndrome, Serratus punch exercise, Wall slide exercise

INTRODUCTION

CrossFit is recognized as one of the fastest-growing exercises for high-intensity functional training.[1] Like other high-intensity exercises, CrossFit has the advantage of increasing VO2 max, power, strength, and endurance while decreasing lean body mass.[2] Previous studies have reported that athletes who perform overhead movements are at a higher risk of shoulder pain and injury related to shoulder impingement syndrome.[3] Shoulder impingement syndrome refers to the narrowing of the subacromial space, which causes erosion of subacromial tissues such as the rotator cuff and bursa.[4] Carbone et al.,[5] reported that CrossFit athletes might develop rotator cuff lesions due to various exercises performed with load during abduction and flexion movements, accompanied by shoulder external rotation. In addition, it has been reported that CrossFit participants may place their shoulders in a vulnerable position by performing shoulder flexion, abduction, and internal rotation, which can lead to damage to the shoulder tissues.[6] General physiotherapy interventions for this impingement syndrome consist of stretching, strengthening, and neuromuscular con-

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trol of the shoulder muscles.[7,8] Specifically, scapular stability exercises have been reported to be effective in reducing pain and functional impairment in subjects with subacromial impingement syndrome in several studies, including that of Ravichandran et al.[8]

The serratus anterior muscle is closely related to scapular stability, and previous studies have introduced various serratus anterior exercises aimed at promoting scapular stability in the context of interventions for subacromial impingement syndrome.[9,10] Decreased scapular upward rotation during shoulder elevation can reduce the subacromial space, impede tissue healing, and contribute to an increase in symptomatic impingement.[11,12] In addition, upward rotation of the scapula by the serratus anterior is a critical movement during shoulder elevation, achieved with the force-couple of the upper trapezius.[13] Therefore, identifying the muscle activity of the serratus anterior muscle, which is closely related to the stability of the scapula during exercise, and the muscle activity of the upper trapezius muscle, which can cause impingement syndrome, are important indicators in impingement syndrome rehabilitation. Various exercises involving adduction and upward rotation of the serratus anterior, such as push-up plus, serratus anterior punch, dynamic hug, and wall slide, have been introduced for the prevention and rehabilitation of shoulder impingement syndrome.[10,13] The serratus punch and wall slide exercises have gained attention for specific reasons. The serratus punch exercise activates the serratus anterior muscle through scapular protraction, providing stability during the plus-phase, and exhibits higher serratus anterior activity compared to other exercises involving the plus-phase.[14] However, if there is paralysis, weakness, or dysfunction of the serratus anterior responsible for protraction, it can cause anterior humeral translation due to overactivation of the pectoralis major during the early and mid-phases of movement, leading to shoulder impingement syndrome.[14] Therefore pectoralis muscle activity is very important to decide shoulder conditions in impingement syndrome. Activating the serratus anterior to ensure proper protraction action is closely related to preventing impingement syndrome. The wall slide exercise effectively increases upward rotation of the serratus anterior muscle by elevating the shoulder from 90 degrees to 180 degrees. Notably, in Hardwick et al.[10], the wall slide exercise was found to be beneficial for early shoulder rehabilitation as it allows for reduced load by partially supporting the weight of the arms against the wall during execution. The wall slide exercise can serve as an early and suitable exercise for activating the serratus anterior in CrossFit practitioners with impingement syndrome by reducing the load and promoting scapular stability during overhead movements.[10] However, previous studies recommending both the serratus punch and wall slide exercises for serratus anterior activation were conducted on pain-free subjects and did not compare shoulder muscle activation between individuals with pain and healthy participants.[10,14]

The purpose of this study is to compare the muscle activation of the serratus anterior, pectoralis major, and upper trapezius muscles during the performance of serratus punch and wall slide exercises in CrossFit practitioners with and without impingement syndrome to investigate their effects on shoulder movement. Additionally, the study aims to investigate the muscle activation ratio of the pectoralis major and upper trapezius muscles with respect to the serratus anterior muscle. The findings of this study will contribute to a better understanding of the impact of these exercises on shoulder stability and their potential implications for individuals with impingement syndrome. We hypothesized the following: (1) Serratus anterior muscle activity will be lower in the shoulder impingement group during both serratus punch and wall slide exercises compared to the non-impingement group. (2) Pectoralis major muscle activity will be higher in the shoulder impingement group during the serratus punch exercise compared to the non-impingement group. (3) Pectoralis major to serratus anterior activation ratio (PM/SA) will be higher in the shoulder impingement group during the serratus punch exercise compared to the non-impingement group. (4) Upper trapezius muscle activity and upper trapezius to serratus anterior activation ratio (UT/SA) will be higher in the shoulder impingement group during the wall slide exercise compared to the non-impingement group. (5) The pectoralis major and upper trapezius muscle activity, as well as the pectoralis major to serratus anterior activation ratio (PM/SA) and upper trapezius to serratus anterior activation ratio (UT/SA), will be higher in the shoulder impingement group during the serratus punch exercise compared to the wall slide exercise.

METHODS

1. Subjects

This study was conducted from April 2022 to September 2022 with 20 CrossFit practitioners who attended the D CrossFit Center in Gongneung-dong, Nowon-gu, Seoul (10 controls, 10 shoulder impingement syndrome). We compared the muscle activities and activity ratios of the scapular stabilizing muscles and shoulder muscles during Serratus punch and wall slide exercises, respectively, to mitigate any potential order effects in the two groups of participants. This study was conducted with the approval of Dankook University Institutional Review Board (DKU 2022-03-023). All participants signed an informed consent form before participating in the

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study. The authors declare that the study was conducted in accordance with the ethical standards of the Helsinki Declaration. The selection criteria for subjects were as follows:

- 6 months or more of CrossFit experience.
- Individuals with no history of surgery on their neck or shoulder.
- Individuals with no referred pain or neurological symptoms originating from the neck or shoulder.

The exclusion criteria for subjects were as follows:

- Individuals with a history of shoulder dislocation or fracture.
- Individuals with signs of rotator cuff tear.

In this study, 3 participants were excluded based on the exclusion criteria. Two of them had previous shoulder dislocation experiences, and one reported muscle weakness due to rotator cuff tear. Out of the remaining 20 participants, 10 were selected as control subjects without pain in the full range of motion of both shoulders,[14] while the experimental group with shoulder impingement syndrome was identified based on positive signs in at least 3 out of 5 tests described below[15]: (a) Painful arc[16] - pain during shoulder abduction between 60°-120°, (b) Pain or weakness during external rotation resistance, (c) Neer test[17,18] - pain when lifting the arm in the direction of shoulder flexion, (d) Hawkins-Kennedy test[18] - impingement induced by internal rotation of the shoulder joint in 90° forward flexion of the humerus, (e) Empty can test[18] - pain during abduction with resistance.

In this study, all 10 participants classified with impingement syndrome were comprised of individuals who experienced a level of pain that did not hinder the performance of serratus punch and wall slide exercises. Information on the sex, dominant arm, age, CrossFit practice time (months), height, weight, body mass index (BMI), body fat percentage, skeletal muscle mass, basal metabolic rate of all subjects was collected before the experiment (Figure 1).

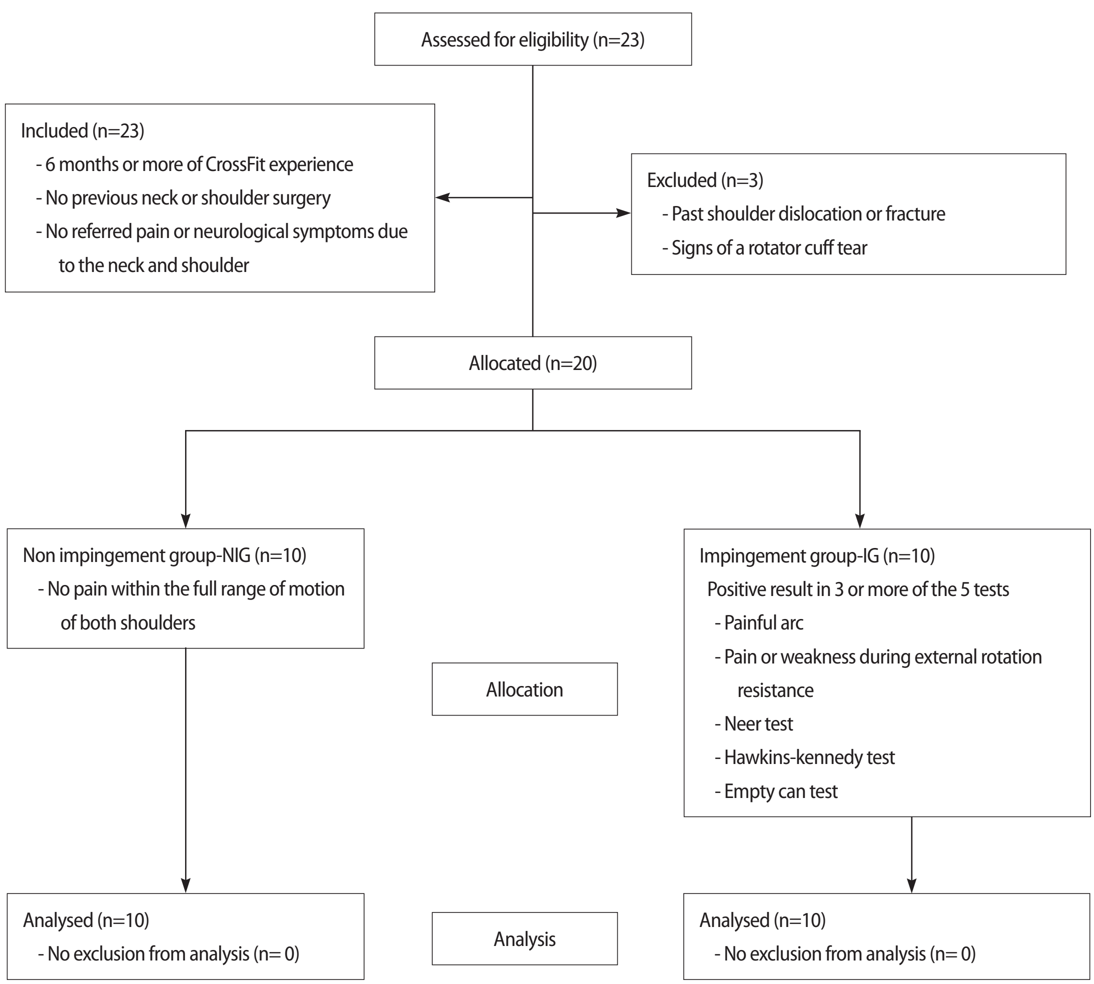

Figure 1. Flow chart of the study

2. Measurements

1) Electromyography (EMG)

Both the experimental group with symptoms of shoulder impingement syndrome and the asymptomatic group used the Desk DTS EMG system (Noraxon Inc., Scottsdale, AZ, USA) to collect and process signals from the upper trapezius muscle, serratus anterior muscle, and pectoralis major muscle on their respective symptomatic and dominant sides. Also, a bipolar surface positive electrode (Biopac System Inc., USA) was used. Acqknowledge 3.9.1 software was used for EMG signal storage and signal processing in this study.

The electrode placement followed previous studies, with the serratus anterior electrode was located on the outside of the scapular inferior angle during shoulder 90° flexion, anterior to latissimus dorsi, and the upper trapezius electrode was located at the midpoint between the 7th cervical spinous process and the outside of the shoulder acromion,[19] while the pectoralis major electrode was attached at a point 2cm medial to the axillary fold.[20] The muscle belly, which is clearly visible during the induction of maximal muscle contraction in the manual strength test was identified, and the EMG attachment site was marked.[10] To remove the resistance of the skin surface to the surface EMG signal, subjects' hair was waxed with a razor, and the skin fat was removed with rubbing alcohol. The ground electrode was fixed and attached with sports tape at a position that does not interfere with MVIC measurement or serratus anterior exercise. The recording electrode was a surface electrode with a radio wave blocking function, and an active electrode with a center-to-center distance of 20mm was used.

Manual muscle testing was conducted for each muscle to measure muscle activity during maximal voluntary isometric contraction (MVIC), followed by the measurement of muscle activity during serratus anterior punch and wall slide exercises.[10,14] During the serratus punch exercise, the subject performed scapular protraction with the shoulder and elbow joints at 90-degree forward flexion while resisting maximum resistance applied by the researcher to the elbow joint.[21,22] For the pectoralis major, the subject placed the palms of both hands together in 90-degree flexion of the elbow joint and 75-degree shoulder abduction.[20] The upper trapezius isometrically resisted the occipital region with the same force applied slightly above the elbow at 90° abduction of the shoulder during neck side-bending and rotation to the opposite side.[19]

Each MVIC muscle contraction lasted 5 seconds and was repeated 3 times with a 10-second rest period between each repetition and a 30-second rest period before moving on to MVIC measurements of other muscles.[14] During the serratus punch and wall slide exercises, the EMG signal measurement was repeated five times. The 1st and 5th signals were excluded, and the values of the 2nd, 3rd, and 4th rounds were processed using the RMS method. The average EMG signal volume for the middle 3 seconds, excluding the first and last 1 second, was used for each muscle's EMG signal for 5 seconds, and %MVIC was calculated using the mean value for analysis after RMS treatment.

A 10-second rest period was provided between repetitions within one exercise, and there was a rest period of at least 1.5 minutes between the serratus punch and wall slide exercises.[14,23] The EMG measurement and data collection followed specific steps: connecting the EMG device and computer, operating the EMG program on the computer, setting the test parameters for muscle activity, and designating channels to receive the EMG signals from each channel (Channel 1/Channel 2/Channel 3). The sample rate for the EMG signal was set to 1,000Hz, and after measuring MVIC, %MVIC raw data was extracted through the MVIC value and the muscle activity observed during intervention.[24] The amplified waveform of the raw data was filtered with a band-pass filter of 10-1,000Hz,[10] and the effective mean value of MVIC and %MVIC was calculated to quantify the collected signals during muscle contraction.

The exercises were thoroughly explained and performed by the same researcher before the experiment, and a familiarization process for the serratus exercises was provided for 3 minutes. The order of the two exercises, serratus punch and wall slide, was randomly assigned to exclude the effect of the sequence on the results.[14,24]

2) Serratus punch and wall slide exercise

Prior to the serratus punch exercise, subjects stand at 1m intervals with the device positioned in front of them. They bend the arm to be tested at a 90-degree angle in front of the shoulder, maintaining elbow extension and scapula protraction for 5 seconds while keeping proper spinal alignment and avoiding lateral rotation or forward tilt (Figure 2). The hand opposite the test hand is placed on the anterior superior iliac spine (ASIS) to counteract pelvic alignment. The weight of the serratus punch varies based on gender, with 5kg for women and 7kg for men weighing between 60 and 69kg, 8kg for men between 70 and 79kg, and 10kg for men over 80-89kg.[14] In this study, the female serratus punch weight was set at 5kg, aligning with previous research to reduce the weight difference based on gender.[14]

In the wall slide exercise, subjects face the wall with the ulnar side of the forearm touching it, while the shoulder and elbow are flexed at 90 degrees. The forearm slides up the wall as the subject's center of gravity shifts from the non-dominant foot to the dominant foot. During the movement, par-

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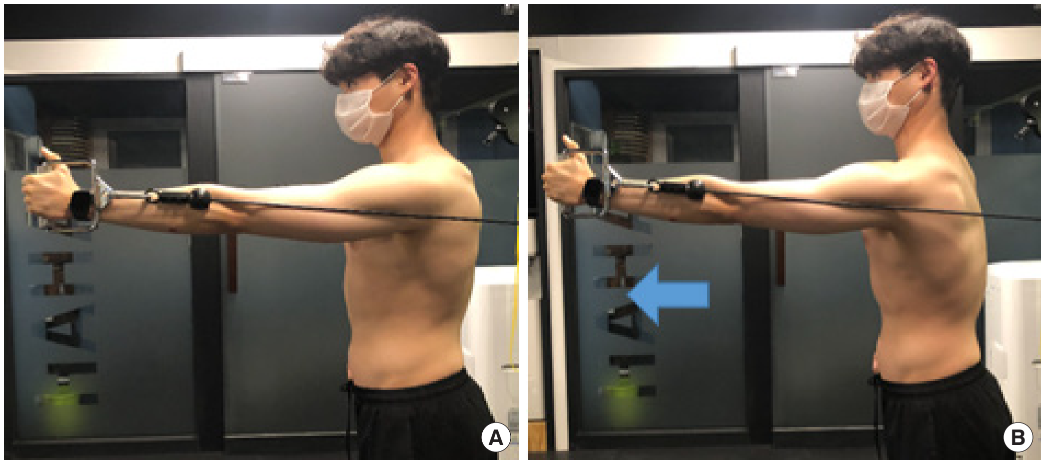

Figure 2. Lateral views of the start and end positions for the serratus punch exercise (A) start position, (B) end position.

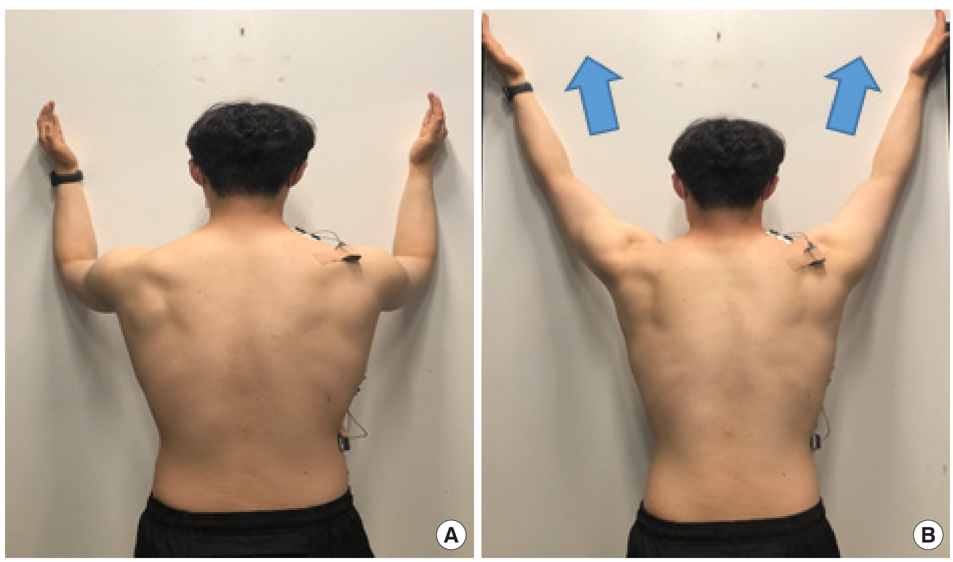

Figure 3. Posterior views of the start and end positions for the wall slide exercise (A) start position, (B) end position.

ticipants are instructed to slide both arms with equal force while maintaining proper weight distribution and avoiding leaning forward. The exercise aims to promote upward movement of the scapula, with the subject receiving a signal when the scapula opens outward. Shoulder muscle activity is measured for 5 seconds during shoulder elevation (Figure 3).

3. Statistical analysis

Descriptive statistics were calculated using IBM SPSS version 25 (IBM Corp, Armonk, NY, USA) for data analysis. To check for normal distribution, the Shapiro-Wilk test was performed on all data. For comparisons of sex and dominant arm between groups, a chi-square test was conducted. For comparisons of age, CrossFit practice time (months), height, weight, BMI, body fat percentage, skeletal muscle mass, and basal metabolic rate between groups, homogeneity testing was conducted using the non-parametric Mann-Whitney U test. For comparisons of the muscle activity of the serratus anterior, pectoralis major, and upper trapezius and the muscle activity ratios of pectoralis major/serratus anterior and upper trapezius/serratus anterior between groups during the serratus punch exercise and wall slide exercise, the non-parametric Mann-Whitney U test was performed. For comparisons of the muscle activity of the serratus anterior, pectoralis major, and upper trapezius and the muscle activity ratios of pectoralis major/serratus anterior and upper trapezius/serratus anterior within each group between the serratus punch exercise and wall slide exercise, the non-parametric Wilcoxon rank test was performed. The statistical significance level was set at $\alpha = 0.05$.

RESULTS

1. General characteristics of participants

The sex, dominant arm, age, height, weight, BMI, body fat percentage, skeletal muscle mass, and basal metabolic rate showed no significant differences between the impingement and non-impingement groups ($p > 0.05$). The only significant difference observed between the two groups was in CrossFit practice time (months)($p < 0.05$). Table 1 provides a summary of the demographic characteristics of the subjects in both groups.

2. Comparisons of EMG parameters within groups

In the group without shoulder impingement syndrome, no significant differences were found between the two exercises, serratus punch, and wall slide, in all measurements ($p > 0.05$)(Table 2). However, in the group with shoulder impingement syndrome, the wall slide exercise showed significantly higher upper trapezius muscle activation and upper trapezius/serratus anterior muscle activation ratio compared to the serratus punch exercise ($p < 0.01$)(Table 2). In serratus anterior muscle activity, no significant difference was found between two exercises in the group with shoulder impingement syndrome ($p > 0.05$)(Table 2).

3. Comparisons of EMG parameters between groups

During the serratus punch exercise, the shoulder impingement group showed significantly higher muscle activation in the pectoralis major and

Table 1. General characteristics of participants

	NIG (n=10)	IG (n=10)	z	p
Sex (M/F)	7/3	7/3	-	1.000
Dominance (right arm)	9 (90%)	7 (70%)	-	0.264
Age	29.4±4.7	28.0±5.0	-0.456	0.649
Practice time (months)	17.3±8.3	13.4±8.1	-2.423	0.015*
Height (cm)	169.6±7.2	167.8±6.4	-0.265	0.791
Weight (kg)	74.4±13.1	64.9±9.6	-1.550	0.121
BMI (kg/m^2)	25.8±3.3	22.9±1.9	-1.664	0.096
Body fat percentage (%)	19.5±6.8	19.1±5.1	-0.076	0.940
Skeletal muscle mass (kg)	34.1±7.2	29.6±5.7	-1.362	0.173
Basal metabolic rate (kcal)	1,662.8±256.4	1,507.4±199.1	-1.361	0.174

Mean±SD. IG: impingement group, NIG: non-impingement group, BMI: body mass index. *$p < 0.05$.

Table 2. Comparison of EMG activity (%MVIC±SD) and muscle activity ratio between exercises for each group

	NIG				IG			
	Serratus punch exercise	Wall slide exercise	z	p	Serratus punch exercise	Wall slide exercise	z	p
SA	62.53±14.58	59.05±10.78	-0.866	0.386	62.28±14.33	60.11±15.84	-0.459	0.646
PM	16.39±4.96	18.76±12.81	-0.255	0.799	35.46±11.18	23.50±11.63	-1.580	0.114
UT	5.55±4.21	7.17±4.65	-1.274	0.203	10.13±5.32	24.61±11.70	-2.803	0.005**
PM/SA	0.26±0.06	0.33±0.23	-0.459	0.646	0.56±0.08	0.42±0.25	-1.376	0.169
UT/SA	0.08±0.05	0.12±0.07	-1.070	0.285	0.17±0.09	0.41±0.15	-2.803	0.005**

IG: impingement group, NIG: non-impingement group, SA: serratus anterior, PM: pectoralis major, UT: upper trapezius. **$p < 0.01$.

Table 3. Comparison of EMG activity and muscle activity ratio between groups

	Serratus punch exercise				Wall slide exercise			
	NIG	IG	z	p	NIG	IG	z	p
SA	62.53±14.58	62.28±14.33	-0.076	0.940	59.05±10.78	60.11±15.84	-0.529	0.597
PM	16.39±4.96	35.46±11.18	-3.630	<0.001**	18.76±12.81	23.50±11.63	-0.983	0.326
UT	5.55±4.21	10.13±5.32	-2.343	0.019*	7.17±4.65	24.61±11.70	-3.553	<0.001**
PM/SA	0.26±0.06	0.56±0.08	-3.780	<0.001**	0.33±0.23	0.42±0.25	-1.058	0.290
UT/SA	0.08±0.05	0.17±0.09	-2.192	0.028*	0.12±0.07	0.41±0.15	-3.553	<0.001**

%MVIC±SD. SA: serratus anterior, PM: pectoralis major, UT: upper trapezius, IG: impingement group, NIG: non-impingement group. *$p < 0.05$, **$p < 0.01$.

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upper trapezius ($p < 0.05$), but no significant difference was found in serratus anterior muscle activation between the two groups (Table 3). Additionally, the muscle activation ratios of pectoralis major/serratus anterior and upper trapezius/serratus anterior were both significantly higher in the shoulder impingement group ($p < 0.05$)(Table 3).

In the wall slide exercise, the shoulder impingement group showed significantly higher upper trapezius muscle activity ($p < 0.01$), but there were no significant differences between the two groups in serratus anterior and pectoralis major muscle activity ($p > 0.05$)(Table 3). Moreover, the upper trapezius/serratus anterior muscle activity ratio was significantly higher in the shoulder impingement group ($p < 0.01$), while the pectoralis major/serratus anterior muscle activity ratio did not show significant differences between the two groups ($p > 0.05$)(Table 3).

DISCUSSION

The purpose of this study was to investigate whether there were differences in the muscle activity and muscle activity ratio of shoulder muscles when performing serratus anterior exercises among CrossFit practitioners with and without shoulder impingement syndrome.

In this study, the group with shoulder impingement syndrome exhibited overactivation of the pectoralis major and upper trapezius, while no significant difference was observed in serratus anterior muscle activity between the groups with and without impingement syndrome. This result can be attributed to the nature of CrossFit, which involves high-intensity training and various movements that heavily engage the serratus anterior muscle, such as overhead movements and push-ups.[25,26] During CrossFit exercises, the serratus anterior muscle plays a crucial role in scapulothoracic joint stability, humerus rotation control, and dynamic stability of the rotator cuff.[9,27] As a result, the serratus anterior muscle activity did not decrease in the group with impingement syndrome during CrossFit exercises, which involve intense training and numerous overhead movements that activate the serratus anterior. However, previous research has shown differences in lower trapezius muscle activity between individuals with and without shoulder pain during shoulder press exercises involving lifting a barbell overhead. The pain group exhibited lower trapezius muscle activity compared to the pain-free group.[26] Both the lower trapezius and serratus anterior muscles play critical roles in scapular upward rotation during initial and mid-range shoulder abduction.[28] The lower trapezius muscle's contribution to scapular upward rotation becomes significant as the scapular rotation axis approaches the shoulder acromion during arm elevation at 60-120 degrees.[15] Improper activation of the lower trapezius muscle in this range may lead to a positive painful arc test in individuals with impingement syndrome.[16] The painful arc test is performed during shoulder active abduction between 60°-120°, where the lower trapezius muscle's role in scapular upward rotation is crucial.[16] Although this study did not find a difference in serratus anterior muscle activity during serratus anterior exercises between groups, considering previous research, a decrease in lower trapezius muscle activity could potentially result in reduced scapular upward rotation and contribute to impingement syndrome.

Regarding the serratus punch exercise, the group with impingement syndrome exhibited higher muscle activation in the pectoralis major and upper trapezius muscles. Additionally, the muscle activity ratios of pectoralis major/serratus anterior and upper trapezius/serratus anterior were also higher in this group. These findings support the hypothesis that the activation of the pectoralis major muscle activity and the pectoralis major/serratus anterior muscle activity ratio will increase during the serratus punch exercise. Previous studies have reported that the pectoralis major muscle acts as a synergist with the serratus anterior during scapular protraction.[25] However, excessive activation of the pectoralis major muscle compared to the serratus anterior can have negative effects on the pathology of the glenohumeral and scapulothoracic joints, such as humeral anterior translation and decreased compressive force.[29] This can negatively impact the dynamic stability system of the rotator cuff, which plays a significant role in shoulder joint stabilization,[30] leading to decreased inferior gliding of the humerus and reduced compressive force, ultimately causing shoulder impingement syndrome.[30,31] Furthermore, overactivity of the pectoralis major in CrossFit practitioners can lead to impingement syndrome due to increased internal rotation of the humerus.[32] Previous research has reported that internal rotation movements in CrossFit exercises can put the shoulder tissues at risk.[32] Additionally, during the serratus punch exercise, muscle activity of the upper trapezius and muscle activity ratio of the upper trapezius/serratus anterior were increased. The upper trapezius, which attaches to the lateral third of the clavicle, affects scapulothoracic mobility through clavicular movement.[28] However, in individuals with impingement syndrome, excessive activation of the upper trapezius can lead to abnormal movement of the acromioclavicular joint, resulting in abnormal kinematics such as excessive scapular elevation.[11] Therefore, individuals with impingement syndrome may experience excessive upper trapezius activation related to scapular elevation even during the serratus punch exercise, where the humerus angle does not change, and the shoulder is maintained at 90 degrees of flexion.

In the wall slide exercise, the group with shoulder impingement syndrome exhibited higher upper trapezius muscle activity and upper trapezius/serratus anterior muscle activity ratio than the group without, supporting the hypothesis of this study. The increased muscle activity of the upper trapezius in CrossFit practitioners with shoulder impingement syndrome during the wall slide exercise can be attributed to its role as the primary agonist in shoulder elevation for proper scapular elevation performance.[10] In individuals with impingement syndrome, excessive scapular elevation occurs due to the overactivation of the upper trapezius muscle, resulting from abnormal scapular kinematics when the shoulder is elevated beyond 90 degrees, leading to shoulder.[21] However, unlike the serratus punch exercise, no significant differences in pectoralis major muscle activity were observed depending on the presence of impingement syndrome. This aligns with a previous study that found decreased pectoralis major muscle activity during the wall slide exercise when performed at this angle, as it involves shoulder elevation from 90 degrees to 180 degrees.[33,34] In contrast, the serratus punch exercise involves protraction in the 90-degree flexion position, increasing the activity of the pectoralis major muscle, a synergist of the serratus anterior muscle. Therefore, the reduced ratio of pectoralis major muscle activity during the wall slide exercise compared to the serratus punch exercise may explain why no significant differences were observed in pectoralis major muscle activity depending on the presence of impingement syndrome.

Finally, the comparison between the two exercises is as follows: among the group without impingement syndrome, no significant differences were observed in any values. However, in the group with impingement syndrome, the wall slide exercise showed higher upper trapezius muscle activity and upper trapezius/serratus anterior muscle activity ratio compared to the serratus punch exercise.

In this study, the loads used in the two exercises were different. The serratus punch exercise applied a load of 5-10kg depending on the subject's gender and weight, while the wall slide exercise involved supporting the weight of the arm against the wall, applying partial weight of the arm, and subjecting it to the load. Previous research has suggested that the wall slide exercise is suitable for early shoulder rehabilitation as it reduces the load compared to other serratus anterior exercises like push-up plus.[10] Hardwick et al.,[10] compared the activity of the upper trapezius muscle between the wall slide exercise and the serratus anterior punch exercise in subjects without shoulder impingement syndrome. They found no statistically significant difference in the activity of the upper trapezius muscle between these two exercises. In other words, in individuals without shoulder impingement syndrome, there was no significant difference in upper trapezius activity between the wall slide exercise and the serratus anterior punch exercise. The increased muscle activity of the upper trapezius during humerus elevation in the group without symptoms of impingement syndrome is thought to be a result of its role as a synergist in upward rotation of the scapula.

In cases of compensatory overactivation of the upper trapezius, previous studies have recommended wall push-up plus exercises to activate the serratus anterior with minimal upper trapezius involvement.[10] In this study, participants with impingement syndrome exhibited higher upper trapezius activation during both the serratus punch and wall slide exercises compared to those without impingement syndrome. Additionally, the wall slide exercise showed higher upper trapezius muscle activity and upper trapezius/serratus anterior muscle activity ratio than the serratus punch exercise. Therefore, for CrossFit practitioners with impingement syndrome, it may be more suitable to perform serratus punch exercises to reduce upper trapezius muscle activity rather than wall slide exercises.

Previous research has reported altered scapular kinematics during humerus elevation above 90 degrees.[21] Therefore, in CrossFit practitioners with impingement syndrome, the serratus punch exercise may be more suitable than the wall slide exercise, even with a lower load, as it can lead to altered scapular kinematics during humerus elevation above 90 degrees. The serratus punch exercise can relatively decrease upper trapezius muscle activity and activate the serratus anterior. To achieve shoulder muscle activity similar to that of individuals without impingement syndrome, the exercise should be performed in a direction that maximizes the reduction of muscle activity in the pectoralis major and upper trapezius while ensuring safety.

The study has several limitations. Firstly, the sample size was small, which makes it challenging to generalize the research findings. Secondly, differences in CrossFit practice time between the group with shoulder impingement and the group without might have influenced the results, although previous studies have shown contrasting injury risk profiles among athletes with extensive CrossFit experience.[35] Thirdly, this study did not compare a broader range of shoulder muscles that could contribute to shoulder impingement syndrome beyond those examined. Finally, due to the nature of the cross-sectional design, the effect of continuous exercise over time was not investigated.

This study was conducted to investigate whether the clinically recommended exercise for the serratus anterior can effectively work for CrossFit practitioners who are at high risk for shoulder impingement syndrome due

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to frequent overhead movements. Despite being recommended as a rehabilitation exercise, muscle activity of the pectoralis major and upper trapezius muscles, which can further aggravate impingement symptoms, increased in subjects with impingement syndrome. Especially, in the comparison between the two exercises, the wall slide exercise resulted in higher upper trapezius muscle activity and upper trapezius/serratus anterior muscle activity ratio in the impingement group, suggesting it may be less suitable for individuals with shoulder impingement syndrome due to excessive upper trapezius activation. Therefore, future studies on modified serratus anterior exercises, such as the modified serratus punch exercise and wall slide exercise, which can lower muscle activity of the pectoralis major and upper trapezius muscles and enable safe exercise, are needed. In conclusion, this study provides valuable insights into muscle activation patterns during different exercises for individuals with and without shoulder impingement syndrome, emphasizing the importance of exercise selection based on specific shoulder conditions.

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