Appropriate Slice Location to Assess Maximal Cross-sectional Area of Individual Rotator Cuff Muscles in Normal Adults and Athletes

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(Received November 21, 2008; Accepted March 25, 2009)

Purpose: We investigated appropriate slice locations for magnetic resonance (MR) imaging evaluation of the maximal cross-sectional area (CSA) of individual rotator cuff (RC) muscles in normal adults and athletes.

Methods: We used a 1.5-tesla MR system with body-array and spine coils to obtain oblique sagittal T1-weighted shoulder images of 29 normal adults (16 men, 13 women); 6 national-level competitive swimmers (4 men, 2 women); 10 collegiate-level female badminton players; and 7 collegiate-level male rowers. We calculated the supraspinatus, infraspinatus, teres minor, and subscapularis CSAs at the 0–1 locations on the scapula (dividing scapula width into 11 locations), 0 representing the medial border of the scapula and 1, the glenoid fossa surface. We evaluated the differences in CSAs at relative locations on the scapula for each muscle in normal adults, swimmers, badminton players, and rowers using a one-way analysis of variance followed by the Tukey test (P<0.05).

Results: The supraspinatus CSAs were maximal at 0.7 for all groups. The infraspinatus CSAs were maximal at 0.5 for normal men and women and badminton players, 0.4- and 0.5 locations for swimmers, and 0.4 for rowers. The teres minor CSAs were maximal at 0.9 for all groups except the swimmers (1 location). The subscapularis CSAs were maximal at 0.7 in men, swimmers, and badminton players and 0.6 in women and rowers.

Conclusion: The appropriate slice locations for evaluating maximal CSAs are slightly lateral to the center of the scapula for the supraspinatus and subscapularis, at approximately the center of the scapula for the infraspinatus, and near the glenoid fossa for the teres minor. These slice locations should be clinically useful for morphological and/or function-related assessments of shoulder RC muscles.

Keywords: magnetic resonance imaging, muscle cross-sectional area, rotator cuff muscles, shoulder

Introduction

Magnetic resonance (MR) imaging has been used to investigate the morphological characteristics of the rotator cuff (RC) muscles (supraspinatus, infraspinatus, teres minor, and subscapularis). It is easier and less time consuming to evaluate muscle cross-sectional area (CSA) than muscle volume. In clinical practice, muscle CSA has been used mainly to evaluate degree of muscle atrophy, an important parameter that can be used to estimate the residual function of RC muscles and/or determine significant predictors of postoperative outcomes following RC repair. Several studies in patients with RC tears have assessed the CSAs of RC muscles on the most lateral sagittal image on which the scapular spine is in contact with the coracoid process (Y-shaped position) or on an oblique sagittal image located 10 mm medial to the glenoid surface. However, the appropriate slice location for evaluating maximal CSA of RC muscles has not
been sufficiently investigated. Identification of this slice location is expected to be useful for evaluating muscle function because maximal CSA is closely related to muscle strength. In addition, because for each RC muscle, in living humans, muscle volume is reported at 1.5–1.7 times and physiological CSA at 1.4–1.6 times the corresponding values in specimens extracted from humans, muscle CSA in the shoulders should be qualitatively evaluated in living humans. Moreover, the CSAs of RC muscles have been evaluated mainly in elderly subjects with tears in the RC tendons, especially the supraspinatus tendon. Very few studies have precisely evaluated the CSA of individual RC muscles in asymptomatic subjects, especially young subjects and athletes with no history of shoulder injury. Because specific repetitive movements performed may be reflected in muscle morphology, evaluation of muscle CSA in shoulder-rehabilitation strategies for athletes should take into consideration the nature of the athletic activity involved.

We used MR imaging to investigate the CSA of individual RC muscles at relative locations on the scapula in living humans with no shoulder injuries and determined appropriate slice locations for evaluating maximal CSA for each RC muscle. We also attempted to evaluate whether specific repetitive movements influence the morphology of RC muscles in athletes who frequently use the shoulder joint. Clarification of slice locations should be clinically available for morphological and/or function-related assessments of each RC muscle.

**Materials and Methods**

**Subjects**

We evaluated 29 normal adults (16 men, 13 women; aged 30.5 ± 5.9 [mean ± standard deviation] years; height, 166.3 ± 8.2 cm; weight, 61.6 ± 9.8 kg); 6 national-level competitive swimmers (4 men, 2 women; aged 23 ± 1.8 years; height, 172.8 ± 9.2 cm; weight, 67.8 ± 9.2 kg; swimming style: freestyle, 1; breaststroke, 1; backstroke, 1; butterfly stroke, 2; and medley, 1); 10 collegiate-level female badminton players (aged 20.1 ± 0.9 years, height 160.7 ± 7.9 cm, weight 56.8 ± 4.1 kg); and 7 collegiate-level male rowers (aged 20 ± 1.4 years; height, 177.4 ± 5.9 cm; weight, 73.1 ± 3.6 kg). The nonathlete subjects were not regular participants in recreational sports. No subject had a history of shoulder-related injury. The athletes participated in the study during their regular athletic season. The institutional review board of the Japan Institute of Sports Sciences approved this study; each subject provided written informed consent; and the personal information and rights of the subjects were protected.

**MR imaging**

We made measurements using a 1.5T MR system (Magnetom Symphony, Siemens, Germany) with body-array and spine coils. Subjects were placed supine, with arms at the side of the body and forearms pronated to bring the thumbs to a forward-pointing position. For all subjects, we acquired consecutive oblique sagittal T1-weighted images (repetition time, 723 ms; echo time, 12 ms; matrix, 256 × 256; number of acquisitions, 1; field of view, 220 mm; slice thickness, 5 mm with no slice gap) of the dominant shoulder from the glenoid surface to over the medial border of the scapula (Fig. 1). We set the first slice location parallel to the surface of the glenoid fossa. Acquisition time was 6 min 14 s. A single radiological technologist performed all MR imaging measurements throughout the study. We transferred the MR images to a personal computer to analyze the anatomical CSAs of the RC muscles. The scale to determine slice locations with respect to scapula width defined the 1 location as the first image that overlapped the oblique sagittal axis of the glenoid fossa and the 0 location as the image of the most medial region, wherein the medial border of the scapula appeared last (Fig. 2A). Eleven total MR images (corresponding to the 0–1 locations, with 10% intervals) were selected for analyzing muscle CSA. The CSAs of the suprapenal information and rights of the subjects were protected.
Fig. 2. (A) Locations defined on the scapula for analysis of muscle CSA. (B) Representative regions of interest on a sagittal T1-weighted image, at the 0.9 location on the right scapula (female badminton player). We investigated the (1) supraspinatus, (2) subscapularis, (3) infraspinatus, and (4) teres minor muscles.

Data analysis

We performed an unpaired t test to evaluate gender differences in normal adults with regard to each muscle CSA, measured at relative locations on the scapula, and used a one-way analysis of variance followed by the Tukey test to evaluate differences in the CSAs measured at various relative locations on the scapula for each muscle for normal adults, swimmers, badminton players, and rowers. P < 0.05 was statistically significant.

Moreover, the slice location with the greatest CSA was represented by the distance from the glenoid fossa (DISTgf; mean ± standard deviation), which was estimated by the number of slice lines from the glenoid fossa.

Results

The CSAs measured for the supraspinatus muscle at the 0.2–1 locations, the infraspinatus muscle at the 0.1–1 locations, and the subscapularis muscle at the 0.1–0.9 locations were significantly greater in normal men than women (P < 0.05).

The greatest CSAs recorded for the supraspinatus muscle in normal adults were measured at the 0.7 location (DISTgf; male, 30.9 ± 2.0 mm; female, 27.3 ± 3.3 mm) on the scapula. However, these values were not significantly greater than the corresponding values measured at the 0.6 location (Fig. 3A).

Further, in normal adults, the largest CSAs for the infraspinatus muscle were measured at the 0.5 location (DISTgf; male, 55.0 ± 3.2 mm; female, 51.2 ± 3.6 mm), but these values did not differ significantly from those measured at the 0.3, 0.4, or 0.6 location (Fig. 3B).

With regard to the teres minor muscle, the greatest CSAs in normal adults were measured at the 0.9 location (DISTgf; male, 5.9 ± 2.0 mm; female, 5.4 ± 1.4 mm), but the values did not differ significantly from those measured at the 0.7, 0.8, or 1 location (Fig. 3C).

The largest CSAs recorded for the subscapularis muscle were measured at the 0.7 location (DISTgf; 30.9 ± 2.0 mm) in men and 0.6 location (DISTgf; 37.7 ± 3.9 mm) in women, but the values did not differ significantly from those measured at the 0.6 location for men and at the 0.7 location for women (Fig. 3D).

Figure 4A graphs the CSAs for the supraspinatus muscle in the athletes, measured at relative locations on the scapula. In the swimmers, the greatest CSA was measured at the 0.7 location (DISTgf; male, 35.0 ± 0.0 mm; female, 31.7 ± 2.9 mm), but this value was not significantly greater than those measured at the 0.5, 0.6, or 0.8 location. Further, the greatest CSA was measured at the 0.7 location (DISTgf; 30.0 ± 0.0 mm) in the badminton players, but this value was not significantly higher than those measured at the 0.6 location. Similarly, although the maximal CSA was measured at the 0.7 location (DISTgf; 33.6 ± 2.4 mm) in the rowers, this value was not significantly greater than those measured at the 0.6 or 0.8 location. Figure 4B graphs the CSAs of the infraspinatus muscle in athletes, measured at relative locations on the scapula. The maximal CSAs in the swimmers were measured at the 0.4 (DISTgf; male, 73.3 ± 2.9 mm; female, 68.3 ± 5.8 mm) and 0.5 locations (DISTgf; male, 60.0 ± 0.0 mm; female, 56.7 ± 2.9 mm), but they were not significantly greater than those measured at the 0.3, 0.6, or 0.7 location. The maximal CSA recorded for the badminton players was measured at the 0.5 location (DISTgf; 52.0 ± 2.6 mm) but was not significantly greater
Fig. 3. Means and standard deviations of the cross-sectional areas (CSAs) of the supraspinatus (A), infraspinatus (B), teres minor (C) and subscapularis muscles (D), measured at relative slice locations, in men and women. The 0 location represented the medial border of the scapula and the 1 location, the glenoid fossa surface. The asterisk (*) indicates the maximal value for each muscle.

Fig. 4. Means and standard deviations of the CSAs of the supraspinatus (A), infraspinatus (B), teres minor (C), and subscapularis muscles (D), measured at relative slice locations, in swimmers, badminton players, and rowers. The 0 location represented the medial border of the scapula and the 1 location, the glenoid fossa surface. The asterisk (*) indicates the maximal value for each muscle.
than those measured at the 0.4 or 0.6 location. In the rowers, the maximal CSA was measured at the 0.4 location (DISTgf: 69.3 ± 3.5 mm), but this value was not significantly greater than those measured at the 0.3 or 0.5 location.

Figure 4C graphs the CSAs of the teres minor muscle in athletes, measured at relative locations on the scapula. The highest value recorded in swimmers was measured at the 1 location (DISTgf: male and female, 0.0 mm), but this was not significantly greater than those measured at the 0.7, 0.8, or 0.9 location. The maximal CSA recorded for badminton players was measured at the 0.9 location (DISTgf: 5.0 ± 0.0 mm), but this value was not significantly greater than those measured at the 0.5 or 1 location. In the rowers, the maximal values were measured at the 0.8 (DISTgf: 8.6 ± 2.4 mm) and 0.9 locations (DISTgf: 20.0 ± 0.0 mm) and were not significantly greater than those measured at the 0.7 or 1 location.

Figure 4D shows CSAs of the subscapularis muscle in athletes, measured at relative locations on the scapula. For the swimmers, the maximal CSA was measured at the 0.7 location (DISTgf: male, 35.0 ± 0.0 mm; female, 31.7 ± 2.9 mm), but this value was not significantly greater than those measured at the 0.5, 0.6, or 0.8 location. Similarly, the maximal value in the badminton players was measured at the 0.7 location (DISTgf: 30.0 ± 0.0 mm), but this was not significantly greater than those measured at the 0.6 location. Although the maximal value was measured at the 0.6 location (DISTgf: 44.3 ± 1.9 mm) in the rowers, this value was not significantly greater than those measured at the 0.5 or 0.7 location.

Discussion

The CSA of the RC muscles has been used as a useful indicator of the functional recovery of impaired muscles.\textsuperscript{1,7,8,11} Hata’s group\textsuperscript{2} suggested that the true status of RC tendons cannot be evaluated solely on the basis of clinical symptoms and results of physical examination, and they indicated the usefulness of MR imaging-based CSA measurements for evaluating the functions of RC muscles following repair. In particular, because maximal CSA is closely related to muscle strength, it is expected to be a useful parameter for evaluating RC muscle status.\textsuperscript{12} We herein suggest the appropriate slice location on the scapula for evaluating maximal CSA of each RC muscle on oblique sagittal MR images. The appropriate slice locations for each muscle were determined to be similar in athletes as well as nonathletes of both sexes.

For all groups, the maximal CSA of the supraspinatus muscle was generally measured at the 0.7 location on the scapula. Zanetti and colleagues\textsuperscript{11} evaluated standardized CSAs (area of each RC muscle divided by the area of the supraspinatus fossa) at the Y-shaped position and suggested that such evaluation could aid discrimination of patients with supraspinatus muscle tears of varying severity from asymptomatic subjects. Further, Lehtinen and associates\textsuperscript{5} evaluated supraspinatus CSAs in the shoulders of cadavers, using oblique sagittal images obtained at the Y-shaped position, and found the Pearson correlation coefficient ($r$) for total muscle volume to be 0.96. They obtained MR images at the Y-shaped position, at a mean of 21 mm from the articular surface of the glenoid fossa (mean width of the scapula was 123 mm), which corresponded approximately to the 0.8 location on the scapula. This location is expected to represent a more lateral point compared to the slice location at which the maximal CSAs were recorded in the present study. Moreover, using MR imaging, Juul-Kristensen’s team\textsuperscript{4} reported that the greatest supraspinatus CSA was recorded at the midpoint of the total length of the muscle, in the plane perpendicular to that of the scapula, in healthy females. This location appears to represent a point slightly lateral to the center of the scapula and may be near the 0.7 location on the scapula as defined in our study.

The infraspinatus muscle tended to exhibit the maximal CSA when measured at the 0.5 location on the scapula in normal men and women, the 0.4 and 0.5 locations in swimmers, the 0.4 location in rowers, and the 0.5 location in badminton players. With regard to the teres minor muscle, the maximal CSAs were measured at the 0.9 location in all groups except the swimmers (1 location). Compared to studies on the supraspinatus muscle, very few studies have attempted to evaluate the CSAs of the infraspinatus and teres minor muscles. Lehtinen’s group\textsuperscript{5} evaluated the CSAs of the infraspinatus/teres minor muscles at the Y-shaped position in the shoulders of cadavers and demonstrated the Pearson correlation coefficient for the total muscle volume to be 0.96. Similar to their study, most previous studies have evaluated the infraspinatus and teres minor muscles as a single muscle group.\textsuperscript{3–5,7,9–11} Therefore, it is difficult to compare our findings with those of previous studies.

The CSA of the subscapularis muscle tended to be maximal when measured at the 0.7 location on the scapula in normal men, swimmers, and badminton players and at the 0.6 location in normal
women and rowers. Very few previous studies have evaluated the CSA of the subscapularis muscle in living subjects. Lehtinen and associates\(^5\) demonstrated that CSA evaluation performed using images obtained at both the Y-shaped position and a more medial location (twice the distance of the Y-shaped position from the glenoid surface) enabled accurate evaluation of the RC muscles, particularly the subscapularis muscle. They obtained the latter image at 42 mm medial from the articular surface of the glenoid fossa, which corresponded approximately to the 0.6–0.7 location on the scapula. This location is expected to be near the slice locations at which the maximal CSAs were measured for the subscapularis muscle in our study.

Several studies have selected oblique sagittal images obtained at the Y-shaped position to evaluate the CSAs of RC muscles\(^1,5,11\) because this image is easily reproducible\(^5,11\) and presents the muscular regions of all the RC muscles. Although this slice location is reported to show a high degree of correlation with the muscle volume of the supraspinatus or infraspinatus/teres minor muscles in the shoulders of cadavers,\(^4\) this correlation has not been sufficiently determined in living subjects. Our findings suggest that in living subjects with normal RC muscles, the appropriate slice location may be more medial to the Y-shaped position in the subscapularis and infraspinatus muscles and more lateral in the teres minor muscle. However, our study could not show only one slice location supported by statistically significant difference for evaluating the maximal CSA of each RC muscle. Thus, this issue needs to be examined using a sufficiently large sample size that comprises male and female subjects of a wide age range. The results of a single-slice analysis may also be limited because of influence by retraction of the musculotendinous junction, which is often observed in patients with chronic RC tears.\(^7\)–\(^9\)\(^,\)\(^11\)

Moreover, it is clear that muscle morphology changes by various resistance training.\(^13,14\) Thus, the maximal CSA location of each RC muscle may change as a physical adaptation to the repetitive sports activities, although we did not clearly find such changes. Future study should evaluate the data of various athletes, especially baseball pitchers, who are subject to shoulder injuries,\(^15\) to further clarify the morphological characteristics of the athlete’s shoulder.

For shoulder imaging, we combined body-array and spine coils rather than using a normal shoulder coil because the combination provides MR images with higher signal-to-noise ratio and resolution for muscle CSA analysis. The CSA analysis used in this study can be performed with MR images obtained using a shoulder coil, but it may be difficult to discriminate the infraspinatus muscle from teres minor muscle.

**Conclusion**

Our study suggests that the appropriate slice locations for evaluating maximal CSAs using oblique sagittal images in live subjects are (1) slightly lateral to the center of the scapula in the supraspinatus and subscapularis muscles, (2) approximately at the center of the scapula in the infraspinatus muscle, and (3) near the glenoid fossa in the teres minor muscle. These locations were similar in nonathletes and competitive athletes. Clarification of appropriate slice locations should be useful for morphological and/or function-related assessments of individual RC muscles in clinical medicine and sports sciences.

**References**

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