

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



---

# The Function of Scapular Muscle

---

Tomohito Ijiri

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/67553>

---

## Abstract

In shoulder rehabilitation, it is important to evaluate scapular stability. However, it is not revealed how the mechanism runs for scapular stability. Additionally, the contribution of scapular muscles for scapular stability remains a matter of debate. Wherefore, I suggest some studies in this section to understand the function of scapulothoracic joint and the mechanism of scapular stability in detail. In the results of these studies, it was revealed that each scapular muscle activation is different for shoulder isometric contraction, and the exercise for a scapular muscle increases only the shoulder muscle strength of specific movement direction. If we can consider each scapular muscle individually by utilizing these results, we can provide more effective rehabilitation program.

**Keywords:** scapular muscle, muscle activity, scapular stability, shoulder disease, muscle strength

---

## 1. Introduction

The shoulder complex is constituted with some joint. It is understood that glenohumeral joint (GHJ) and scapulothoracic joint (STJ) are important for shoulder complex and they make up a large fraction of shoulder movement. Especially, scapulothoracic joint has been focused recently. It was reported that patients with shoulder disease show abnormal scapular movement and scapular muscle activation during shoulder motion, so to normalize the scapular movement, it is important to improve the symptom [1–3]. Clinically, the therapist usually prescribes the scapular exercise to the patients. So, we will be able to provide the more effective rehabilitation program if we understand more about the scapulothoracic joint. Some functions of the scapula were reported in previous studies. These include contributing to the range of shoulder motion synchronizing the motion of humerus, supporting the humerus, keeping the muscle tension, maintaining the appropriate muscle length on glenohumeral joint, and

getting off the impingement raising the glenoid fossa [4]. However, not only these, scapulothoracic joint is also related to the “exertion of muscle power” on shoulder joint, so we have to consider keeping rehabilitation in mind. However, there remain some ambiguities regarding the function of scapular muscle. In previous studies, scapular muscles with high activation during specific exercises for scapular muscles [5, 6] have been reported. And it was reported that the combination of standard rehabilitation interventions and scapulothoracic joint control training exercises were effective treatments for the shoulder joint dysfunction [7, 8]. But the change of shoulder muscle strength by only one scapular muscle exercise is not examined in exact detail, not by a number of exercises. In other words, the evidence is not enough to choose the best exercise from a number of exercises for each patient. Additionally, it is not revealed how the mechanism runs for scapular stability. Wherefore, which exercise is the best for the improvement of scapular movement for each patient remains a matter of research. And so, I suggest some studies in this section to understand the function of scapulothoracic joint. From this, I expect upgrading your ability about the clinical rehabilitation.

## 2. The study

### 2.1. The changes of muscle strength on shoulder joint after strengthening of serratus anterior

The muscle weakness is usually involved in the rehabilitation of patients with shoulder disease. So, we have to have the skill to improve this. The reason for muscle weakness on shoulder joint is not only due to glenohumeral joint like the weakness on deltoid and rotator cuff muscle but due to scapular instability with scapular muscle weakness. The patient with scapular instability usually have “winging scapula.” The winging scapula was also caused by long thoracic nerve paralysis and the patients with this have weakness of shoulder muscle strengths. Serratus anterior innervated by long thoracic nerve is scapular protractor muscle and it plays a prominent role in scapular stability in consort with trapezius. Clinically, the exercise for serratus anterior has an effect on improved strength on shoulder joint. But the study which investigated how the change in the muscle strength on shoulder joint by the strengthening for serratus anterior is modest in size. Wherefore, I examined the changes of muscle strength on shoulder joint after the exercise for serratus anterior.

#### 2.1.1. Materials and methods

Thirty-six healthy young men who had no orthopedic and neurological abnormality participated in this study. The subjects were separated into two groups randomly, one was the training group where members were exercised for serratus anterior, and the other was the control group where members did not exercise. The mean anthropometric characteristics  $\pm$  standard deviation (SD) of the training group were age,  $22.1 \pm 1.5$  years; height,  $172.2 \pm 6.5$  cm; and weight,  $62.7 \pm 8.7$  kg. Those of the control group were age,  $21.6 \pm 1.5$  years; height,  $171.4 \pm 5.6$  cm; and weight,  $62.4 \pm 6.3$  kg.

First, the subjects in the training group and control group were measured for muscle strength. Then, in the training group, they performed exercise every day for a week. The exercise was established at the modified elbow pushup plus, which was known as the typical exercise for serratus anterior. In control group, they spent without exercise. After 1 week, they were measured for the muscle strength in common for the first time.

The measurement of muscle strength was composed by the muscle strengths of scapular protraction, shoulder flexion, abduction, external rotation, and internal rotation. The measurement was done using handheld-dynamometer (MicroFET2, Hoggan Health Industries, Inc., USA). Regarding the muscle strength of shoulder flexion, abduction, external rotation, and internal rotation, the measurement values ( $N$ ) were multiplied by the lever arm length ( $m$ ), and the muscle strength was represented by torque values ( $Nm$ ). The measurement position of shoulder flexion and abduction was the same as manual muscle testing, and that of shoulder external and internal rotation was at  $0^\circ$  abduction. The measurement position of scapular protraction was defined at supine and  $90^\circ$  shoulder flexion and  $90^\circ$  elbow flexion (**Figure 1**). From this position, the subjects thrust their upper limb vertically upwards. The measurer measured the power by handheld - dynamometer on olecranon. The measurement of each muscle strength was done three times and the average was adopted as the muscle strength value.

The exercise was established at the modified elbow pushup plus (**Figure 2**). The pushup plus indicated high serratus anterior activity by Decker et al. and Moseley et al. [9, 10]. The basic position of this exercise was on elbow, and the femoral area was grounded. Then, the subjects moved their scapula to maximum scapular retraction position like moving their body close to the floor. And they moved their scapular to the maximum scapular protraction position like getting their body away from the floor. Additionally, they returned to the maximum scapular retraction position and this process was defined one time. The subjects in the training group performed this exercise in three sets: one set was 20 times, each day for 1 week.

Each muscle strength for the first time was normalized as 100% and the muscle strengths after 1 week were computed as percentage. The muscle strengths between the first time and after 1 week were compared for each group using paired  $t$ -test.

### 2.1.2. Results

The result is shown in **Table 1**. Representative value is as follows. The muscle strength of scapular protraction in the right side was  $113 \pm 14\%$ , shoulder flexion  $106 \pm 9\%$ , abduction  $110 \pm 10\%$ , external rotation  $104 \pm 8\%$ , and internal rotation  $112 \pm 12\%$  in the training group. In the control group, scapular protraction  $99 \pm 4\%$ , shoulder flexion  $101 \pm 6\%$ , abduction  $100 \pm 5\%$ , external rotation  $101 \pm 5\%$ , and internal rotation  $101 \pm 6\%$ . The same tendency was indicated in the left side on both groups.

In the training group, the muscle strengths of scapular protraction, shoulder flexion, shoulder abduction, and internal rotation after 1 week were significantly higher than the first time on both sides. The muscle strength of shoulder external rotation was not increased. On the other hand, the muscle strength in the control group was not changed after 1 week.

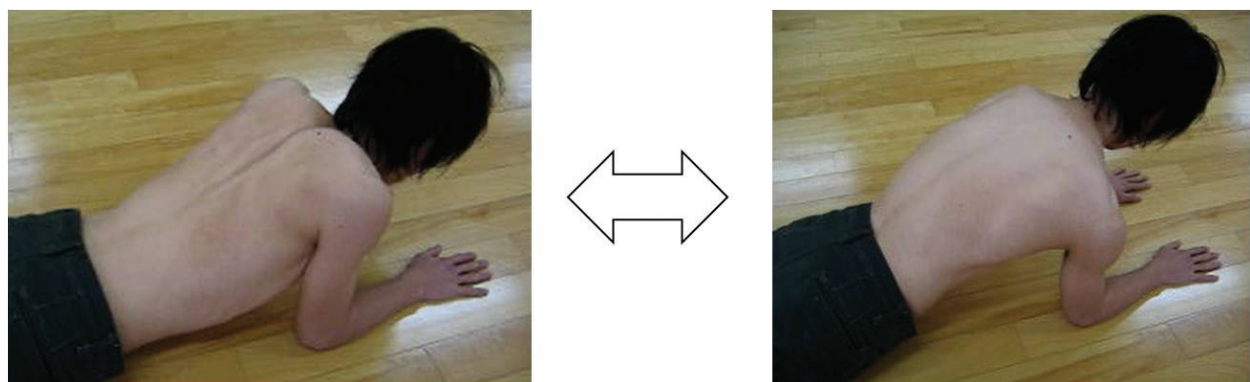


**Figure 1.** The measurement position of scapular protraction. The measurement position of scapular protraction was defined at supine and 90° shoulder flexion and 90° elbow flexion. From this position, the subjects thrust their upper limb for vertical upward.

### *2.1.3. Discussion*

In this study, the muscle strength of scapular protraction was higher after 1 week in the training group. So, the exercise was effective for serratus anterior. And it was indicated that the exercise for serratus anterior can increase the shoulder muscle strength, but the direction is





**Figure 2.** The modified elbow pushup plus. The basic position of this exercise was on elbow, and femoral area was grounded. They moved their scapular to maximum scapular protraction position like getting their body away from the floor.

not all limited. We have to gain consciousness of this fact. In the rehabilitation of shoulder disease patients, we usually assess the scapular position and scapular movement. If the therapist infers that abnormal scapular position and movement encumber the normal motion, then we will treat for the scapular abnormality. Additionally, the reason for the scapular abnormality is assessed in the impairment of functional level. We assess the scapular muscle strength, like manual muscle testing for scapula. In this assessment, even if the weakness of serratus anterior is found, it is not always effective for the chief complaint motion. From this study, serratus anterior must influence the motion which consists of shoulder flex, abduction, and internal rotation, but does not influence the motion which does not consist of their movements. So, we have to consider the task characteristically and calculate the weakness of serratus anterior

	Right	Left
<b>Training group</b>		
Scapular protraction	113 ± 14*	112 ± 12*
Shoulder flexion	106 ± 9*	107 ± 9*
Shoulder abduction	110 ± 10*	109 ± 11*
Shoulder external rotation	104 ± 8	103 ± 8
Shoulder internal rotation	112 ± 12*	109 ± 11*
<b>Control group</b>		
Scapular protraction	99 ± 4	99 ± 5
Shoulder flexion	101 ± 6	101 ± 5
Shoulder abduction	100 ± 5	99 ± 4
Shoulder external rotation	101 ± 5	102 ± 4
Shoulder internal rotation	101 ± 6	100 ± 4

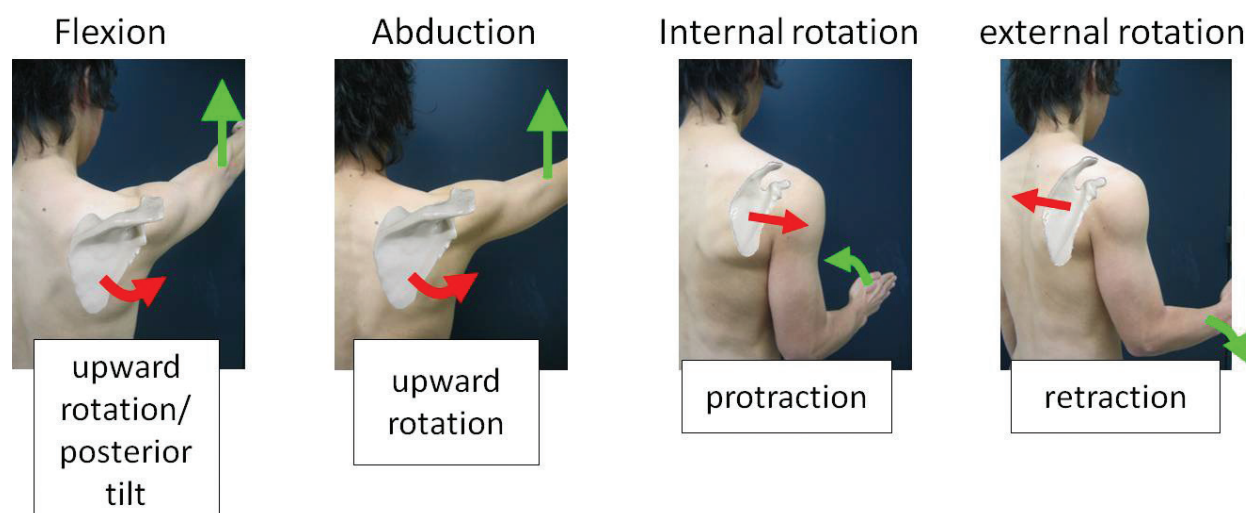
\* $p < 0.01$ .

**Table 1.** The muscle strength after 1 week.

for improved motion. As a matter of fact, the relationship between scapular stability and each scapular muscle strength remains unclear, and the therapist often confuses oneself. Therapists usually believe that one scapular muscle can contribute to scapular stability of all motion. However, this is not true. As previously noticed, therapists need to consider the movement direction of the task and make a decision about the muscle's influence to the task. This decision is important.

The reason that the exercise for serratus anterior led to an increase in the muscle strength of shoulder flexion, abduction, and internal rotation will relate to interlocking between humerus and scapula. Shoulder joint is constituted with glenohumeral joint and scapulothoracic joint and so on. Every shoulder motion involves scapular movement. Shoulder flexion includes scapular upward rotation and posterior tilt, shoulder abduction includes scapular upward rotation, and internal rotation includes scapular protraction (Figure 3). The function of serratus anterior is scapular upward rotation, protraction, and posterior tilt, so the scapular movements of shoulder flexion, abduction, and internal rotation, where muscle strengths were increased in this study, agree with the functions of serratus anterior. Wherefore, I conclude that the increasing of serratus anterior muscle strength conducted the increasing of these shoulder muscle strengths. On the other hand, shoulder external rotation includes scapular retraction, which does not agree with the function of serratus anterior. Therefore, I suspect that the muscle strength of shoulder external rotation did not increase in this study.

In this study, it is revealed that the muscle strength at scapulothoracic joint influences the muscle strength at shoulder complex, but not all movement directions. The muscle strength of the only shoulder movement direction having the scapular movement agrees with the function of strengthened muscle which will be increased. From this reflection, if the scapular retractor, like middle trapezius, was strengthened, the muscle strength of shoulder external



**Figure 3.** Scapular movement of each shoulder motion. Shoulder flexion includes scapular upward rotation and posterior tilt, shoulder abduction includes scapular upward rotation, and internal rotation includes scapular protraction. These scapular movements agree in the functions of serratus anterior.

rotation will be increased because external rotation at 0° abduction is associated with scapular retraction.

## **2.2. The changes of muscle strength on shoulder joint after strengthening of scapular retractor muscles**

In a previous study, the muscle strengths of shoulder flexion, abduction, and internal rotation were increased after exercise for serratus anterior. And it was thought that the reason for this change must be related to the scapular movement during each motion. Contrary to previous study, if the exercise for scapular retractor was done, the muscle strength of external rotation will be increased. So, I examined the change of muscle strength on shoulder joint after exercise for scapular retractor, mainly on the middle trapezius.

### *2.2.1. Materials and methods*

Thirty healthy men participated in this study. These subjects were divided into two groups, training group and control group, randomly. The mean anthropometric characteristics of 15 subjects in the training group were age,  $23.3 \pm 2.8$  years; height,  $172.1 \pm 5.8$  cm; and weight,  $65.7 \pm 8.5$  kg. Those of the control group were age,  $22.5 \pm 1.6$  years; height,  $170.7 \pm 5.3$  cm; and weight,  $63.7 \pm 11.5$  kg. There were no significant differences between two groups regarding anthropometric characteristics.

The subjects in the training group and control group were measured for muscle strength on the first day. Then, in the training group, they performed exercise every day for a week. The exercise was scapular retraction exercise at 0° shoulder abduction. In the control group, they spent without the exercise. After 1 week, they were measured for the muscle strength in common for the first time.

The muscle strengths on scapulothoracic retraction, shoulder flexion, abduction, external rotation, and internal rotation were measured. The measurement of muscle strength on shoulder flexion, abduction, external rotation, and internal rotation was the same as above-referenced previous study. The measurement of muscle strength on scapular retraction was on prone. The subject performed scapular retraction at 90° shoulder abduction and 90° elbow flexion (**Figure 4**). At that time, the muscle strength was measured by resisting their movement at the point of 3 cm inside from the axilla using handheld-dynamometer (MicroFET2, Hoggan Health Industries, Inc., USA).

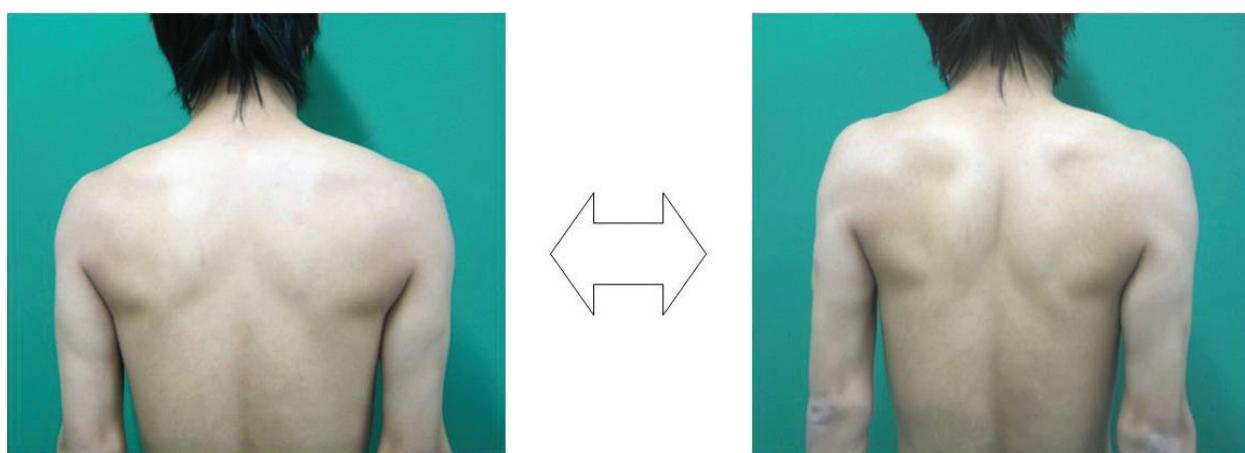
The exercise was scapular retraction at 0° shoulder abduction consulted from the report by Andrews and Wilk [11] (**Figure 5**). The subjects performed scapular retraction with shoulder internal rotation for preventing to strengthen external rotator muscles by external rotation accompanied by scapular retraction. And they returned to neutral position. This process was defined one time. The subjects in the training group performed this exercise in three sets: one set was 20 times, each day for 1 week.

Each muscle strength for the first time was normalized as 100% and the muscle strengths after 1 week were computed as percentage. The muscle strengths between the first time and after 1 week were compared for each group using paired *t*-test.





**Figure 4.** The measurement position of scapular retraction. The subject performed scapular retraction at 90° shoulder abduction and 90° elbow flexion. At that time, the muscle strength was measured by resisting their movement at the point of 3 cm inside from the axilla using handheld-dynamometer.



**Figure 5.** Scapular retraction exercise. The subjects performed scapular retraction with shoulder internal rotation for preventing to strengthen external rotator muscles by external rotation accompanied by scapular retraction. And they returned to neutral position.

2.2.2. Results

The results are shown in **Table 2**. The muscle strength of scapular retraction in the right side was  $106 \pm 8\%$ , shoulder flexion  $101 \pm 4\%$ , abduction  $103 \pm 6\%$ , external rotation  $105 \pm 6\%$ , and internal rotation  $103 \pm 7\%$  in the training group. In the control group, scapular retraction  $101 \pm 9\%$ , shoulder flexion  $100 \pm 6\%$ , abduction  $101 \pm 5\%$ , external rotation  $101 \pm 5\%$ , and internal rotation  $100 \pm 6\%$ . The same tendency was indicated in the left side on both groups.

In the training group, the muscle strengths of scapular retraction and shoulder external rotation after 1 week were significantly higher than the first time on both sides. The muscle strengths of shoulder flexion, abduction, and internal rotation were not increased. On the other hand, the muscle strength in control group was not changed after 1 week.

2.2.3. Discussion

In this study, the exercise for middle trapezius led to an increase in the muscle strength of scapular retraction and shoulder external rotation. From this result, the hypothesis was proved to be correct. The reason regarding increasing the muscle strength of shoulder external rotation will be the same as the previous study of exercise for serratus anterior. Shoulder external rotation includes scapular retraction. The function of middle trapezius is scapular retraction. This homology must be the reason about increasing the muscle strength of shoulder external rotation.

Considering these two studies, the muscle strength of serratus anterior must have a part of muscle strength of shoulder flexion, abduction, and internal rotation, and that of middle trapezius

	Right	Left
<b>Training group</b>		
Scapular retraction	$106 \pm 8^*$	$109 \pm 12^*$
Shoulder flexion	$101 \pm 4$	$101 \pm 6$
Shoulder abduction	$103 \pm 6$	$98 \pm 6$
Shoulder external rotation	$105 \pm 6^*$	$106 \pm 5^*$
Shoulder internal rotation	$103 \pm 7$	$100 \pm 8$
<b>Control group</b>		
Scapular protraction	$101 \pm 9$	$102 \pm 9$
Shoulder flexion	$100 \pm 6$	$99 \pm 5$
Shoulder abduction	$101 \pm 5$	$100 \pm 9$
Shoulder external rotation	$101 \pm 5$	$101 \pm 4$
Shoulder internal rotation	$100 \pm 6$	$99 \pm 4$

*\*p* < 0.01.

**Table 2.** The results about the changing muscle strength.

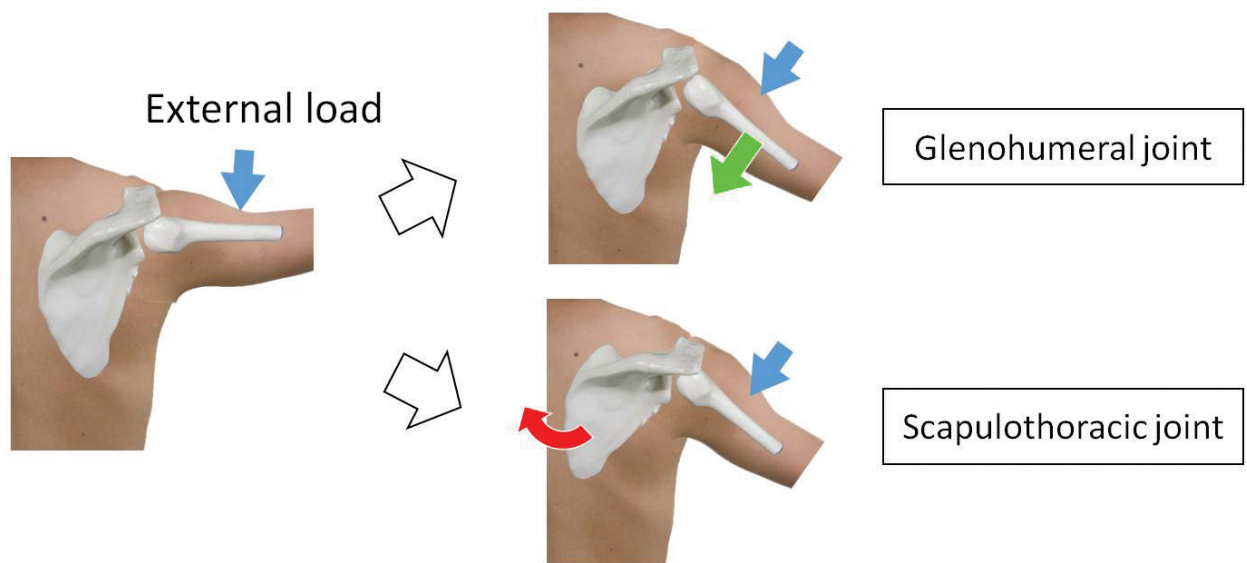
must have a part of shoulder external rotation. In fact, the muscle strength of shoulder complex will combine the muscle strength of glenohumeral joint and scapulothoracic joint. Therefore, muscle weakness occurred either on glenohumeral joint or on scapulothoracic joint, and the muscle strength of shoulder complex will decrease (**Figure 6**). Winging scapula by long thoracic nerve palsy decreases the shoulder muscle strength, and this case is an easy-to-follow typical example. It is necessary to consider the function of not only glenohumeral joint but also scapulothoracic joint during the measurement of muscle strength. And we have to make a hypothesis about specific scapular muscle weakness when shoulder muscle strength is decreased.

**2.3. The activities of scapular muscles during isometric contraction**

I indicated the characteristic about scapular muscle strengthening in the previous paragraphs. From this, it was shown that scapular muscle strength relates with the muscle strength of shoulder complex. During daily living and sports situation, there are many opportunities requiring powerful force, for example, transfer the burden and have a frying pan. In contact sports, they require continuing their performance resisting external force. In these cases, which scapular muscle is important? I thought that it is necessary to investigate the scapular muscle activity during shoulder isometric contraction to clear the question. From previous studies, to have all scapular muscle activities during shoulder isometric contraction is hard to imagine and I predicted the characteristic muscle-active pattern. Therefore, I investigated each scapular muscle activity during isometric shoulder abduction, internal rotation, and external rotation.

*2.3.1. Materials and methods*

Seventeen healthy men participated in this study. The mean anthropometric characteristics were age,  $26.0 \pm 3.6$  years; height,  $172.9 \pm 4.3$  cm; and weight,  $65.8 \pm 9.1$  kg.



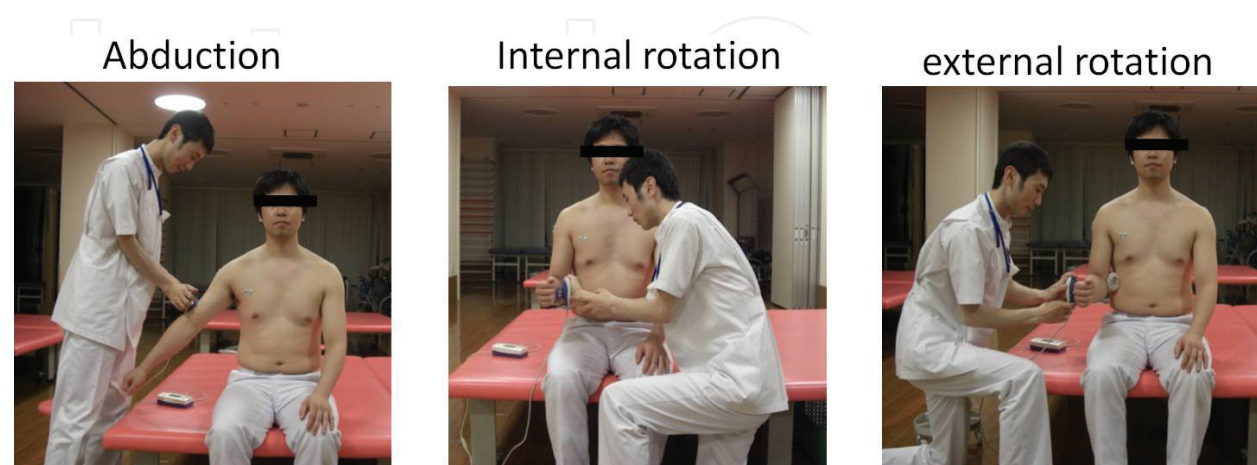
**Figure 6.** Muscle weakness on shoulder complex. Muscle weakness occurred either on glenohumeral joint or on scapulothoracic joint.



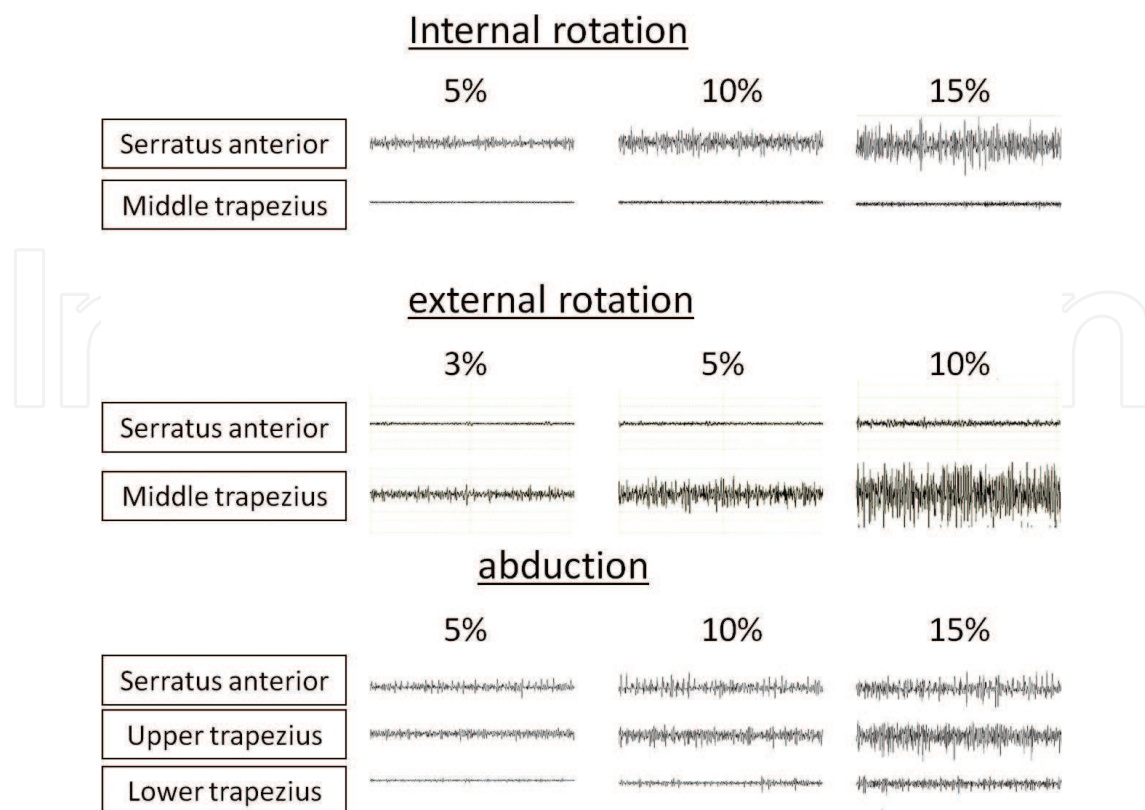
Muscle activity was measured during isometric shoulder abduction, internal rotation, and external rotation in the sitting position. Surface electromyography (EMG; MQ-8, Kissei Comtec, Japan) was used to collect raw EMG data during the task. EMG was reported in 3 s and the signal was recorded at a sampling rate of 1000 Hz. The measurement position of shoulder abduction was configured at shoulder 45° abduction and internal rotation and external rotation were at shoulder 0° abduction (**Figure 7**). The external load was set at three weights in order to evaluate the change with different loads using a handheld-dynamometer (Mobie, SAKAI Medical Co., Japan). The external load during abduction and internal rotation was set at 5, 10, and 15% of each subject's body weight and external rotation was set at 3, 5, and 10%. The target muscles at scapulothoracic joint of abduction task were the serratus anterior, upper, and lower trapezius. Those of internal and external rotation were serratus anterior and middle trapezius. The EMG electrode position was set according to previous studies by Ekstrom et al. and Delagi and Perotto [12, 13]. The integrated EMG (IEMG) was obtained for 3 s in the stable wave during each task and was counted per second. The IEMG per second was normalized by the IEMG at each starting position without an external load. Relative IEMGs were used for statistical comparison of each load in the same muscle. The Friedman test was used to determine whether a load condition had a statistically significant effect on relative IEMG for each muscle. Post hoc analysis was then applied for specific comparisons among the three loads and determined for individual effect differences.

### 2.3.2. Results

The results of raw waveform are shown in **Figure 8**. Typical raw wave was shown on internal and external rotation. During isometric shoulder internal rotation, the muscle activity of serratus anterior was high and middle trapezius was slightly high. In an opposite way, during isometric shoulder external rotation, the muscle activity of middle trapezius was high and serratus anterior was slightly high. During isometric shoulder abduction, all muscle activities, serratus anterior, upper trapezius, and lower trapezius, were high.



**Figure 7.** Measurement position regarding shoulder isometric contraction. The measurement position of shoulder abduction was configured at shoulder 45° abduction and internal rotation and external rotation were at shoulder 0° abduction. The external load was set at three weights using a handheld-dynamometer.



**Figure 8.** The results of raw waveform during isometric contraction. During isometric shoulder internal rotation, the muscle activity of serratus anterior was high and middle trapezius was slight. In an opposite way, during isometric shoulder external rotation, the muscle activity of middle trapezius was high and serratus anterior was slight. During isometric shoulder abduction, all muscle activities, serratus anterior, upper trapezius, and lower trapezius were high.

Next, relative IEMG was focused (Table 3). The relative IEMGs of all muscles were significantly increased at 15% compared to 5 and 10% during abduction and internal rotation. In a similar way, the relative IEMGs of all muscles were significantly increased at 10% compared to 3 and 5% during external rotation. Basically, all muscle activities increased with increasing external load during all trials.

2.3.3. Discussion

From the result of internal and external rotation, it was shown that the amount of muscle activities was unequal during isometric contraction on all scapular muscles. Some muscles have high activities, others have low. But the relative EMGs of all muscle were increased with increasing external load, so these muscles which have low activities were also necessary during isometric contraction. I inferred which muscle had high activity from this and previous studies. If the muscle has the same function with the scapular movement being comprised within the shoulder motion, the muscle must have high activity. In particular, internal rotation includes scapular protraction, which is the function of serratus anterior, and external rotation includes scapular retraction, which is the function of middle trapezius. It is just the same as the result of the studies about strengthening scapular muscles. About isometric shoulder abduction task, serratus anterior, upper trapezius, and lower trapezius have relation to scapular upward rotation, so all



	Serratus anterior	Middle trapezius
5%	4.9 ± 2.4	1.4 ± 0.300
10%	8.4 ± 4.300	1.8 ± 0.600
15%	12.8 ± 7.300	2.7 ± 1.300

\*:p<0.05

**Internal rotation**

	Middle trapezius	Serratus anterior
3%	10.5 ± 9.3	1.8 ± 0.800
5%	16.1 ± 12.700	2.6 ± 1.400
10%	29.6 ± 23.400	4.7 ± 2.700

\*:p<0.05

**External rotation**

	Serratus anterior	Upper trapezius	Lower trapezius
5%	2.6 ± 0.7	2.5 ± 1.000	2.4 ± 1.500
10%	3.7 ± 1.500	4.0 ± 2.400	4.5 ± 3.100
15%	5.7 ± 2.600	6.8 ± 3.400	7.6 ± 5.500

\*:p<0.05

**Abduction**

Table 3. The results of relative IEMG.

muscles might have high activities. As can be seen, it suggested that not all scapular muscles have high activity during isometric contraction and the changes in scapular muscle activity by movement direction are analogous to the case of isotonic contraction. So, for example, when we improve the ability of the endurance to the collision in athletes, we have to consider which direction the force is added and predict which muscle is actively higher. When this is done, the good rehabilitation program will be provided to the patients.

Additionally, considering the result of unequal scapular muscle activities, we can infer the mechanism about scapula stability. Generically, the theory that the scapula was stabilized by “fixation to thorax” has been heard. If something is to fix the scapula to the thorax, the scapula needs to be pulled by the same tension from side to side and up and down. Co-contraction with scapular muscle is needed. Scapula does not fix the thorax if the only unilateral scapular muscle has high activity. So, from this study, the scapula is stabilized not by the fixation to thorax, but by individualized scapular muscle activity to counteract the external load. Individualized scapular muscle activity must contribute to maintain the scapular position. In other words, these scapular muscles which have high activities have the function of resisting external load as the agonist at glenohumeral joint. These muscles may be called the agonist at scapulothoracic joint. Scapular muscles may be classified the agonist and the antagonist like other joint muscles. From this study, it is predicted that the agonist at scapulothoracic joint has the function of countering the external load and the antagonist at scapulothoracic joint has the function of adjusting the scapular position.

## **2.4. The changes of muscle activity on shoulder joint during maximum isometric contraction by the difference of muscle-weakness region**

As above, it was suggested that scapular muscle reacts individually and has the function of counteracting the external load. In clinical situation, therapists usually evaluate the scapular stability using the assessment of whether or not scapular downward rotation occurred during shoulder abduction manual muscle testing. And therapists evaluate whether the muscle strength of shoulder abduction is increased with manual fixation against scapular downward rotation (**Figure 9**). From this assessment, therapists calculate the policy about scapular stability. Considering previous studies, it is predicted that we can use this evaluation at all directions as shoulder abduction. And if the patients have the scapula instability, the scapula will be swaying during the test. Wherein, I verified whether or not this phenomenon occurs in the patients with shoulder disease. Additionally, I measured the scapular muscle activities using electromyography during the muscle testing.

### *2.4.1. Materials and methods*

Two patients with shoulder disease participated in this study. One had muscle weakness mainly at glenohumeral joint (Patient A) and the other had muscle weakness mainly at scapulothoracic joint (Patient B). Additionally, a healthy man without shoulder disease was measured and compared to the patients (Subject C). Patient A was affected with dislocated shoulder and dislocation was reduced. The muscle strength is shown in **Figure 10**. On manual muscle testing,



**Figure 9.** Evaluation about the change of muscle strength by scapular manual fixation. Therapists evaluate whether the muscle strength of shoulder abduction is increased with manual fixation against scapular downward rotation.

scapular protraction and protraction/downward rotation were indicated as level 4, but shoulder external rotation and internal rotation were indicated as level 3. Patient A had muscle weakness mainly at glenohumeral joint. Patient B was affected with humeral head fracture. The muscle strength was that shoulder abduction and external rotation were indicated as level 3 and internal rotation was level 4, but scapular retraction/downward rotation and protraction/upward

Patient A			Patient B		
MMT	Non-affected side	Affected side	MMT	Non-affected side	Affected side
Shoulder flexion	5	4	Shoulder flexion	5	4
Shoulder abduction	5	4	Shoulder abduction	5	3
Shoulder external rotation	5	3	Shoulder external rotation	5	3
Shoulder internal rotation	5	3	Shoulder internal rotation	5	4
Scapular elevation	5	5	Scapular elevation	5	4
Scapular retraction	5	4	Scapular retraction	5	3
Scapular retraction/ depression	4	4	Scapular retraction/ depression	5	2
Scapular protraction/upward rotation	5	4	Scapular protraction/upward rotation	5	2

**Figure 10.** Muscle strength of two patients. Patient A had the muscle weakness at glenohumeral joint and Patient B had the weakness at scapulothoracic joint.

rotation were level 2. Patient B had the muscle weakness mainly at scapulothoracic joint. Two patients had no pain and had comfortable range of motion to measurement. The measurement task was set as three kinds of maximum isometric contraction: shoulder flexion at 90° shoulder flexion, shoulder internal rotation at 0° shoulder abduction, and shoulder external rotation at 0° shoulder abduction. The subjects were measured for the muscle activities and scapular movement during three tasks with external load to break their position slightly. The muscles that were predicted to have high activities during these tasks consulted from previous studies were measured. I assessed the change in the muscle activities when the external load was given.

2.4.2. Results

The result in Subject C, which was healthy man, was shown first. Please look at the raw wave (Figure 11). On shoulder flexion, not only just anterior deltoid but also serratus anterior, upper trapezius, middle trapezius, and lower trapezius had high activities that corresponded with the external load. In a way like that, infraspinatus, middle trapezius, and lower trapezius had high activities on external rotation, and pectoralis major and serratus anterior on internal rotation. In other words, the high muscle activities appeared not only at glenohumeral joint but also at scapulothoracic joint by external force.

Next, the result in Patient A, which had the muscle weakness at glenohumeral joint, was shown. On shoulder flexion, the muscle activity of anterior deltoid was increased. But serratus anterior, upper trapezius, middle trapezius, and lower trapezius were not increased like anterior deltoid.

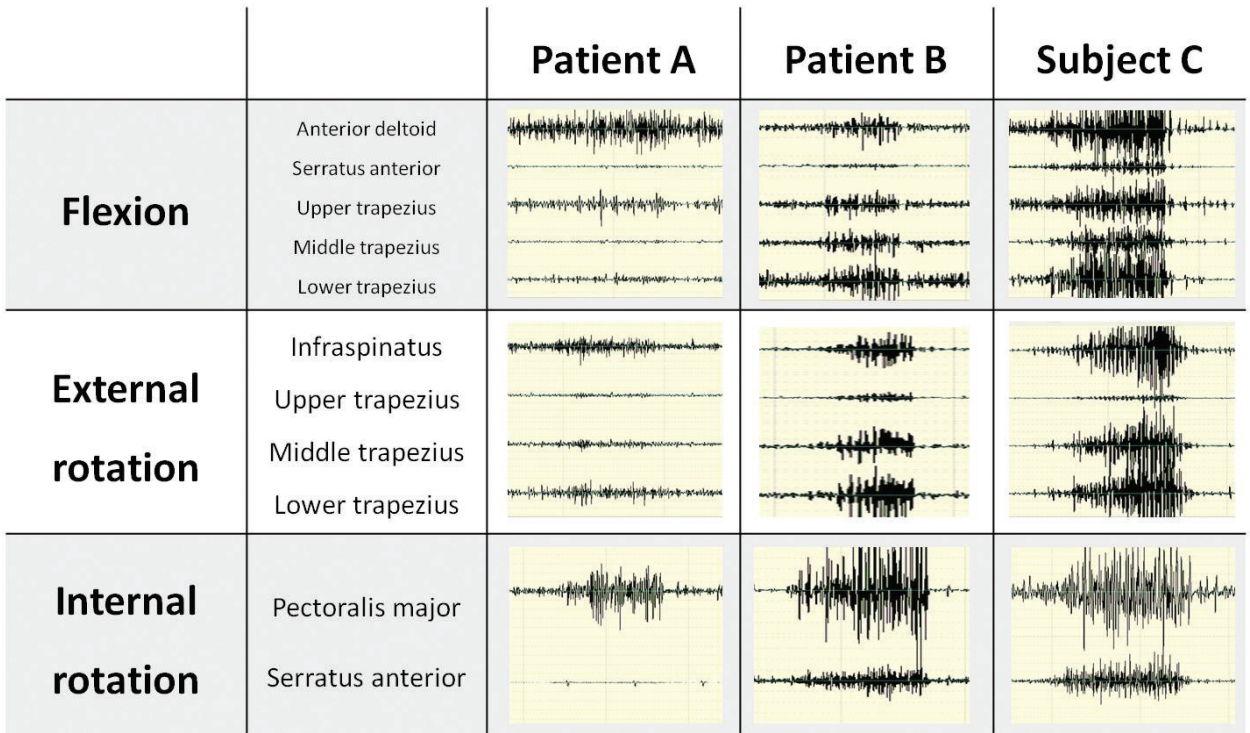


Figure 11. Raw wave in each subject. The result in Patient A was that the muscle activity at glenohumeral joint was high corresponding to the external load but that at scapulothoracic joint was modest in size. In Patient B and Subject C, muscle activities at glenohumeral joint and scapulothoracic joint were increased together.



On external rotation, the muscle activity of infraspinatus was increased in a measure, but those of upper trapezius, middle trapezius, and lower trapezius which were increased in Subject C were not changed. On internal rotation, the muscle activity of pectoralis major was increased by external load and serratus anterior had little change. When taken together, the result was that the muscle activity at glenohumeral joint was high corresponding to the external load but that at scapulothoracic joint was modest in size. From the movie, which was filmed for the scapular stability at the same time, the scapular swaying did not appear by external load.

Lastly, the result in Patient B, which had weakness at scapulothoracic joint, was shown. On shoulder flexion, the muscle activities of anterior deltoid, upper trapezius, middle trapezius, and lower trapezius were increased by external load. On external rotation, not only infraspinatus but also upper trapezius, middle trapezius, and lower trapezius had high activities. On internal rotation, pectoralis major and serratus anterior had high activities. On the whole, muscle activities at glenohumeral joint and scapulothoracic joint were increased together like Subject C. And the movies showed that the scapular movement occurred by external load, the task of flexion; scapular downward rotation, external rotation; scapular protraction, internal rotation; scapular retraction.

#### 2.4.3. Discussion

As can be seen, there were different results between Patient A and Patient B. Now, let us think about these results with the inclusion of previous studies. First, I had indicated that the muscle weakness at scapulothoracic joint causes the muscle weakness on whole shoulder joint. In Patient B, because he had the scapular muscle weakness and the scapular movement occurred by external load, the reason for the whole shoulder muscle weakness will be the weakness at scapulothoracic joint. By the electromyographic wave, scapular muscles had high activities and it is predicted that their activities appeared to resist the external force. So, it is thought that the external force to upper limb reached scapulothoracic joint through glenohumeral joint because the muscle strength at glenohumeral joint was maintained for some level, and the scapular muscles had the activities to resist the external force. But the upper limb was moved causing scapular movement because the muscle strength at scapulothoracic joint was not enough (**Figure 6**). The reason is the weakness at scapulothoracic joint.

On the other hand, in Patient A, it is predicted that the external load did not reach scapulothoracic joint because he had muscle weakness at glenohumeral joint and humerus was moved by external load. So, scapular muscles did not have activities and scapular sway might not appear. The important factor is that the load did not reach scapulothoracic joint.

From this, we will be able to calculate which joints have weakness for improvement by observing the scapular movement during muscle testing with every movement direction not only abduction (**Figure 12**). And it is important that this scapular movement during muscle testing is anticipated movement direction. If the scapular movement appears seriously, we have to provide the exercise for scapular muscle. We can evaluate the responsible region by understanding which muscle should have high activities and analyzing the motion to see the swaying region.





**Figure 12.** Evaluation regarding scapular movement during muscle testing. We will be able to calculate which joints have weakness for improvement by observing the scapular movement during muscle testing with every movement direction. For example, during muscle testing of external rotation, if scapular protraction appears serious, the responsible region of shoulder muscle weakness will be at scapulothoracic joint.

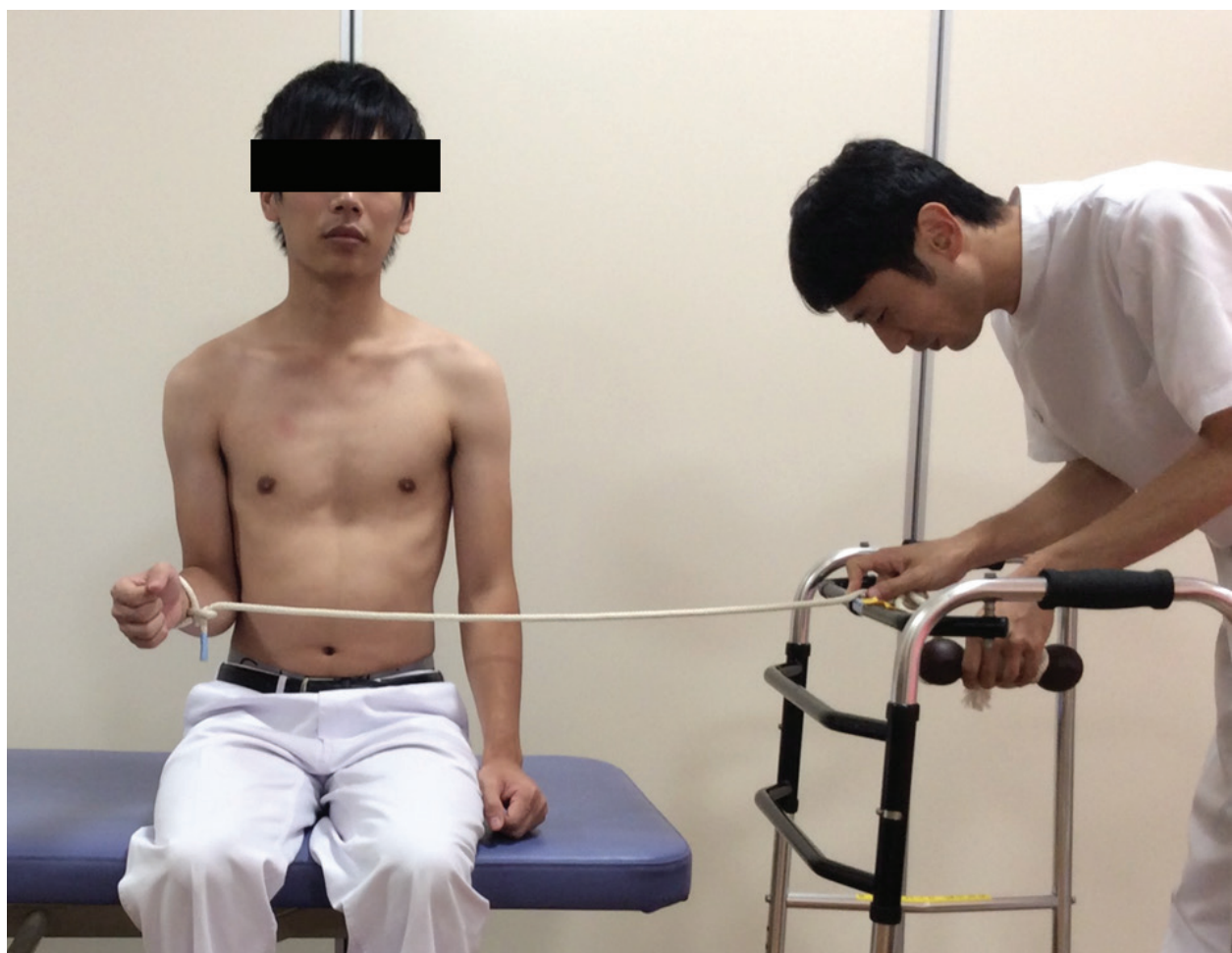
## 2.5. The study about the order of activity in scapular muscles

In previous studies, I have shown that there is high activity of scapular muscle and little activity of scapular muscle during shoulder isometric contraction, and these muscles are changed by movement direction. And the muscle strength of scapular muscle influences the muscle strength of whole shoulder joint. From these facts, I have described that we will classify the scapular muscles into the agonist and the antagonist, and the agonist at scapulothoracic joint will have the function of resisting the external load. I thought that if the agonist at scapulothoracic joint has the function of resisting the external load like the agonist at glenohumeral joint, the time of starting the muscle activity of the agonist at scapulothoracic joint will be the same as the agonist at glenohumeral joint. In other words, I thought that the hypothesis about the classification of scapular muscles will be able to be verified by examination in the timing of scapular muscle activity during shoulder motion. However, as the muscle activity of transversus abdominis muscle starts before the motion of upper limb, therapists sometimes regard that scapular stability by scapular muscle activity is established before humeral motion. In this case, scapular muscle activity must start before the muscle activity at glenohumeral joint. Which pattern appeared? So, I examined the order of muscle activities during shoulder motion.

### 2.5.1. Materials and methods

Seventeen healthy men participated in this study. The mean anthropometric characteristics of 15 subjects were age,  $25.5 \pm 2.2$  years; height,  $169.4 \pm 5.6$  cm; and weight,  $62.8 \pm 7.8$  kg. The trials were isometric works against external load in shoulder internal and external rotation at  $0^\circ$  shoulder abduction. And two conditions were set that was and was not informed of the timing of obtaining external load. Then, we measured the time to start activities in the agonist at GHJ and the agonist and antagonist at STJ in these trials.

The subjects were measured in sitting position. A cord of 1.5-kg plumb bob was tightly fastened at the end to the subject's end of the forearm. The cord was set on the level run on the same height-adjusted device. The internal and external rotation directional external load was given to the subject by dropping the plumb bob using trochlear fundamental (**Figure 13**). Electrical switch was set to the subject's forearm and the starting movement was measured by this switch. To measure the muscle activities during the task, electrodes of electromyography were applied to pectoralis major, infraspinatus, serratus anterior, and middle trapezius. The task was tried in two conditions: one was to inform the timing of obtaining external load



**Figure 13.** The method of the measurement. A cord of 1.5-kg plumb bob was tightly fastened on the end to the subject's end of the forearm. The cord was set on the level run on the same height-adjusted device. The internal and external rotation directional external load was given to the subject by dropping the plumb bob using trochlear fundamental.

(informational task) and the other was uninformed (non-informational task). The order of the tasks was random.

I calculated the time from starting the motion to starting each muscle activities. Starting the motion was judged by the electrical switch. The definition of starting muscle activity was decided by the time point that recorded amplitude over twice of maximum amplitude in 500 ms before the task. And I classified the measured muscle into the agonist at glenohumeral joint, the agonist at scapulothoracic joint, and the antagonist at scapulothoracic joint on each movement direction (**Figure 14**). First, in shoulder internal rotation at 0° shoulder abduction, the agonist at glenohumeral joint was the pectoralis major. The agonist at scapulothoracic joint was set as the serratus anterior because scapular protraction is by shoulder internal rotation. The antagonist at scapulothoracic joint was defined as the middle trapezius because it has the opposite function of the serratus anterior. The agonist at glenohumeral joint for the external rotation task at 0° shoulder abduction was set as infraspinatus. The middle trapezius was defined as the agonists at scapulothoracic joint because scapular retraction is achieved by external rotation. Serratus anterior was defined as the antagonist at scapulothoracic joint.

The reaction times were compared between the agonist at glenohumeral joint, the agonist at scapulothoracic joint, and the antagonist at scapulothoracic joint in each trial. From this, I examined the order of muscle activities.

2.5.2. Results

The result is shown in **Figure 15** in internal rotation task. Both informational task and non-informational task, the reaction time on serratus anterior which was defined as the agonist at scapulothoracic joint was the same as pectoralis major which was defined as the agonist at glenohumeral joint. However, the reaction time on middle trapezius which was set to the antagonist at scapulothoracic joint was late than on these two muscles significantly.

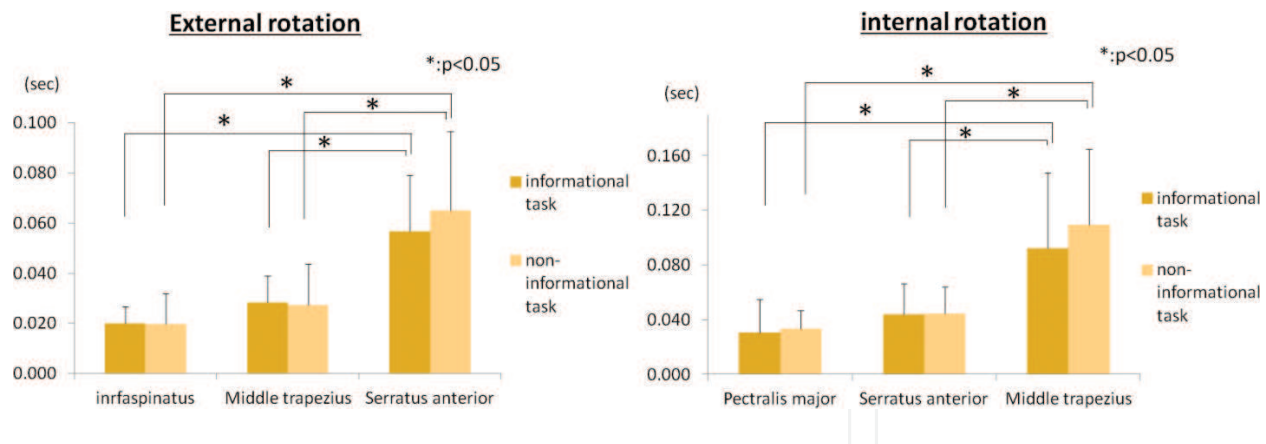
The result in external rotation was as follows. Both informational task and non-informational task, the reaction time on middle trapezius which was the agonist at scapulothoracic joint was not different from that on infraspinatus which was the agonist at glenohumeral joint. But the reaction time on serratus anterior which was defined as the antagonist at scapulothoracic joint was late than on these two muscles significantly.

In all, similar results were obtained.

	Agonist at glenohumeral joint	Agonist at scapulothoracic joint	Antagonist at scapulothoracic joint
Internal rotation	Pectoralis major	Serratus anterior	Middle trapezius
External rotation	Infraspinatus	Middle trapezius	Serratus anterior

**Figure 14.** Classification about the agonist and the antagonist. I classified the measured muscle into the agonist at glenohumeral joint, the agonist at scapulothoracic joint, and the antagonist at scapulothoracic joint on each movement direction by scapular movement during the shoulder motion.





**Figure 15.** The reaction time of each muscle. The reaction time of the agonist at scapulothoracic joint was the same as that of the agonist at glenohumeral joint. However, the reaction time of the antagonist at scapulothoracic joint was significantly delayed than that of these two muscles.

### 2.5.3. Discussion

In all trials, the reaction time of the agonist at scapulothoracic joint was the same as that of the agonist at glenohumeral joint. However, the reaction time of the antagonist at scapulothoracic joint was significantly delayed than that of these two muscles.

The study about the relationship between agonist and antagonist was tested a lot for other joints. It is common knowledge that the training for agonist leads to bigger torque at the joint and be able to maintain the joint against stronger external load. On the other hand, regarding antagonist, the muscle activity was examined at the knee, elbow, and glenohumeral joint and the slight muscle activity comes in during isometric, isotonic, and isokinetic contraction [14–16]. And it was known that the muscle activity of antagonist increases on unstable condition at the lower leg. From these facts, it is known that the antagonist has the function about the control of the joint movement caused by agonist and the contribution to the joint stability by co-contraction with agonist [17, 18]. Additionally, Hase et al. reported the result of the measurement about muscle activity at wrist joint during catching of a falling ball dropped on the palm [19]. The maximal muscle activity of the antagonist appeared after that of the agonist slightly and the antagonist had persistent muscle activity before catching. It was concluded that the antagonist will work for the fixation of the joint. Compared to my studies with the previous studies about antagonist on other joints, it was founded that these are some similar points. In my previous studies, the exercise for the agonist at scapulothoracic joint led to an increase in the muscle strength of whole shoulder joint. And the study about the measurement of muscle activities during isometric contraction showed that the antagonist at scapulothoracic joint had slight muscle activity. These results are the same as the other joint studies. Additionally, in this study, the reaction time of the antagonist at scapulothoracic joint was significantly delayed than that of the agonist at glenohumeral joint and scapulothoracic joint. This result has similarity in part as the previous study of wrist joint. By the way, although I did not indicate this report, the same result, the reaction time of the antagonist at scapulothoracic joint was significantly delayed than that of the agonist at glenohumeral joint and scapulothoracic joint, was demonstrated in my study of the task about starting the movement for oneself. As just described, the studies about scapular muscles indicate very similar result to the studies regarding agonist and antagonist at other joints, so we must be able to consider the scapular

muscles using the classification as agonist and antagonist. It is conceivable that the agonist at scapulothoracic joint has the function of resisting the external load and the antagonist works for controlling the scapular position.

### 3. Summary

I had shown some studies about scapular muscles. Summarizing from all studies, we have to discuss the next content during clinical rehabilitation.

First, we do not integrate scapular muscles when thinking about scapular stability. For example, there is the athlete who has poor upper limb ability for endurance to contact by other athlete during sports situation and he/she has scapular instability on these occasions. In this case, we will give him/her the exercise for scapular muscles. However, when the exercise is considered, we have to discuss which muscle especially needs to be strengthened, not gather scapular muscle together. I mean it is important to calculate which direction the external load is absorbed, which direction the athlete have to exert muscle force, and which muscle has the highest muscle activity. The ability for endurance to contact by other athlete must be advanced effectively by strengthening the muscle intensively. We have to consider the impairment using mechanics about scapulothoracic joint.

Next, it is also important that we examine the responsible joint, glenohumeral joint or scapulothoracic joint carefully in every direction when a patient has shoulder muscle weakness. Therapists usually judge this in shoulder flexion and abduction, but we must try in shoulder internal rotation, external rotation, horizontal abduction, and horizontal adduction. The technique of judgment is to observe scapular instability during shoulder muscle testing. Let us check for sure during muscle testing.

Lastly, we have to understand that it is not true that the subject exerts muscle power at glenohumeral joint after scapular stability. The power on shoulder joint is exhibited by working harmoniously with glenohumeral joint and scapulothoracic joint at once. This is very important to think about scapular stability. It is whether scapula stabilizes for external load and weight of the arm. The rehabilitation order that first the scapular position is adjusted and second glenohumeral joint is exercised is not pertinence. Furthermore, in turn, we have to examine the affect for the motion by assessment to glenohumeral joint and scapulothoracic joint at once.

Taking these points into consideration, it should be clear how the scapular is concerned with the motion. From this, the policy will be definitude and we can provide more effective rehabilitation program. Please make good use for clinical reasoning.

### Author details

Tomohito Ijiri

Address all correspondence to: tomohito316@hotmail.co.jp

Department of Rehabilitation, Kiba Hospital, Medical Corporation, Juzankai, Osaka, Japan



## References

- [1] Ludewig PM, Reynolds JF. The association of scapular kinematics and glenohumeral joint pathologies. *J Orthop Sports Phys Ther.* 2009;**39**:90–104.
- [2] Michener LA, Sharma S, Cools AM, Timmons MK. Relative scapular muscle activity ratios are altered in subacromial pain syndrome. *J Shoulder Elbow Surg.* 2016;**25**:1861–1867.
- [3] Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. *Br J Sports Med.* 2004;**38**:64–68.
- [4] Mottram SL. Dynamic stability of the scapula. *Man Ther.* 1997;**2**(3):123–131.
- [5] Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative balance of serratus anterior and upper trapezius muscle activity during push-up exercises. *Am J Sports Med.* 2004;**32**:484–493.
- [6] Turuik M, Ellenbecker TS. Serratus anterior and lower trapezius muscle activities during multi-joint isotonic scapular exercises and isometric contractions. *J Athl Train.* 2015;**50**(266):199–210.
- [7] Zhang M, Zhou JJ, Zhang YM, Wang JH, Zhang QY, Chen W. Clinical effectiveness of scapulothoracic joint control training exercises on shoulder joint dysfunction. *Cell Biochem Biophys.* 2015;**72**:83–87.
- [8] Cools AM, Struyf F, De Mey K, Maenhout A, Castelein B, Caqnie B. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. *Br J Sports Med.* 2014;**48**:692–697.
- [9] Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle activity during selected rehabilitation exercises. *Am J Sports Med.* 1999;**27**(6):784–791.
- [10] Moseley JB Jr, Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular muscles during a shoulder rehabilitation program. *Am J Sports Med.* 1992;**20**:128–134.
- [11] Andrews JR, Wilk KE. The athlete's shoulder. America: Churchill Livingstone; 1994. 453–457.
- [12] Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis of exercise for the trapezius and serratus anterior muscles. *J Orthop Sports Phys Ther.* 2003;**33**:247–258.
- [13] Delagi EF, Perotto A. Anatomic guide for the electromyographer—the limbs. Springfield: Thomas; 1980.
- [14] Bazzucchi I, Sbriccoli P, Marzattinocci G, Felici F. Coactivation of the elbow antagonist muscles is not affected by the speed of movement in isokinetic exercise. *Muscle Nerve.* 2006;**33**(2):191–199.
- [15] Kronberg M, Németh G, Broström LA. Muscle activity and coordination in the normal shoulder. An electromyographic study. *Clin Orthop Relat Res.* 1990;**257**:76–85.

- [16] Remaud A, Cornu C, Guével A. Agonist muscle activity and antagonist muscle co-activity levels during standardized isotonic and isokinetic knee extensions. *J Electromyogr Kinesiol.* 2009;**19**(3):449–458.
- [17] Humphrey DR, Reed DJ. Separate cortical systems for control of joint movement and joint stiffness: reciprocal activation and coactivation of antagonist muscles. *Adv Neurol.* 1983;**39**:347–372.
- [18] Bazzucchi I, Riccio ME, Felici F. Tennis players show a lower coactivation of the elbow antagonist muscles during isokinetic exercises. *J Electromyogr Kinesiol.* 2008;**18**(5): 752–759.
- [19] Hase K. Motor control of the forearm muscles during catching of a falling ball. *Jpn J Rehabil Med.* 1997;**34**:218–225.