

# Location of Rotator Cuff Tear Initiation

## A Magnetic Resonance Imaging Study of 191 Shoulders

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**Background:** Degenerative rotator cuff tears (RCTs) are generally thought to originate at the anterior margin of the supraspinatus tendon. However, a recent ultrasonography study suggested that they might originate more posteriorly than originally thought, perhaps even from the isolated infraspinatus (ISP) tendon, and propagate toward the anterior supraspinatus.

**Hypothesis/Purpose:** It was hypothesized that this finding could be reproduced with magnetic resonance imaging (MRI). The purpose was to determine the most common location of degenerative RCTs by using 3-dimensional multiplanar MRI reconstruction. It was assumed that the location of the partial-thickness tears would identify the area of the initiation of full-thickness tears.

**Study Design:** Cross-sectional study; Level of evidence, 3.

**Methods:** A retrospective analysis was conducted including 245 patients who had RCTs (nearly full- or partial-thickness tears) at the outpatient department between January 2011 and December 2013. RCTs were measured on 3-dimensional multiplanar reconstruction MRI with OsiriX software. The width and distance from the biceps tendon to the anterior margin of the tear were measured on T2-weighted sagittal images. In a spreadsheet, columns of consecutive numbers represented the size of each tear (anteroposterior width) and their locations with respect to the biceps brachii tendon. Data were pooled to graphically represent the width and location of all tears. Frequency histograms of the columns were made to visualize the distribution of tears. The tears were divided into 2 groups based on width (group A, <10 mm; group B, <20 and  $\geq$ 10 mm) and analyzed for any differences in location related to size.

**Results:** The mean width of all RCTs was  $11.9 \pm 4.1$  mm, and the mean length was  $11.1 \pm 5.0$  mm. Histograms showed the most common location of origin to be 9 to 10 mm posterior to the biceps tendon. The histograms of groups A and B showed similar tear location distributions, indicating that the region approximately 10 mm posterior to the biceps tendon is the most common site of tear initiation.

**Conclusion:** These results demonstrate that degenerative RCTs most commonly originate from approximately 9 to 10 mm posterior to the biceps tendon.

**Keywords:** rotator cuff tear; tear location; tear initiation

Rotator cuff tears (RCTs) are among the most common shoulder disorders. The early diagnosis and treatment of RCTs has now become more common because of high-resolution diagnostic tools, such as ultrasonography, magnetic resonance imaging (MRI), and arthroscopy. However, the

pathogenesis of RCTs has not been clearly determined, and neither has the understanding of this clinical entity improved over the past few decades. Many controversies still exist: From where do chronic degenerative RCTs originate? How do they propagate?

Several previous studies reported that degenerative RCTs most commonly involve the supraspinatus (SSP) tendon, beginning at the anterior site of the SSP insertion and spreading posteriorly.<sup>2,3,6,7,9</sup> However, more recent studies stated that rotator cuff (RC) degeneration is isolated to the infraspinatus (ISP) tendon or that the tears propagate from the ISP to the anterior side.<sup>14,15</sup> Furthermore, using ultrasonography, Kim et al<sup>8</sup> measured the location of RCTs in a clinical trial of 360 patients and stated that degenerative RCTs most commonly involve the near junction of the SSP and ISP, more posterior than previously thought.

In contrast, in our daily arthroscopic surgical practice, especially for partial RC and nearly full-thickness tears, we tend to find RCTs more anterior than the SSP/ISP

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The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

junction. We considered whether the ultrasonography findings could be reproduced with high-resolution MRI as performed with a consistent protocol and resolution. With this in mind, the purpose of this study was to determine the most common location of degenerative nearly full- or partial-thickness RCTs by measuring the anterior-posterior length of the tears through 3-dimensional (3D) multiplanar reconstructions of MRI scans. We hypothesized that RCTs originate from a more anterior part of the RC complex than the SSP/ISP junction. It was assumed that the location of the partial-thickness tears would identify the area of initiation of full-thickness tears.

## METHODS

### Patient Selection

This research was performed at our institute with institutional review board approval from January 2011 to December 2013 and made use of outpatient shoulder MRI data. The study group consisted of 245 patients with diagnosed nearly full- and partial-thickness SSP or SSP/ISP tears.

The inclusion criteria were as follows: (1) patients receiving the same shoulder MRI protocol at our institution, (2) patients with a diagnosed SSP or SSP/ISP tear (either a nearly full- or a partial-thickness tear), (3) patients with no history of trauma, and (4) patients whose biceps tendon was located in the bicipital groove (no biceps subluxations or rupture).

The exclusion criteria were as follows: (1) patients with a history of shoulder surgery, (2) patients with a history of trauma, (3) patients with inflammatory arthropathy (eg, rheumatoid arthritis or infectious arthritis), (4) patients with a history of seeking medical attention for other problems (eg, instability or arthritis), (5) patients who use walkers/cane with upper extremity, (6) patients with very small partial-thickness tears (<3 mm) or overly large tears (anterior-posterior width >2 cm), and (7) patients with bifocal or multifocal tears.

After the exclusion criteria were applied, a total of 191 shoulders were available for evaluation. They were divided into 2 groups based on anterior-to-posterior width of tear (group A, <10 mm; group B,  $\geq 10$  and <20 mm). We compared differences among the tear patterns of all patients and between the groups. This study was conducted after obtaining informed consent from all patients.

### MRI Evaluation

All patients underwent MRI at the time of diagnosis. The sequences included T1- and T2-weighted images from the oblique coronal, sagittal, and axial planes with coronal proton density VISTA images (ie, volume isotropic turbo spin-echo acquisition). The slice thickness was 3 mm with an interslice gap of 1 mm. A 16-cm field of view and a matrix size of  $256 \times 192$  were used.

Using a Centricity RA-1000 system (GE Medical Systems), we employed the DICOM (digital imaging and communications in medicine) picture archiving and communication

system. The data were imported to and processed with free medical imaging software (OsiriX; v 5.8.2).<sup>12</sup>

We measured the following 3 elements of 3D multiplanar reconstruction function: width of the tear, length of the tear, and location of the tear (distance from landmark [biceps tendon]).

In a previous report, the RCT width and length were measured with MRI.<sup>5</sup> However, in this previous study, the location of the RCTs could not be measured because no landmark was mentioned. We therefore used the same landmark (biceps tendon) as described by Kim et al<sup>8</sup> to measure the location of RCTs.

All measurements were checked by 2 shoulder fellowship-trained orthopaedic surgeons. In cases where there was doubt regarding the size of the tears, a discussion was held among 4 shoulder surgeons until a consensus could be reached.

### Measurement

Coronal, axial, and sagittal images could be obtained via the 3D multiplanar reconstruction function of OsiriX based on T2-weighted coronal images. The coronal view of the reconstruction images was clear, whereas the others appeared comparatively dull. Therefore, the tear was observed only from the coronal view.

The centers of the axis on the screen were each placed on the humeral head center and adjusted to be parallel to the humeral shaft (Figure 1).

After the biceps tendon was located in the coronal view, the image was slowly scrolled in the anterior-to-posterior direction. We stopped scrolling at the point where the biceps tendon met the SSP tendon (ie when the biceps tendon could no longer be seen). The center of the axis was placed on that point (Figure 2).

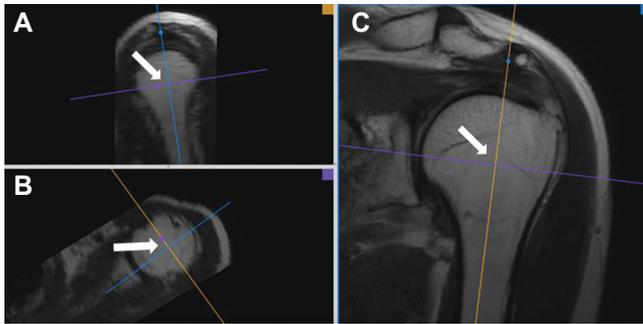
The axis was removed just from the sagittal view. After the axes of the coronal and axial views were adjusted to pinpoint the center, a point was marked on the sagittal view—specifically, the posterior margin of the biceps tendon (point A; see Figure 3). To measure the distance between the points in the latter stages, the points needed to have the same values in the coronal and axial views.

The coronal-view image was then slowly progressed in the posterior direction, and we stopped when the tear first appeared. A point was made in the sagittal view in a similar manner. Figure 4 (point B) shows the anterior margin of the tear.

The coronal-view image was further progressed in the posterior direction until the tear appeared the largest. The length was measured from this site (Figure 5).

The image was progressed even more to find the spot where the tear was no longer seen, and a final point was marked. Figure 6 (point C) shows the posterior margin of the tear.

Finally, the sagittal view was magnified to measure the tear width and location from the 3 marked points (A-C; Figure 7).



**Figure 1.** Image obtained by using the 3-dimensional multiplanar magnetic resonance imaging function of OsiriX: (A) sagittal, (B) axial, and (C) coronal views. We focused the cross-lines at the center of the humeral head (white arrows) in the coronal, sagittal, and axial planes. We then checked that the cross-line axis was parallel to the humeral axis.

### Numerical Representation of the Size and Location of RCTs

The anteroposterior distance from the posterior margin of the biceps tendon to the anterior margin of the cuff tear was measured to determine tear location. As in the previous study,<sup>8</sup> this measured value represented the distance between the anterior margin of the tear and the biceps tendon. Tear locations were represented as the distance from the biceps tendon in a consecutive order. A spreadsheet marking each lesion was used to visualize the distribution of the tears.

The values measured were modified to nearest 0.5-mm multiples to arrange them in 0.5-mm units (eg, 1.2 mm  $\rightarrow$  1.0 mm, 1.3 mm  $\rightarrow$  1.5 mm). Kim et al<sup>8</sup> measured in units of 1 mm. We chose to reduce this to allow more precise measurement of tear location. The tear size (the distance between its anterior margin and posterior margin) was then entered into a column of the spreadsheet, with 1 cell representing 0.5 mm. For instance, a 10-mm-width tear with an anterior margin that was 5 mm posterior to the biceps tendon (this tear would have a 15-mm posterior margin, posterior to the biceps tendon) would be plotted beginning with 10 columns at the top and ending with 30 at the bottom, in total, as a column of 21 cells (0.5 mm). This method allowed the tear size and location with respect to the biceps tendon to be represented numerically.

A data table of statistical software was used to type in the column of cells and to pool with other tear data. The columns represented the size of each tear (anteroposterior widths) and their locations with respect to the biceps tendon. To locate the most common tear site within the posterior portion of the RC, the most common numbers were obtained. Frequency histograms of the columns were made to visualize the tear distributions.<sup>8</sup> Tear widths were separated into 2 groups ( $<10$  and  $\geq 10$  mm) and checked for any differences in location related to size.

### Statistical Analysis

An independent statistician measured the reliability of the measurements by examining the intra- and interobserver

reliability via the intraclass correlation coefficient. Based on the 1-sample Kolmogorov-Smirnov test, the 3 variables (ie, width, length, and distance from the biceps tendon to the anterior tear margin) were tested for normality in each group.<sup>8</sup> This test showed that the data for all 3 variables were distributed much differently than the normal Gaussian distribution ( $P < .05$ ). Therefore, a Mann-Whitney  $U$  test was performed to compare the variables. The correlations among the variables were evaluated with Spearman rank correlation. The data are represented as the means and standard deviations. The level of statistical significance was set at  $P < .05$ . Statistical analyses were performed with SPSS for Windows (v 20.0; IBM) and SAS (v 9.4; SAS Institute Inc).

### RESULTS

A total of 191 patients were included in this study, of which 89 were men. The mean age was  $57.9 \pm 8.2$  years (range, 33-77 years). The mean tear width was  $11.9 \pm 4.1$  mm, and the mean length was  $11.1 \pm 5.0$  mm.

Group A (patients with a tear width  $<10$  mm) contained 68 people, while group B (patients with a tear width of 10-20 mm) contained 123 people. The mean width and length in group A were  $7.6 \pm 1.5$  mm and  $9 \pm 3.7$  mm, respectively. The mean width and length in group B were  $14.3 \pm 2.9$  mm and  $12.4 \pm 5.1$  mm, respectively. The mean distance from the biceps tendon to the anterior margin of the tear was  $4.3 \pm 3.8$  mm (range, 0-19.5 mm). The mean distances from the biceps tendon in groups A and B were  $6 \pm 4.4$  and  $3.3 \pm 3.1$  mm, respectively. The intraclass correlation coefficient of the 2 investigators was 0.992, suggesting excellent agreement. The intraobserver reliability was 0.998.

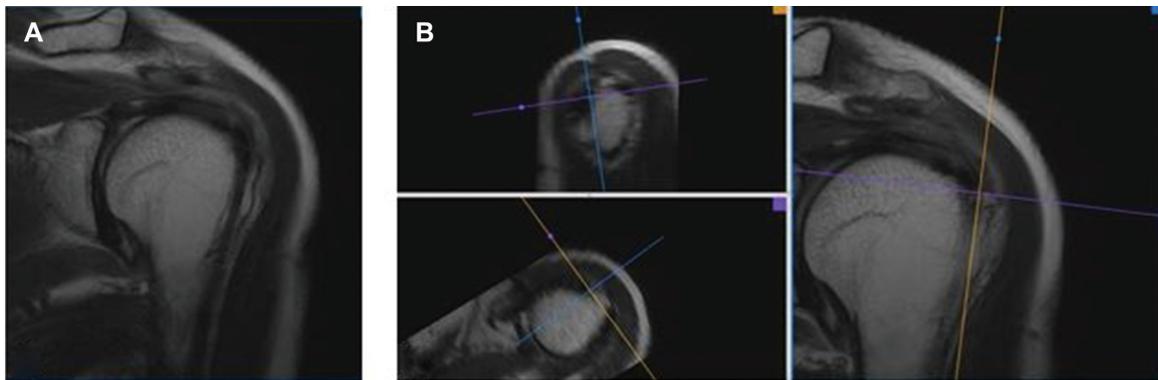
### Analysis of Tear Location

When all 191 tears were plotted on a histogram, a unimodal distribution was observed. The 2 most frequent locations of RCT origin were 9.5 and 10 mm posterior to the biceps tendon. The next most common tear location was 9 mm posterior to the biceps tendon (Figure 8).

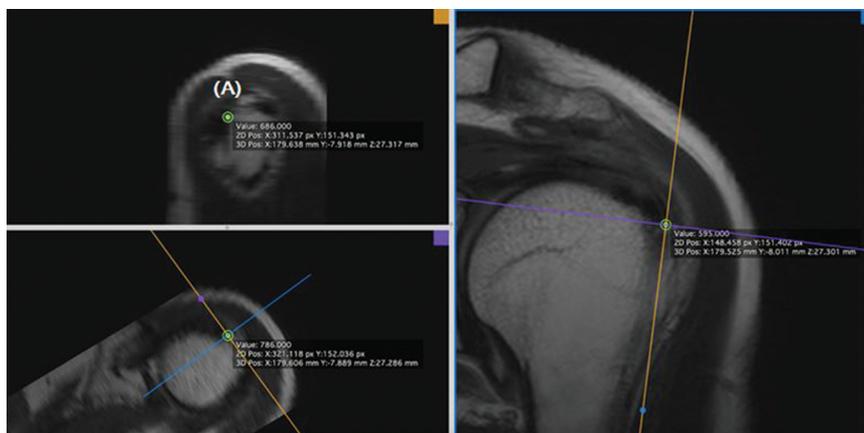
In other words, the most common sites of tear origin were all within the anterior part of the RC that was 9.5 to 10 mm posterior to the biceps tendon (86.9%, 166 of the 191 tears involving this region), with 9 mm posterior to the biceps tendon being the next most common location (86.3%, 165 of the 191 RC tears involving this region). Only approximately 13% of all tears had an intact RC insertion at 9 to 10 mm posterior to the biceps tendon.

When the data from group A (tear size  $<10$  mm) were plotted, the histogram displayed a unimodal distribution, and the most common tear site was 9 mm posterior to the biceps tendon (Figure 9). This was found to be the case in 51 (75%) of 68 tears.

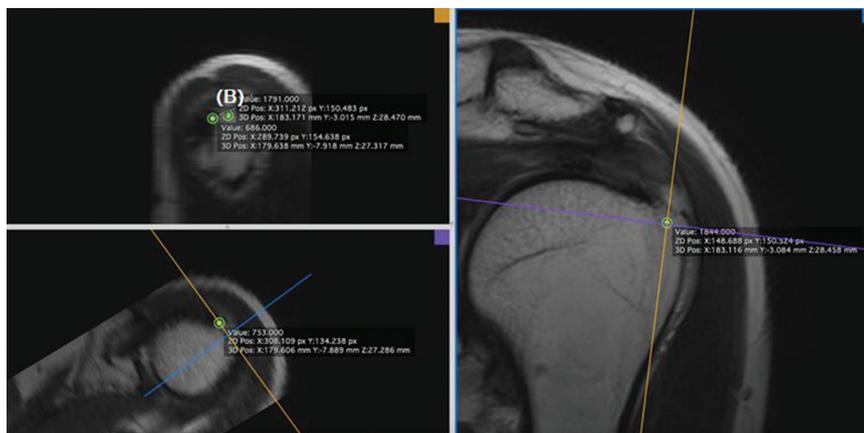
When the data from group B (tear size  $>10$  mm) were plotted, the histogram also revealed a unimodal distribution with the 2 most frequent locations of tears being 10 and 10.5 mm posterior to the biceps tendon (Figure 10). In total, 122 (99%) of the 123 tears involved this region.



**Figure 2.** Scrolling in the anterior-to-posterior direction in the coronal plane: (A) finding the biceps tendon; (B) when the biceps tendon was no longer seen on the screen. The center of the axis was placed on the point where the biceps tendon met the supraspinatus tendon.



**Figure 3.** After the axes of the coronal and axial views were adjusted to pinpoint the exact center, a point was marked on the sagittal view. Point A, posterior margin of the biceps tendon.



**Figure 4.** When the definite site of tear initiation was located in the coronal plane, a second mark was made on the sagittal plane. Point B, anterior margin of the tear.



**Figure 5.** The coronal view image was further progressed in the posterior direction until the tear appeared the largest. The mediolateral length was measured.

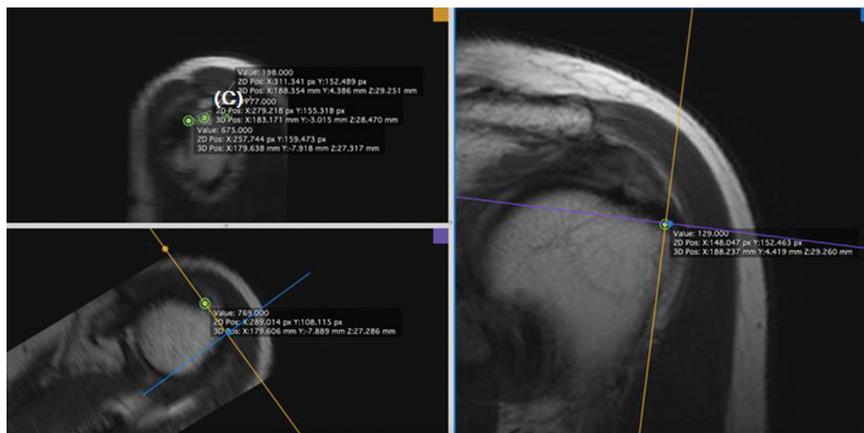
**DISCUSSION**

The results of the present study showed that the most common site of RCTs was 9 to 10 mm posterior to the biceps tendon. The most common sites in groups A and B were 9 mm and 10 to 10.5 mm posterior to the biceps tendon, respectively. Contrary to the results of a previous study employing ultrasonography,<sup>8</sup> the RCTs were found to initiate more anterior to the SSP/ISP junction. The histograms presented similar unimodal distributions centered on a site 9 to 10 mm posterior to the biceps tendon in both groups.

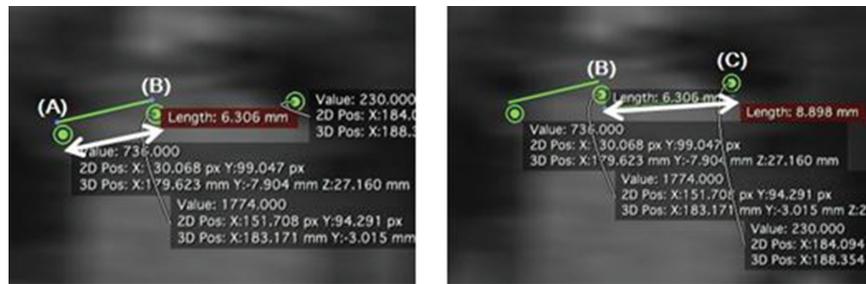
This led us to assume that the tears might propagate anteriorly and posteriorly from this point. Furthermore, after analyzing the similarities in the locations of small tears (group A) and all tears, we found a strong correlation suggesting that most degenerative RCTs might initiate from this region. If small tears tended to originate from a different site, then this could not be assumed to be the most common site for all tears.

Many patients with RCTs have positive outcomes owing to early detection and intervention through surgical or nonsurgical treatment. In dealing with RCTs, it is important to understand the pathogenesis and progression of the entity. Therefore, it is crucial to understand the common location and initiation site of RCTs. Degenerative lesions of the cuff tendons are generally thought to initiate deep in the surface of the anterior insertion of the SSP near the long head of the biceps tendon.<sup>2,3,6,7,9</sup> Codman<sup>2</sup> and Codman and Akerson<sup>3</sup> reported that the SSP tendon is the most commonly involved tendon in RCTs. Hijioka et al<sup>6</sup> reported that degenerative change of the RC is aggravated by friction and rubbing against the undersurface of the acromion, which lead to the development of more complete tears.

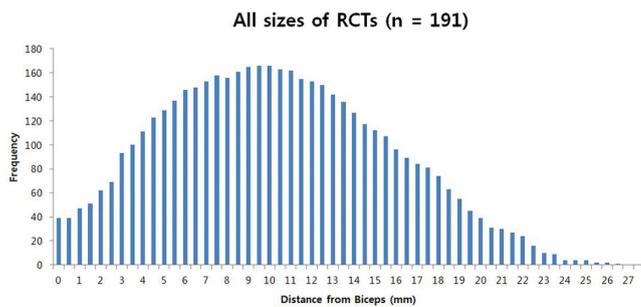
However, Kim et al<sup>8</sup> recently reported that degenerative RCTs begin in a region 13 to 17 mm posterior to the biceps tendon and extend anteriorly and posteriorly from this point. This site is either the junction between the SSP and ISP or purely within the ISP.<sup>8</sup> The authors came to this conclusion based solely on a large ultrasonographic data set. Given the observer-dependent aspect of ultrasonography, we believed that 3D MRI would be more consistent among observers for detecting tear size. Our results showed that RCTs most commonly involved a location approximately 10 mm posterior to the biceps tendon. This was also the common site for tears of all sizes (group A and B). It has been suggested that the center of the rotator crescent or cable is 15 mm posterior to the biceps tendon.<sup>1</sup> This is the area of poor vascularity within the RC tendon, making the hypovascularity theory of RCT development more convincing. However, our results indicate



**Figure 6.** The image was progressed more to find the spot where the tear was no longer seen, and a final point was made. Point C, posterior margin of the tear.



**Figure 7.** A magnified sagittal image used to measure distance. Tear location was defined as the distance from (A) the biceps posterior margin to (B) the anterior margin of the tear. Tear width was defined as the distance from (B) the anterior margin of the tear to (C) the posterior margin of the tear.

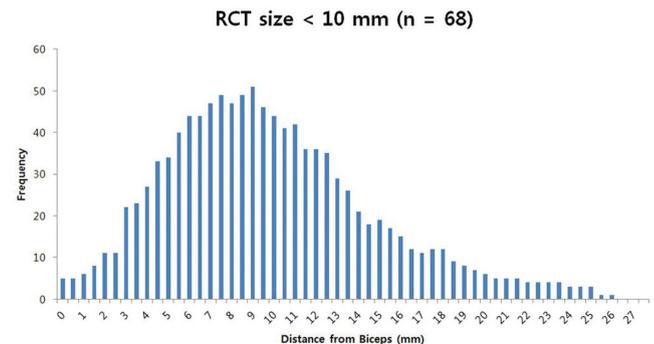


**Figure 8.** Histogram of all 191 tears—the 2 most frequent locations were 9.5 and 10 mm posterior to the biceps tendon. The second-most common location was 9 mm posterior to the biceps tendon. RCT, rotator cuff tear.

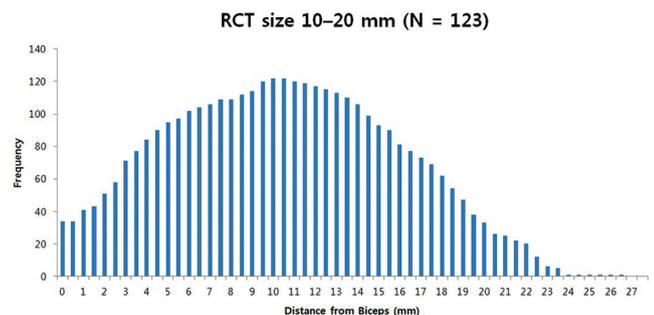
a more anterior initiation site, and friction and rubbing (impingement) within the undersurface of the anterior-lateral acromion might play a more important role in the development of tears. The exact cause of this biomechanical imbalance and impingement remains to be elucidated.

Recent reports questioned the conventional definitions of the humeral footprints of the SSP and ISP tendons.<sup>10,11</sup> According to the traditional theory, the location 13 to 17 mm posterior to the biceps tendon is recognized as the entire part or portion of the SSP tendon.<sup>4,13</sup> However, a recent anatomic study by Mochizuki et al<sup>11</sup> reported findings in contrast with what previous studies had demonstrated. They reported that only 1.3 mm of the anterior portion of the RC footprint was covered with the SSP tendon. From this perspective, the next 11.3 mm of the tendon insert constitutes the SSP medially and the ISP laterally. The remaining posterior portion of the cuff insert consists entirely of the ISP tendon. However, in most arthroscopic surgery, we observed that approximately 10 to 15 mm of the anteroposterior length resembles the SSP. Whether the tissue just posterior to the biceps tendon is the SSP tendon only or a combination of the SSP/ISP tendon microscopically, it does indeed resemble the SSP. In this respect, the anterior tear margin is within the SSP or SSP/ISP junction.

The purpose of this study was to use MRI or arthroscopy to investigate whether the anterior tear margin was more posterior than previously reported, in accordance with our



**Figure 9.** Histogram of group A displaying a unimodal distribution. The most common tear location was 9 mm posterior to the biceps tendon. RCT, rotator cuff tear.



**Figure 10.** Histogram of group B showing a unimodal distribution. The 2 most frequent locations were 10 mm and 10.5 mm posterior to the biceps tendon. RCT, rotator cuff tear.

experience. Although we cannot definitively state the location of the tear initiation site, we inferred it through locating the tear's anterior margin with respect to the biceps tendon, and we correlated this location with the apex of the tear.

The strengths of our study are as follows: (1) OsiriX was used to analyze 3D multiplanar reconstruction with high-resolution MRI (Intera Achieva 3.0T; Philips Healthcare); (2) a large number of subjects were involved; (3) small tears, including partial tears ( $\leq 2$  cm), were analyzed;

and (4) measurements of 0.5 mm allowed very precise measurements to be made.

However, the present study has some limitations. First, the ideal method to investigate the initiation and propagation of a RCT is to analyze it continuously from the beginning of the tear. However, this was not possible in the present study. We consider our approach to partial rupture to be valid, as most degenerative cuff tears begin with small defects that become larger subsequently. Second, the definitive pattern of the tear progression could not be determined with the methodology of this study, and further longitudinal studies should be conducted. Third, discordant results can be obtained even from the same patient upon retesting. However, since the measurements were performed in 1/1000-mm units, the error is not greatly affected because it is within 0.1 mm. Some measurement errors no doubt occurred in this study. Fourth, we did not analyze tear and muscle degeneration. Further research on muscle atrophy, fatty degeneration, tear size, and location will be essential in elucidating the pathogenesis of RCTs. Fifth, patients with partial-thickness tears represented those with articular- and bursal-side tears. However, this study focused only on the tear distance from the bicipital groove—that is, the tear initiation area. Therefore, further studies are needed to determine the developmental differences between bursal- and articular-side tears in partial RCTs. Finally, tear size might have been affected by the fact that this study was performed among Asian patients. Previous reports were performed in the United States, where patients are generally larger. This may mean that our results do not necessarily hold true in other populations or that the site might be similar when applied to a larger or bigger rotator cuff. However, tear location relative to the biceps tendon should be representative of patients of all races and body sizes.

## CONCLUSION

This study shows that degenerative SSP/ISP tendon tears most commonly originate from a more anterior location (9-10 mm posterior to the biceps tendon) than previously reported (15-16 mm posterior to the biceps tendon).<sup>8</sup> Most degenerative RCTs may initiate from this region because all histograms (group A, group B, and all tears) demonstrated similar unimodal distributions centered on the 9- to 10-mm initiation site.



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