

# Muscle Activity Pattern Of The Shoulder External Rotators Differs In Adduction And Abduction: An Analysis Using Positron Emission Tomography

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## Disclosures:

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**Introduction:** During physical examination of the shoulder, external rotation strength is usually measured with the arm in adducted position (with the arm at side). However, it is necessary to externally rotate the shoulder in abducted position for various activities of daily living, such as eating, shaking hands, combing, etc. The infraspinatus and teres minor are known to be the main external rotators of the shoulder. Although several authors investigated the difference in shoulder external rotation between abducted and adducted positions, each muscle contribution has not been fully clarified yet.

To date, several studies have demonstrated the efficacy of positron emission tomography with [18F]-fluoro-2-deoxyglucose (FDG PET) in evaluating the function of the skeletal muscles.

The purpose of this study was to determine the muscle activities during external rotation with the arm at 0 degrees and 90 degrees of abduction using FDG PET.

**Methods:** Seven healthy volunteers without any history of shoulder pain or trauma were examined using PET in the present study. All participants were male and their dominant sides were right. Their average age was 33 years (range; 27 - 42). All the subjects refrained from eating and drinking except water for at least 8 hours before the examination.

The FDG dissolved in 2 ml saline was injected intravenously via the cubital vein. The mean dose and the standard deviation of injected FDG were 75.7 and 3.1 MBq, respectively.

As for the external rotation exercise at 0 degrees of abduction, the exercise protocol consisted of repetitive shoulder external rotation in the supine position with the arm at the side. In each exercise, the shoulder was rotated from 30 degrees of internal rotation to 30 degrees of external rotation with a resistance using an elastic band (Thera-Band® Yellow, The Hygenic Corporation, Ohio, USA) (Image 1A). A 60-cm elastic band was wrapped around the wrist and was elongated to 150% of the original length when the exercise was started. The repetition number of exercise was 100 times before FDG injection and 200 times after the injection. PET images were collected 50 min after the injection with a whole-body positron camera (SET-2400W; Shimadzu, Kyoto, Japan). For each subject, PET scan was repeated two more times on separate days to obtain the data of external rotation exercise at 90 degrees of abduction (Image 1B) as well as that of a resting condition.

To quantify the muscle activity in each muscle, it was necessary to determine the exact location of each muscle on PET images. For this purpose, MR images of the dominant shoulder were obtained for image fusion in each subject (Signa Horizon LX 1.5T Ver.9.1; GE Healthcare, Milwaukee, WI, USA). Each PET image was fused to the corresponding MR image at the identical level using a software Dr. View / LINUX (AJS Inc., Tokyo, Japan), which enabled to delineate the contour of each shoulder muscle (Image 2). A T2-weighted transverse MR image was used to determine the contour of each segment in the deltoid muscle on PET image and a T2-weighted oblique sagittal MR image was used for determining the supraspinatus, subscapularis, infraspinatus, and teres minor. Subsequently, the volume of interest (VOI) was placed on the MR image for each shoulder muscle. Then, the standardized uptake values (SUVs) in each segment of the shoulder muscles were calculated to quantify their activities using the following equation:

$$\text{SUV} = (\text{Mean VOI count (cps / g)} \times \text{Body weight (g)}) / (\text{Injected dose (MBq)} \times \text{Calibration factor (cps / MBq)})$$

For further comparisons, the exercise/rest ratio was established in each muscle to minimize the individual variation of SUV.

In the present study, we performed the following two comparisons. First, the exercise/rest ratio was compared among five muscles both for 0 degrees and 90 degrees of abduction to clarify which muscle was most activated through the external rotation exercise, Second, TMi/ISP ratio of SUV (TMi: teres minor, ISP: infraspinatus) was established to determine the relative contribution of these two muscles to the external rotation exercise. Then, this ratio was compared at 0 degrees and 90 degrees of abduction.

**Results:** After external rotation exercise at 0 degrees of abduction, the SUV of the infraspinatus was the highest among all the shoulder muscles (Table1). Interestingly, after external rotation exercise at 90 degrees of abduction, the teres minor showed the highest SUV values in 6 out of 7 subjects (Table1).

The exercise/rest ratio both of the infraspinatus and teres minor were significantly higher than that of other muscles at 0

degrees of abduction (Image 3A). These two muscles also represented significantly higher exercise/rest ratio than other muscles at 90 degrees (Image 3B).

Mean TMI/ISP ratio was 0.84 (standard deviation: 0.15) at 0 degrees of abduction, whereas it was 1.21 (standard deviation: 0.23) at 90 degrees of abduction. The TMI/ISP ratio at 90 degrees was significantly higher than that at 0 degrees ( $p < 0.01$ ) (Image 4).

**Discussion:** The results of the present study showed that the activities of both the infraspinatus and teres minor muscles were significantly higher than that of other shoulder muscles during external rotation exercises. Moreover, we found that the muscle activity patterns of these two muscles were different in adduction and abduction. In adduction, the infraspinatus was more activated than the teres minor. On the other hand, teres minor was more activated than the infraspinatus in abduction. These results support the clinical observations by Walch et al.

The torque production by each muscle is determined by two factors: muscle force and moment arm. The amount of force produced by the muscle depends on the potential maximum force each muscle can produce, which correlates with the cross-sectional area (CSA) and percentage of activity, which can be measured by EMG. Using these parameters, the torque of shoulder muscles can theoretically be calculated. However, calculation based on the previous studies of moment arms, CSA, and EMG does not show clear distinction in external rotation function of the infraspinatus and teres minor in abduction and adduction. All these studies were done in different setup, different samples (volunteers, patients, or cadavers) and different investigators. Heterogeneity of these different studies makes it difficult to estimate the true in vivo function of these muscles. This is the first study to show the difference in external rotator function of these two muscles in vivo with the arm in adduction and abduction. This is the strength of this study.

**Significance:** This is the first study to directly prove the concept that the teres minor takes more importance as an external rotation in abduction than in adduction.

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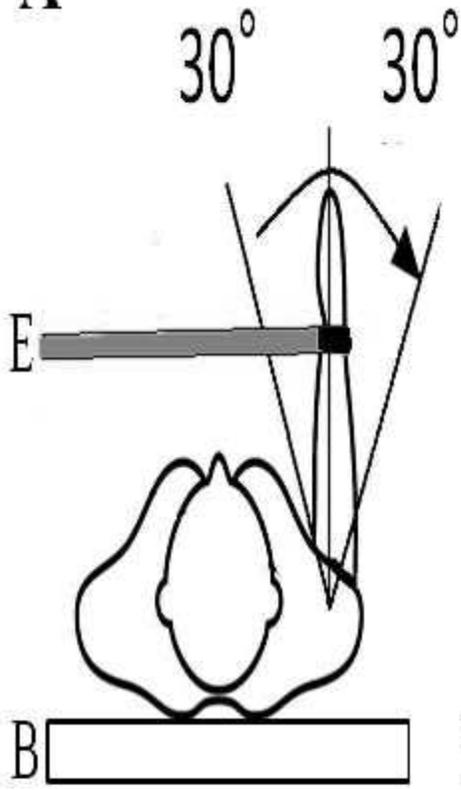
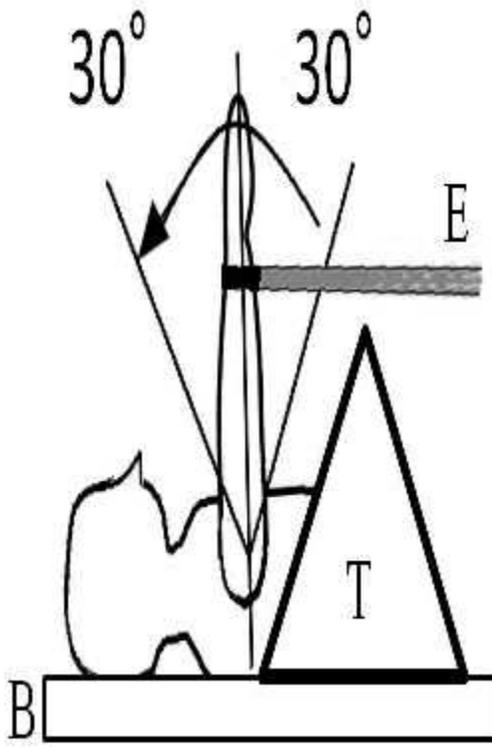
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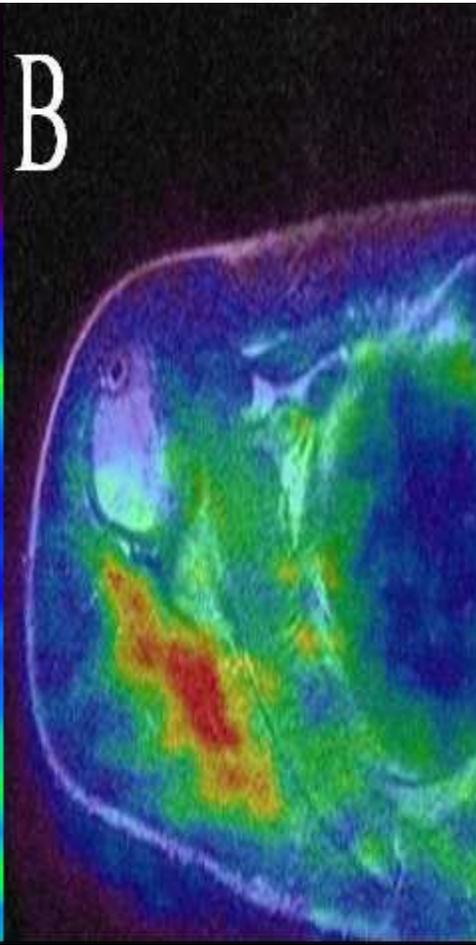
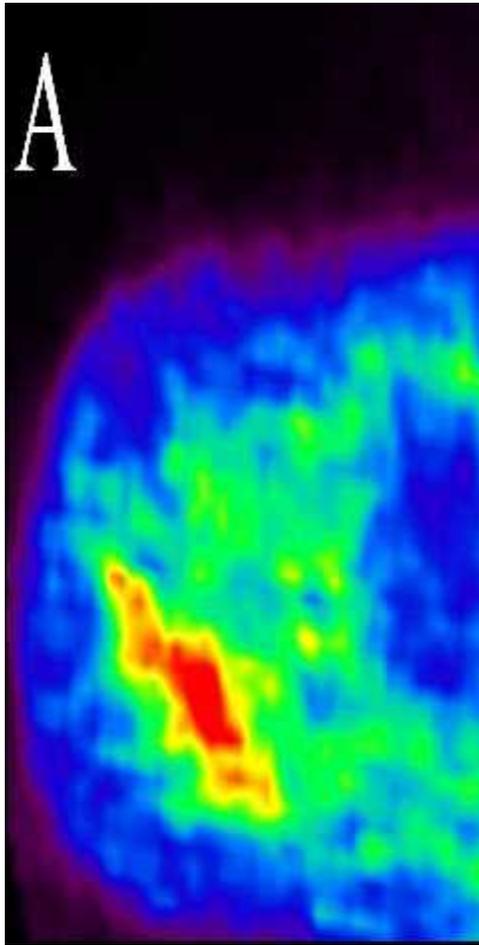
Itoi et al. Biomechanics of the shoulder. In: Rockwood CA Jr MFI, Wirth MA, Lippitt SB, editor. *The shoulder*, 4th Ed. Philadelphia: Saunders/Elsevier; 2009, p. 213-65.

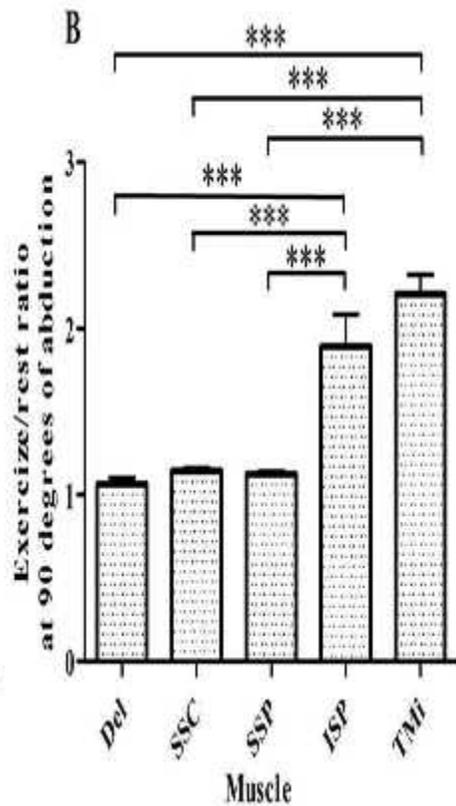
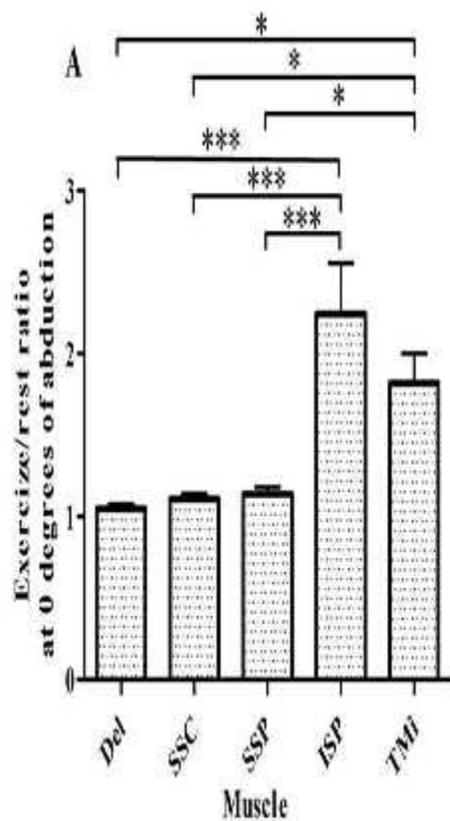
The standardized uptake value for each shoulder girdle muscle

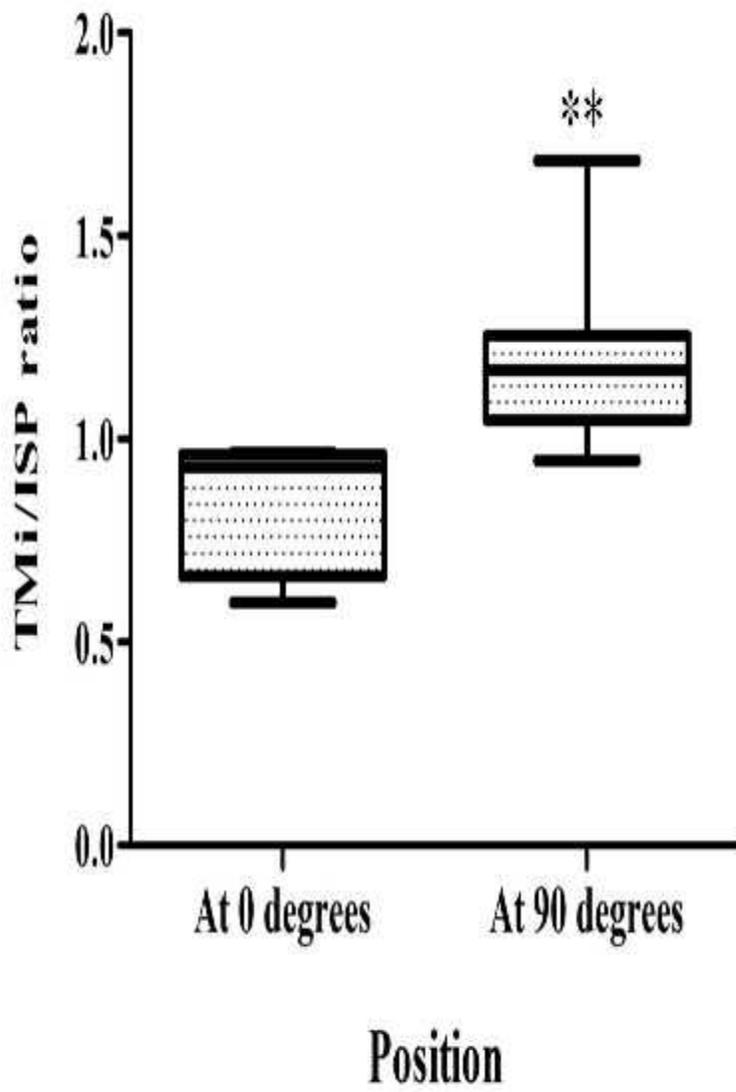
Muscle	Rest	External rotation at 0 degrees of abduction	External rotation at 90 degrees of abduction
Deltoid	0.72 ± 0.10	0.74 ± 0.08	0.76 ± 0.04
Subscapularis	1.29 ± 0.05	1.43 ± 0.12*	1.48 ± 0.10**
Supraspinatus	1.19 ± 0.10	1.35 ± 0.10**	1.34 ± 0.08*
Infraspinatus	1.13 ± 0.07	2.50 ± 0.81***	2.12 ± 0.55**
Teres minor	1.15 ± 0.10	2.11 ± 0.64**	2.54 ± 0.43***

Mean ± standard diversion. \*Statistically significant increase compared to at rest (\*  $P < 0.05$ , \*\*  $P < 0.01$ , \*\*\*  $P < 0.001$ ).

**A****B**







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