Original Article
Clinics in Orthopedic Surgery 2025;17:274-282 • https://doi.org/10.4055/cios24079

Is the Subscapularis Function Preserved after the Latarjet Procedure? A Quantitative Analysis Using Positron Emission Tomography

Kazuho Aizawa, MD, Nobuyuki Yamamoto, MD, Jun Kawakami, MD, Takayuki Muraki, PT*, Shoichi Watanuki, RT[†], Kotaro Hiraoka, MD[†], Manabu Tashiro, MD[†], Toshimi Aizawa, MD, Eiji Itoi, MD[‡]

Department of Orthopedic Surgery, Tohoku University School of Medicine, Sendai,
**Department of Physical Medicine and Rehabilitation, Tohoku University Graduate School of Medicine, Sendai,*
[†]Division of Cyclotron Nuclear Medicine, Cyclotron and Radioisotope Center, Tohoku University, Sendai,
[‡]Department of Orthopedic Surgery, Tohoku Rosai Hospital, Sendai, Japan

Background: In the Latarjet procedure, the subscapularis is divided at the superior two-thirds junction. It has been believed that this subscapularis split approach resulted in better internal rotation strength rather than an L-shaped subscapularis tenotomy. However, there are few studies demonstrating the preserved function of the subscapularis after the Latarjet procedure. The aim of the present study was to clarify the subscapularis activity using positron emission tomography (PET) in patients after the Latarjet procedure.

Methods: Six men who had undergone the Latarjet procedure were enrolled. The internal rotation exercise with elastic bands was performed with the arm at 0° and 90° of abduction. After the exercises, the patients had an intravenous injection of fluorine 18 fluorodeoxyglucose (^{18}F FDG). Each PET image was fused to the corresponding computed tomography image to calculate the standardized uptake value (SUV). The internal rotation muscle strength was measured by a dynamometer.

Results: At 0° of abduction, the subscapularis SUVs of the involved side were significantly lower than those of the uninvolved side (p = 0.010), although there was no significant difference at 90° of abduction. The SUVs of the involved subscapularis were significantly lower at 0° of abduction than at 90° (p = 0.034). The internal rotation strength of the involved side was 81.1% ± 12.1% of the uninvolved side at 0° of abduction.

Conclusions: After the Latarjet procedure with the subscapularis split approach, subscapularis activity was well preserved at 90° of abduction. However, internal rotation strength was reduced by 19%.

Keywords: *Subscapularis muscle, Latarjet procedure, Positron-emission tomography, Internal rotation*

Recently, the Latarjet procedure has gained growing popularity.[1-4] It is mainly because excellent clinical results have been reported even in high-risk patients such as contact athletes and in patients with a large glenoid defect.[4-6] In this procedure, the subscapularis is tenotomized or split for better exposure of the glenoid neck. It has been pointed out that the patients who had the Latarjet procedure with subscapularis tenotomy or an L-shaped partial tenotomy of the subscapularis showed decreased internal rotation strength after surgery.[7-10] To resolve this problem, Walch and Boileau[6] reported the subscapularis split approach. The subscapularis was divided at the superior two-thirds junction to reduce a muscle damage. Since this report was published, this surgical technique has been widely used.

There are several reports describing the muscle strength of internal rotation after the Latarjet procedure

Received February 16, 2024; Revised July 4, 2024;
Accepted July 5, 2024
Correspondence to: Nobuyuki Yamamoto, MD
Department of Orthopedic Surgery, Tohoku University School of Medicine, 1-1 Seiryo-machi, Aoba-ku, Sendai 980-8574, Japan
Tel: +81-22-717-7245, Fax: +81-22-717-7248
E-mail: koyomoe@med.tohoku.ac.jp

using a dynamometer.[11-14] However, their results varied between 70% and 98% of the contralateral side. This variation may arise from the difficulty of assessing the shoulder function. There are some difficulties investigating the function of internal rotators using electromyography (EMG). It picks up a pin-point activity of the muscle, which may be different from portion to portion. Strength measurement by a handheld dynamometer was pointed out to have lower sensitivity and intra- and inter-examiner reliabilities in measuring the rotator cuff strength.[15-17] Thus, the conventional EMG studies have certain limitations. We can use positron emission tomography (PET) with fluorine 18 (^{18}F) fluorodeoxyglucose (FDG) to assess muscle activities in live subjects.[18] FDG-PET is a nuclear medicine tool that is capable of the quantification of tissue glucose metabolism. The values examined by PET indicate the sum of muscle activities. It is clarified that the uptake of FDG reliably reflects muscle activities.[19,20] We hypothesized that the subscapularis function would be preserved after the Latarjet procedure. The aim of the present study was to clarify the subscapularis activity in patients after the Latarjet procedure using PET.

METHODS

The Institutional Review Board of Tohoku University Hospital approved this study (IRB No. 23345). Written informed consent was obtained from all patients.

Patients

Six men with a mean age of 33 years (range, 21–52 years) who had undergone the Latarjet procedure for recurrent anterior dislocations of the shoulder were enrolled in this study. The indications for the surgery were as follows: (1) patients with a bony defect of the glenoid ≥ 25% of the glenoid width and/or an off-track Hill-Sachs lesion,[21] (2) collision/contact athletes such as rugby or judo, and (3) patients who had failed Bankart repair. Patients with postoperative redislocation, bilateral dislocations, or glucose metabolism disorders or those who were not able to finish the study protocol were excluded from this study. Contralateral shoulders were included as control shoulders in the present study. Postoperative follow-up period was 29 ± 14 months. Patients underwent computed tomography (CT) examination of the bilateral shoulders during postoperative follow-up period. The patients' background data such as age, sex, and dominant hand, complication of surgery, and range of motion of the shoulders were picked up from the medical records. Clinical assessment at the final follow-up included the Rowe score and Western Ontario Shoulder Instability Index (WOSI) score. Bone union of the grafted coracoid process was examined on CT.

Surgical Procedure

We performed the Latarjet procedure through a deltopectoral approach. Patients were placed in the supine position. The osteotomy was done at the base of the coracoid process to secure at least 20 mm of the graft length. The subscapularis muscle was then split along the muscle fiber direction at the junction of the middle and lower thirds. The joint capsule was cut vertically for 2 cm along the anterior rim of the glenoid. The bone block was positioned flush with the articular surface of the glenoid at 4 o'clock. Coracoid graft was fixed to the glenoid using two 4.0-mm cannulated cancellous screws. The capsule was repaired to the native glenoid with 2 suture anchors at the 3 and 5 o'clock positions in the right shoulder.

Muscle Strength Measurement

Muscle strength was measured using a hand-held dynamometer (EG-220, SAKAI med). The arm positions were internal rotation at 0° and 90° of abduction, external rotation at 0° of abduction, and abduction in the scapula plane. Internal rotation strength at 0° of abduction was measured in the standing position with the elbow flexed at 90°. Internal rotation strength at 90° of abduction was measured in the sitting position with the shoulder abducted at 90° and the elbow flexed at 90°. External rotation strength

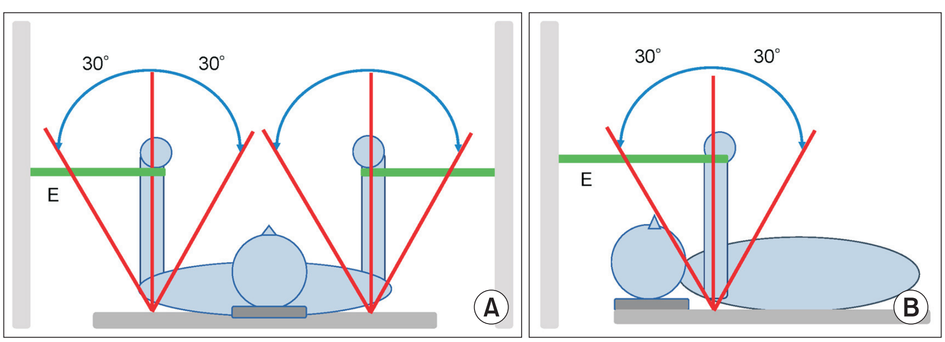

Fig. 1. Schematic drawing of the test procedure with the arm at 0° (A) and 90° (B) of abduction. The patients were asked to move bilateral shoulders from 30° of external to 30° of internal rotation. E: elastic band.

was measured in the standing position with the shoulder abducted at 0° and the elbow flexed at 90°. Abduction strength in the scapular plane was measured in the sitting position. Each muscle strength was measured 5 times and the average value was calculated.

Experimental Protocol

Regarding the study protocol, we followed an established study.[22)] All patients started fasting from at least 12 hours before performing the following repetitive exercise. The patients performed the exercise in the supine position with their elbows flexed at 90° (Fig. 1). Then, the patients moved bilateral shoulders from 30° of external rotation to 30° of internal rotation in adduction. An elastic band was used for the exercise. The patients were asked to rotate the shoulder internally from the starting position (30° of external rotation) to the endpoint of internal rotation (30° of internal rotation) in 1 second and then back to the starting position in 1 second. After this exercise, they took a rest for 20 seconds to avoid muscle fatigue. This was 1 session. They performed 5 sessions continuously before the injection of FDG. At 25 minutes after the first exercise, the patients had FDG injection intravenously. The patients were asked to complete 10 sessions continuously 10 minutes after the injection. The PET examination was performed 50 minutes after the injection of FDG. One or 2 weeks later, the patients performed the same exercise protocol with the shoulders in abduction at 90°, with the PET examination. The average dose (± standard deviation) of injected FDG was 75.9 ± 3.8 MBq. The examinations at 2 different shoulder positions were performed at least 1 week apart.

PET Examinations

We used a PET scanner (Eminence STARGATE, SHIMAZU Corp.) to acquire the image data with a spatial resolution of 3.5 mm full width at half maximum in the current study. The field of view of this scanner was 208 mm (axial) and 600 mm (trans-axial). After the injection of FDG, PET scans were done. PET images were acquired by a single scan, which took 16 minutes. They were reconstructed into a 256 × 256 × 113 matrix for a set of 3-dimensional volume images by a 2-dimensional dynamic row-action maximum likelihood algorithm.

CT Examinations

To assess quantitatively the activity of each muscle by PET examination, reference images were necessary to localize each muscle of the shoulder. CT images were used instead for fusion with the PET images. In order to minimize radiation exposure to the patients, only CT images that were taken as a routine postoperative examination were used in the clinic. During the CT examination, both shoulders were positioned at 0° of abduction, mirroring the same posture maintained during the PET examination.

Quantification of Muscle Activities

We fused each PET image to the corresponding CT image with use of a software (Dr. View/LINUX; AJS) (Fig. 2). In the present study, axial images were used for detecting the contour of the deltoid, pectoralis major, pectoralis minor, latissimus dorsi, and the conjoint tendon muscles. The oblique sagittal images were used for detecting the supraspinatus, infraspinatus, teres minor, subscapularis, and teres major muscles. The previous studies using PET assessed wide muscles such as the deltoid, infraspinatus, and subscapularis segmentally.[22-24)] We divided the deltoid muscle into 3 parts by drawing lines from the center of the humerus head to the 12:00 and 9:00 directions on axial images of the right shoulder. The infraspinatus muscle was divided equally into 2 parts (superior and inferior) by the horizontal line. The subscapularis muscle was also divided into 3 parts by drawing 2 horizontal lines. On the involved side, the border of the middle and inferior third of the subscapularis was defined by the screw location.

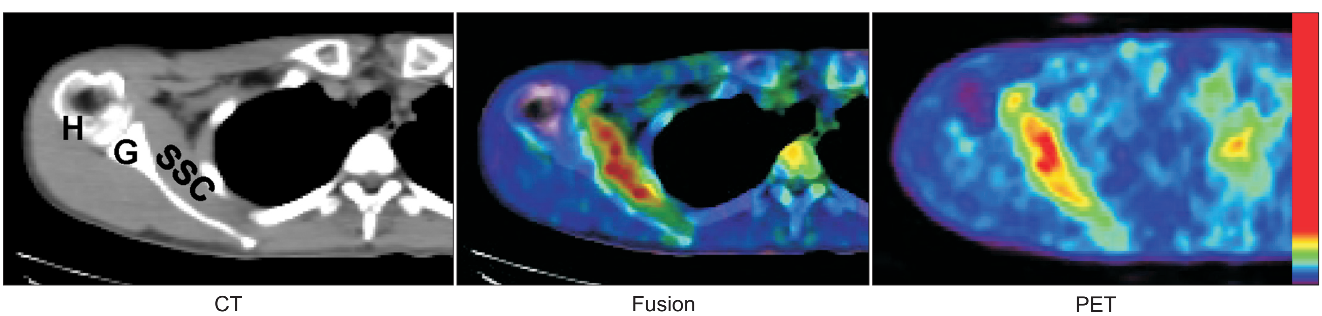

Fig. 2. Fused image of positron emission tomography (PET) and computed tomography (CT). Each PET image was fused to the corresponding CT image. H: humeral head, G: glenoid, SSC: subscapularis.

The volume of interests (VOI) of each muscle detected on CT images was marked on the corresponding PET images with use of a software to measure radioactivity of muscles. The standardized uptake value (SUV) was calculated using the following equation:

$$\text{SUV} = \frac{\text{Mean VOI count (cps / g)} \times \text{body weight (g)}}{\text{Injection dose (MBq)} \times \text{calibration factor (cps / MBq)}}$$

The SUV is defined as the ratio of the amount of FDG accumulated in a certain VOI compared with the total amount of FDG that is distributed over the whole human body. The SUVs of each muscle or portion were compared between the involved and uninvolved sides and between the 0° and 90° of abduction after exercise.

Statistical Analysis

All SUVs were expressed as the average value with standard deviation. The one-way factorial analysis of variance followed by Tukey's Honestly Significant Difference test was performed for multiple comparisons of the SUVs of each muscle. Intraobserver and interobserver agreements on the SUV in a certain VOI was assessed by calculating the interclass correlation coefficient. The intraobserver correlation coefficient was calculated by 2 blinded separate measurements of SUV with a time interval of 7 days. The interobserver correlation coefficient was calculated comparing the measurements of SUV between 2 different experienced orthopedic surgeons (KA and JK). Assessment and statistical analysis of all data were done by orthopedic surgeons with over 10 years of experience (KA and JK). A p-value of 0.05 was considered as statistically significant. Statistical analyses were done using JMP Pro 15 (SAS Institute Inc.) software programs.

Table 1. Characteristics of the Patients

Variable	Value
Sex (male : female)	6 : 0
Age (yr)	33 ± 12
Involved side (right : left)	2 : 4
Mean postoperative period (mo)	29 ± 14
Mean height (cm)	172 ± 5
Mean body weight (kg)	64 ± 11
Clinical score	
WOSI (Preop)	72.9 ± 16.7 (52.5 ± 19.2)
Rowe (Preop)	92.5 ± 6.9 (32.5 ± 28.4)
Range of shoulder motion (°)	
Flexion	Involved side, 158 ± 12; uninvolved side, 168 ± 4
Abduction	Involved side, 170 ± 9; uninvolved side, 175 ± 5
External rotation	Involved side, 55 ± 14; uninvolved side, 74 ± 7
Internal rotation	Involved side, seventh thoracic vertebra; uninvolved side, sixth thoracic vertebra

Values are presented as mean ± standard deviation.
WOSI: Western Ontario Shoulder Instability Index, Preop: preoperative.

RESULTS

Clinical Assessments

Demographic data of the patients are shown in Table 1. There were no significant differences in range of shoulder motions, except for external rotation, which was significantly decreased on the involved side ($p = 0.012$). The WOSI and Rowe scores significantly improved ($p < 0.05$ and $p = 0.001$, respectively). In all cases, bony union was confirmed between the grafted coracoid process and the glenoid on CT images.

Muscle Strength Measurement

The muscle strength of internal rotation in adduction on the involved side was significantly decreased compared to that on the uninvolved side ($p = 0.001$), whereas there were no significant differences of that in abduction, 90° of abduction, and external rotation (Table 2). There were 2 cases where the dominant hand was the affected side, and 4 cases where the non-dominant hand was the affected side.

Table 2. Muscle Strength Measurements

Variable	Muscle strength (kgf)		
	Involved side	Uninvolved side	Percentage (%)
IR in adduction	5.3 ± 0.9	6.5 ± 1.6	81.1 ± 12.1*
IR in abduction	5.9 ± 1.7	6.5 ± 1.8	89.6 ± 10.3
Elevation	5.8 ± 1.7	6.5 ± 1.8	89.1 ± 6.7
ER in adduction	5.6 ± 1.4	5.7 ± 1.1	97.5 ± 14.8

Values are presented as mean ± standard deviation.
IR: internal rotation, ER: external rotation.
*$p < 0.005$.

PET Examination

The SUVs of all muscles are shown in the Table 3. After exercise, there was a significant increase of FDG accumulation in the subscapularis muscle with the arm at both 0° and 90° of abduction compared with the other muscles (Fig. 3). Conjoint tendon muscles showed high SUVs compared with the other muscles. The mean SUV of the subscapularis after internal-rotation exercise at 0° of abduction

Table 3. The Standardized Uptake Values of Each Shoulder Muscle

Variable		0° of abduction		90° of abduction	
		Involved	Uninvolved	Involved	Uninvolved
Subscapularis	All	1.02 ± 0.23*,†	1.30 ± 0.30‡	1.45 ± 0.31	1.84 ± 0.66
	Superior	1.06 ± 0.25†	1.28 ± 0.31‡	1.40 ± 0.32	1.84 ± 0.67
	Middle	1.08 ± 0.26†,§	1.39 ± 0.28‡	1.55 ± 0.34	1.99 ± 0.76
	Inferior	0.96 ± 0.20*,†	1.26 ± 0.38‡	1.47 ± 0.34	1.83 ± 0.71
Supraspinatus		0.50 ± 0.02	0.48 ± 0.04	0.55 ± 0.15	0.46 ± 0.06
Infraspinatus	All	0.68 ± 0.12	0.56 ± 0.05	0.70 ± 0.08	0.57 ± 0.06
	Superior	0.68 ± 0.12	0.55 ± 0.05	0.69 ± 0.11	0.57 ± 0.04
	Inferior	0.70 ± 0.15	0.57 ± 0.05	0.74 ± 0.09	0.57 ± 0.07
Teres minor		0.67 ± 0.17	0.66 ± 0.14	0.69 ± 0.12	0.55 ± 0.06
Conjoint tendon		1.28 ± 0.40	1.32 ± 0.40‡	1.01 ± 0.10*	0.81 ± 0.14
Teres major		0.58 ± 0.13	0.63 ± 0.15	0.64 ± 0.12	0.59 ± 0.12
Deltoid	All	0.49 ± 0.03	0.44 ± 0.04	0.48 ± 0.03	0.41 ± 0.04
	Anterior	0.60 ± 0.08	0.50 ± 0.06	0.55 ± 0.09	0.46 ± 0.04
	Middle	0.43 ± 0.04	0.40 ± 0.05	0.46 ± 0.06	0.40 ± 0.04
	Posterior	0.48 ± 0.02	0.44 ± 0.04	0.47 ± 0.04	0.40 ± 0.03
Pectoralis major		0.61 ± 0.18	0.67 ± 0.26	0.44 ± 0.06	0.45 ± 0.11
Pectoralis minor		0.61 ± 0.17	0.57 ± 0.13	0.50 ± 0.02	0.49 ± 0.06
Latissimus dorsi		0.55 ± 0.17	0.54 ± 0.13	0.52 ± 0.10	0.44 ± 0.03

Values are presented as mean ± standard deviation.
Statistically significant difference: *$p < 0.05$ between the involved and uninvolved sides. †$p < 0.005$ between 0° and 90° of abduction. ‡$p < 0.05$ between 0° and 90° of abduction. §$p < 0.005$ between the involved and uninvolved sides.

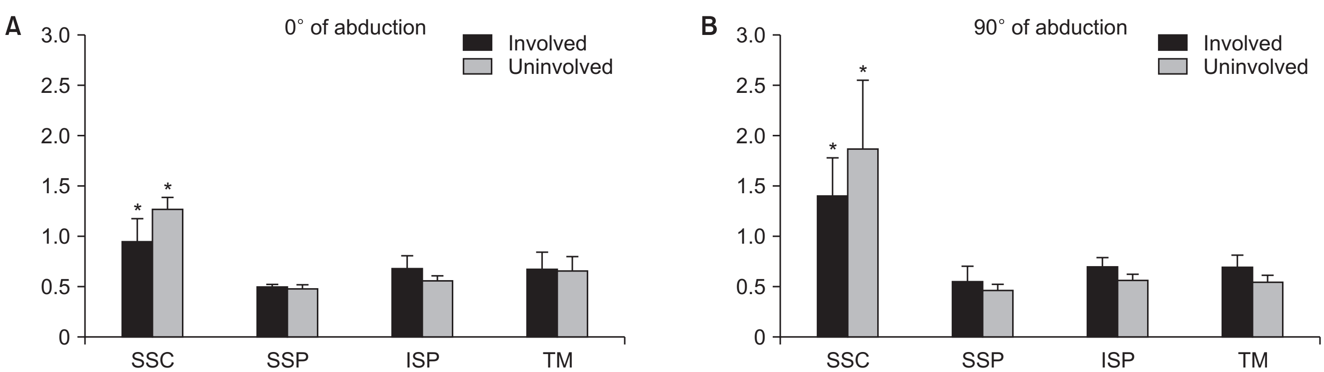

Fig. 3. Fluorodeoxyglucose (FDG) accumulation in the subscapularis muscle. A marked increase of FDG accumulation in the subscapularis muscle was observed at both arm positions, 0° (A) and 90° (B) of abduction. SSC: subscapularis, SSP: supraspinatus, ISP: infraspinatus, TM: teres minor. *$p < 0.01$.

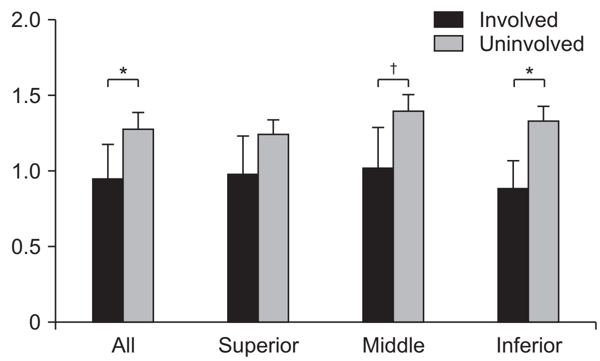

Fig. 4. The standardized uptake values (SUVs) of subscapularis muscle after exercise with the arm at 0° of abduction. The SUVs of the middle and inferior portions on the involved side were significantly lower than those on the uninvolved side. *$p < 0.05$, †$p < 0.01$.

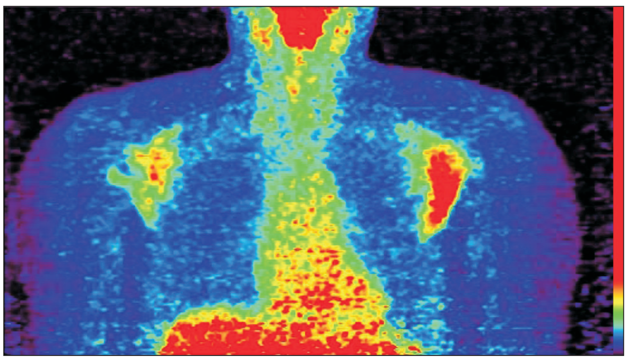

Fig. 5. A representative positron emission tomography image of a 28-year-old man after exercise with the arm at 0° of abduction. A marked decrease in fluorodeoxyglucose accumulation was observed on the involved side (right shoulder) compared to the uninvolved side.

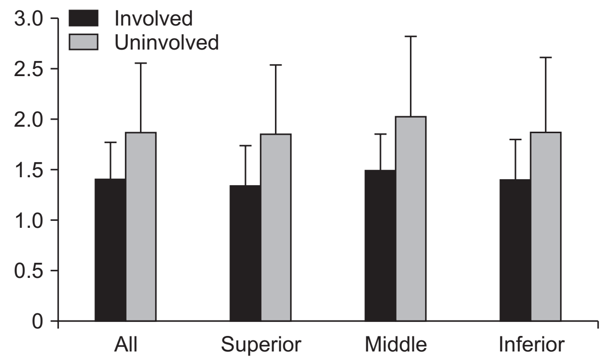

Fig. 6. The standardized uptake values of subscapularis muscle after exercise with the arm at 90° of abduction. There is no significant difference between the involved and uninvolved side.

was significantly decreased in the involved side (p = 0.021) (Figs. 4 and 5). The SUVs of the middle and inferior portion on the involved side at 0° of abduction were significantly lower than those on the uninvolved side (superior: p = 0.071, middle: p = 0.009, inferior: p = 0.026). However, there were no significant differences in SUVs of 3 parts at 90°of abduction (Fig. 6). Although the SUVs were lower in the involved side, no significant differences were found in any parts between both sides. All parts of the subscapularis showed significantly higher SUVs at 90° of abduction compared to those at 0° of abduction. The SUVs of the conjoint tendon muscles at 0° of abduction showed no significant differences between the involved and uninvolved sides, but at 90° of abduction, the SUV was significantly higher in the involved side (p = 0.030). The other muscles showed no significant differences between the involved and uninvolved sides. The intraobserver correlation coefficient (ICC [1,2]) on the SUV in a certain VOI was 0.983 (range, 0.996–0.997), and the interobserver correlation coefficient (ICC [2,1]) was 0.989 (range, 0.986–0.991). There were no complications in the present study.

DISCUSSION

After the internal-rotation exercise, FDG accumulation significantly increased in the subscapularis muscle at both 0° and 90° of abduction compared with other muscles. The SUVs of the subscapularis were lower at 0° of abduction than at 90°. After exercise at 0° of abduction, the SUVs of the subscapularis were significantly lower in the middle and inferior parts of the involved shoulder than of the uninvolved one. On the other hand, at 90° of abduction, there was no significant difference between the involved and uninvolved shoulders. Also, there was no significant difference at each portion of the subscapularis between involved and uninvolved shoulders. The muscle strength of internal rotation in adduction in the involved shoulder decreased by 20% compared to the uninvolved shoulder.

In the present study, we used no magnetic resonance imaging (MRI) or CT but PET because we were not able to evaluate the muscle activity of the specific motion on MRI or CT. There are some benefits of using PET examination: we are able to evaluate (1) many muscles at the same time, (2) not some parts of the muscle but the entire muscle, (3) deep muscles, and (4) muscle activity of the specific motion.

The subscapularis contributes to shoulder stability in addition to working as an internal rotator. Ackland et al.[25-27] reported that the superior portion of the shoulder muscles worked during arm abduction, while the inferior portion contributed to shoulder stability. Decker et al.[28] demonstrated that upper subscapularis muscle activity was greater at 90° of abduction than 0°. This may be because the upper subscapularis muscle is used to keep the arm in abduction.

A PET study by Omi et al.[23] indicated the superior one-third played an important role during shoulder elevation motion. A recent PET study showed that the middle and inferior parts of the subscapularis are the main shoulder internal rotators in 0° of abduction, whereas the inferior part was the main internal rotator at 0° of abduction.[22]

There are a couple of reasons why the subscapularis muscle activity was not suppressed at 90°. First, due to an increased subscapularis muscle activity at 90° of abduction, the contraction of the conjoint tendon muscles, which was less active at 90°, seemed to have less effect on the subscapularis compared to 0° of abduction. Second, at 0° of abduction, the transferred conjoint tendon runs perpendicular to the subscapularis muscle and may interfere with the contraction of the subscapularis, which may have resulted in the decrease of the SUVs of the middle and inferior parts of the subscapularis. At the intersection of the transferred conjoint tendon and the subscapularis tendon, the conjoint tendon is bent by the inferior portion of the subscapularis tendon at 0° of abduction. This is the reason why the conjoint tendon showed significantly increased SUVs compared with those at 90°. On the other hand, at 90° of abduction, the muscle orientation of the conjoint tendon is almost parallel to that of the subscapularis. Due to similar orientations of these muscles, the conjoint tendon is less likely to interfere with the contraction of the subscapularis muscle.

The previous biomechanical study[29] reported that the split subscapularis tendon contributed to muscle stability: the intersection of the transferred conjoint tendon provided tension to the inferior part of the subscapularis muscle. After exercise at 0° of abduction, the conjoint tendon showed significantly increased SUVs compared with those at 90°. This suggests that the intersection of the transferred conjoint tendon may have worked more at 0° of abduction. On the other hand, since the orientation of the conjoint tendon was similar to that of the uninvolved side at 90° of abduction, there were no significant differences of the SUVs of the conjoint tendon between the involved and uninvolved sides.

The results of this study indicate that almost 80% of the muscle strength of the subscapularis was preserved by splitting the subscapularis muscle. At 90° of abduction, this muscle activity was preserved by 90%, although it was reduced at 0° of abduction. As far as we know, there are no studies evaluating internal rotation function at 90° of abduction after the Latarjet procedure. Many surgeons have believed that the subscapularis split approach resulted in better internal rotation strength when compared with a tenotomy approach. However, there are few studies demonstrating that the subscapularis function is preserved after the Latarjet procedure. Our study for the first time clarified the preserved function of the subscapularis using PET examination. The subscapularis split approach has been widely used and we have believed that internal rotation strength is preserved after surgery when compared with a tenotomy approach. However, there are a few studies demonstrating that the subscapularis function is preserved after the Latarjet procedure. Our study for the first time clarified the preserved function of the subscapularis using PET examination.

This study has several limitations. First, only 6 patients were enrolled in the present study. The number of patients is comparable to that of the previous PET studies (Tashiro et al.[18]: n = 7; Fujimoto et al.[19]: n = 7; and Omi et al.[23]: n=6). Although the number of patients was small, we were able to demonstrate the difference in muscle activity patterns. By increasing the number of patients, it may be possible that highly reproducible SUV data and significant differences could have been obtained. Second, we used postoperative CT images to fuse with the PET images for muscle compartment identification. It is better for the patients to take CT scans at the same time as the PET examination. The radiation dose of a CT scan is relatively high, ranging from about 0.7 to 4 mSv, so the number of CT scans was minimized in order to reduce patient radiation exposure. Therefore, we used CT images taken during the postoperative period in the present study. Third, while the previous study[22] evaluated muscle activity during unilateral internal-rotation exercises, the present study performed simultaneous bilateral exercises. If PET scan was performed separately on each side, 4 examinations would be required for 1 patient, which causes a problem of radiation exposure. Fourth, there were 2 cases where the dominant hand was the affected side and 4 cases where the non-dominant hand was the affected side. If the non-dominant hand was the affected side, it may have affected the results.

In the Latarjet procedure, the muscle activity of the subscapularis was preserved at 90° of abduction, but internal rotation strength was reduced by 19% and the muscle activity detected by PET examination was decreased at 0° of abduction.

CONFLICT OF INTEREST

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

ACKNOWLEDGEMENTS

This work was supported by Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (Grant No. 20K11277).

ORCID

Kazuho Aizawa https://orcid.org/0009-0003-9339-7149
Nobuyuki Yamamoto https://orcid.org/0000-0003-2053-9348
Jun Kawakami https://orcid.org/0000-0002-3321-9637
Takayuki Muraki https://orcid.org/0000-0003-2548-1165
Shoichi Watanuki https://orcid.org/0009-0007-6618-7946
Kotaro Hiraoka https://orcid.org/0000-0003-2422-3121
Manabu Tashiro https://orcid.org/0000-0002-8860-6917
Toshimi Aizawa https://orcid.org/0000-0003-1571-5618
Eiji Itoi https://orcid.org/0000-0002-9859-6791

REFERENCES

1. Frank RM, Gregory B, O'Brien M, et al. Ninety-day complications following the Latarjet procedure. J Shoulder Elbow Surg. 2019;28(1):88-94.
2. Gilat R, Haunschild ED, Lavoie-Gagne OZ, et al. Outcomes of the Latarjet procedure versus free bone block procedures for anterior shoulder instability: a systematic review and meta-analysis. Am J Sports Med. 2021;49(3):805-16.
3. Horner NS, Moroz PA, Bhullar R, et al. Open versus arthroscopic Latarjet procedures for the treatment of shoulder instability: a systematic review of comparative studies. BMC Musculoskelet Disord. 2018;19(1):255.
4. Jeon YS, Jeong HY, Lee DK, Rhee YG. Borderline glenoid bone defect in anterior shoulder instability: latarjet procedure versus Bankart repair. Am J Sports Med. 2018;46(9):2170-6.
5. Edwards TB, Walch G. The Latarjet procedure for recurrent anterior shoulder instability: rationale and technique. Oper Tech Sports Med. 2002;10(1):25-32.
6. Walch G, Boileau P. Latarjet-Bristow procedure for recurrent anterior instability. Tech Shoulder Elb Surg. 2000;1(4):256-61.
7. Maynou C, Cassagnaud X, Mestdagh H. Function of subscapularis after surgical treatment for recurrent instability of the shoulder using a bone-block procedure. J Bone Joint Surg Br. 2005;87(8):1096-101.
8. Picard F, Saragaglia D, Montbarbon E, Tourne Y, Thony F, Charbel A. Anatomo-clinical consequences of the vertical sectioning of the subscapular muscle in Latarjet intervention. Rev Chir Orthop Reparatrice Appar Mot. 1998;84(3):217-23.
9. Scheibel M, Habermeyer P. Subscapularis dysfunction following anterior surgical approaches to the shoulder. J Shoulder Elbow Surg. 2008;17(4):671-83.
10. Scheibel M, Tsynman A, Magosch P, Schroeder RJ, Habermeyer P. Postoperative subscapularis muscle insufficiency after primary and revision open shoulder stabilization. Am J Sports Med. 2006;34(10):1586-93.
11. Caubère A, Lami D, Boileau P, Parratte S, Ollivier M, Argenson JN. Is the subscapularis normal after the open Latarjet procedure?: an isokinetic and magnetic resonance imaging evaluation. J Shoulder Elbow Surg. 2017;26(10):1775-81.
12. Chillemi C, Guerrisi M, Paglialunga C, Salate Santone F, Osimani M. Latarjet procedure for anterior shoulder instability: a 24-year follow-up study. Arch Orthop Trauma Surg. 2021;141(2):189-96.
13. Garewal D, Evans M, Taylor D, Hoy GA, Barwood S, Connell D. Shoulder structure and function following the modified latarjet procedure: a clinical and radiological review. Shoulder Elbow. 2014;6(1):23-8.
14. Malavolta EA, Cruz DG, Gracitelli ME, et al. Isokinetic evaluation of the shoulder and elbow after Latarjet procedure. Orthop Traumatol Surg Res. 2020;106(6):1079-82.
15. Cahalan TD, Johnson ME, Chao EY. Shoulder strength analysis using the Cybex II isokinetic dynamometer. Clin Orthop Relat Res. 1991;(271):249-57.
16. Chamorro C, Arancibia M, Trigo B, Arias-Poblete L, Jerez-Mayorga D. Absolute reliability and concurrent validity of hand-held dynamometry in shoulder rotator strength assessment: systematic review and meta-analysis. Int J Environ Res Public Health. 2021;18(17):9293.
17. Magnusson SP, Gleim GW, Nicholas JA. Subject variability of shoulder abduction strength testing. Am J Sports Med. 1990;18(4):349-53.
18. Tashiro M, Fujimoto T, Itoh M, et al. 18F-FDG PET imaging of muscle activity in runners. J Nucl Med. 1999;40(1):70-6.
19. Fujimoto T, Itoh M, Kumano H, Tashiro M, Ido T. Whole-body metabolic map with positron emission tomography of a man after running. Lancet. 1996;348(9022):266.
20. Fujimoto T, Itoh M, Tashiro M, Yamaguchi K, Kubota K,

Ohmori H. Glucose uptake by individual skeletal muscles during running using whole-body positron emission tomography. Eur J Appl Physiol. 2000;83(4-5):297-302.

21. Di Giacomo G, Itoi E, Burkhart SS. Evolving concept of bipolar bone loss and the Hill-Sachs lesion: from "engaging/non-engaging" lesion to "on-track/off-track" lesion. Arthroscopy. 2014;30(1):90-8.

22. Matsuzawa G, Sano H, Yamamoto N, et al. Muscle activities during shoulder internal rotation differ in arm position: a preliminary quantitative analysis using positron emission tomography. Skeletal Radiol. 2020;49(11):1839-47.

23. Omi R, Sano H, Ohnuma M, et al. Function of the shoulder muscles during arm elevation: an assessment using positron emission tomography. J Anat. 2010;216(5):643-9.

24. Shinozaki N, Sano H, Omi R, et al. Differences in muscle activities during shoulder elevation in patients with symptomatic and asymptomatic rotator cuff tears: analysis by positron emission tomography. J Shoulder Elbow Surg. 2014;23(3):e61-7.

25. Ackland DC, Pak P, Richardson M, Pandy MG. Moment arms of the muscles crossing the anatomical shoulder. J Anat. 2008;213(4):383-90.

26. Ackland DC, Pandy MG. Lines of action and stabilizing potential of the shoulder musculature. J Anat. 2009;215(2):184-97.

27. Ackland DC, Pandy MG. Moment arms of the shoulder muscles during axial rotation. J Orthop Res. 2011;29(5):658-67.

28. Decker MJ, Tokish JM, Ellis HB, Torry MR, Hawkins RJ. Subscapularis muscle activity during selected rehabilitation exercises. Am J Sports Med. 2003;31(1):126-34.

29. Yamamoto N, Muraki T, Sperling JW, et al. Stabilizing mechanism in bone-grafting of a large glenoid defect. J Bone Joint Surg Am. 2010;92(11):2059-66.