Evaluation of Scapula and Humerus Bone Change after Repair of Small- to Medium-Sized Rotator Cuff Tears: Comparison between Healing and Retear Groups Using Three-Dimensional Computed Tomography

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Background: Rotator cuff tendon retears after rotator cuff repair cause glenohumeral joint instability, which results in changes in the glenoid and humerus head. However, limited data are available on the bone change after repair of small- to medium-sized rotator cuff tears. The aim of this study was to evaluate the difference of glenoid and humerus bone changes between healing and retear groups after repair of small- to medium-sized rotator cuff tears.

Methods: Among patients who had arthroscopic repair due to small- to medium-sized rotator cuff tears from January 2009 to January 2017, 49 patients who underwent both preoperative and postoperative (at least 3 years after surgery) shoulder computed tomography were enrolled. Using three-dimensional reconstruction program (3D Slicer) and shape analysis program (SlicerSALT), we compared the occurrence and degree of glenoid bone change, glenoid inclination change, retroversion change, and glenoid center, as well as the degree of humerus head change, between the healing and retear groups.

Results: The occurrence of glenoid bone change was significantly more common in the retear group than in the healing group (p = 0.026). The degree of bone change in the 11–1 o’clock axial plane and 10–8 o’clock, 11–7 o’clock, and 12–6 o’clock coronal plane and the degree of glenoid inclination change were significantly larger in the retear group than the healing group (p = 0.026, p = 0.026, p = 0.026, p = 0.026, and p = 0.014, respectively), but the average value of glenoid bone change in the retear group was within the range of 0.14 to 1.01 mm for each plane. The mean humeral head change was 5.69 ± 3.67 mm increase in the retear group and 1.27 ± 2.02 mm increase in the healing group. Compared with the healing group, the retear group showed statistically significantly increased humeral head change (p < 0.001).

Conclusions: There was difference in glenoid and humerus bone change between the healing and retear groups at midterm follow-up after repair of small- to medium-sized tears. However, considering the measurement bias, the difference between the two groups was within the measurement error range.

Keywords: Rotator cuff tears, Arthroscopic surgery, Computed tomography, Retear, Bone change
The rotator cuff is a group of muscles that covers the humeral head and plays an important role in the strength, mobility, and stability of the shoulder by fixing the humeral head to the glenoid. The causes of rotator cuff tears (RCTs) are multifactorial. However, degeneration is believed to be an essential factor. Thus, the number of patients is increasing with an increase in life expectancy. These tears can cause intense shoulder pain, functional limitation, and decreased quality of life. In addition, it has been generally considered that RCTs may affect joint constraints, causing changes in the bone and cartilage and inducing secondary glenohumeral osteoarthritis (OA) in the long term.

Rotator cuff repair can reliably improve shoulder function, decrease pain, and stabilize the glenohumeral joint. In a recent systematic review, clinically significant improvements in patient-reported outcomes, range of motion, and strength were noted after arthroscopic rotator cuff repair (ARCR).

However, a meta-analysis reported a mean rotator cuff repair surgery healing rate of 73.4%, with a high rate of non-healing or failures, ranging 10%–80%. These tears can cause intense shoulder pain, functional limitation, and decreased quality of life. In addition, it has been generally considered that RCTs may affect joint constraints, causing changes in the bone and cartilage and inducing secondary glenohumeral osteoarthritis (OA) in the long term.

Even though there are studies in the literature suggesting that patients with retears after rotator cuff repair still have significant improvement compared with their preoperative state, rotator cuff tendon tear-induced fatty infiltration can be stopped and muscle atrophy can even be minimally reversed after successful ARCR. If a repair fails to heal the rotator cuff, degenerative muscle changes increase substantially. In particular, recent studies have shown that retears after rotator cuff repair lead to the progression of glenohumeral degenerative bone changes and that the maintenance of cuff integrity is correlated with the degree of OA progression after rotator cuff repair. In contrast, a report demonstrated minimal progression of OA despite poor cuff integrity. Thus, the association between the degree of postoperative OA progression and cuff integrity remains unclear.

In previous studies, postoperative OA progression after rotator cuff repair was evaluated by measuring bony change of the humeral head; therefore, bone change of the glenoid was not evaluated. Moreover, bone change after rotator cuff retears was evaluated using only plain radiography. The purpose of this study was (1) to evaluate the glenoid and humeral head bone change by comparing preoperative and postoperative computed tomography (CT) and (2) compare differences in glenoid and humeral head bone change between a healing group and a retear group after repair of small- to medium-sized RCTs.

METHODS

This study was approved by Institutional Review Board of Inje University Busan Paik Hospital (No. 2021-03-005). Owing to the retrospective design, the requirement for informed consent was waived.

Subjects

After obtaining institutional review board approval, we retrospectively evaluated patients who had ARCR from January 2009 to January 2017. The inclusion criteria were as follows: (1) patients who underwent a postoperative shoulder CT in our institution, which has an image of both humeral head and scapula at least 3 years after the surgery and (2) patients who underwent a preoperative shoulder CT in our institution, which also has an image of both humeral head and scapula. The exclusion criteria included the following: (1) partial-thickness RCTs, (2) large to massive RCTs, (3) concomitant subscapularis tendon tears, (4) irreparable cuff tears, (5) arthritic changes of the glenohumeral joint on radiographs (Hamada stage 3–5 and Samilson-Prieto [SP], stage 2–4), (6) revision operation after ARCR, and (7) history of fractures or operations on the affected shoulder. Among the 823 patients who had ARCR from January 2009 to January 2017, 121 patients had postoperative shoulder CT or chest CT scans at least 3 years after surgery. Among these 121 patients, 93 patients had preoperative shoulder CT or chest CT and 90 patients had CT scans with which the humeral head and scapula could be confirmed. After applying the exclusion criteria, we selected 49 patients as final subjects.

Imaging Protocols for CT

All scans were made with the patient in the supine position with the arm by the side and the hand on the lateral aspect of the thigh. All imaging procedures were performed with a Siemens scanner (SOMATOM 128, Definition AS+, Siemens Healthcare, Forchheim, Germany), using a single-energy CT protocol (120 kVp, 180 mA; dose modulation, 0.6 mm collimation; effective pitch, 0.8), a B60 (sharp) reconstruction kernel, a reconstructed slice thickness of 1.0 mm, and a slice increment of 1.0 mm.

Assessment of Tendon Healing

Anatomic assessment of tendon healing was performed with CT arthrography (CTA) at least 6 months after ARCR. A radiologist who specialized in musculoskeletal imaging (SJL) evaluated CTA to confirm the patients’
postoperative cuff continuity. If there was a detectable defect or gap in the repaired tendon or if the repaired tendon appeared to have undergone a significant retraction, the investigator recorded this outcome as retear.

**Image Reconstruction and Analysis**

We saved the CT image of the patients as a digital imaging and communications in medicine (DICOM) file, and 3D reconstruction was performed using an image reconstruction software (3D Slicer, version 4.10.2). We were able to obtain the two distinct segmentation bone models of the scapula and humerus (Fig. 1). This method was used in both preoperative and postoperative CT.

Fiducial registration was used to compare preoperative CT and postoperative CT. Fiducial registration method is to overlap two images, referring to the same landmark that is placed on two different images. We first imported a preoperative CT DICOM file to the 3D Slicer program and volume rendering was carried out. The viewing panel was changed into orthogonal setting and landmarks were placed on three points over the scapular surface (the angular inferior, trigonum scapulae, and glenoid center of the scapula) and saved as fixed landmarks. Then, the postoperative CT DICOM file was imported and the same procedure was carried out. Landmarks were saved as moving landmarks. The fiducial registration module was opened and a transform file (from landmark coordinate system to fixed landmark coordinate system) was made and saved. The general registration module was opened and fixed volume was set as preoperative CT volume rendering and moving volume as postoperative CT volume rendering. Saved transformed files were applied to the two volumes and registration was carried out. After the two volumes were overlapped as the same coordinate system, preoperative and postoperative scapular morphology change was evaluated (Fig. 2) and this fiducial registration showed the root mean square (RMS) distance between hom.
Thereafter, the 3D model was saved in STL file format. Then, the 3D model STL file was imported through the Slicer Shape Analysis Toolbox (SlicerSALT, version 2.0.0; Kitware Inc., USA), and different colors were used if the length of the two scapular bone models differed before and after the surgery. Differences were displayed in different colors according to the difference in change. A change of 0–1 mm was shown in indigo, 1–2 mm in blue, 2–3 mm in yellow, 3–4 mm in orange, 4–5 mm in red, and 5–6 mm in brown. Glenoid bone change was defined as yellow or higher, taking into account errors in analyses (Fig. 3).

Using the 3D Slicer again, a best-fit circle was drawn for the glenoid in the sagittal view of the overlapped scapular bone model and divided clockwise from 0 o’clock to 12 o’clock. In the overlapped scapular bone model, we measured the area with the greatest degree of change in the axial view corresponding to 11 o’clock–1 o’clock, axial 10 o’clock–2 o’clock, axial 9 o’clock–3 o’clock, axial 8 o’clock–4 o’clock, axial 7 o’clock–5 o’clock, coronal view corresponding to 10 o’clock–8 o’clock, coronal 11 o’clock–7 o’clock, coronal view 12 o’clock–6 o’clock, coronal 1 o’clock–5 o’clock, and coronal 2 o’clock–4 o’clock (Fig. 4). The degree of change was measured in parallel to each axis (Fig. 5). To measure the change of the glenoid center between preoperative CT and postoperative CT, the distance difference in the axial view of the glenoid center before and after surgery was compared by registering as in the previous procedure. The distance difference was measured perpendicular to the scapula coronal plane (Fig. 6).

To measure glenoid version and retroversion, inclination angle was determined in the scapula coronal plane. A line was drawn from the trigonum scapulae to the glenoid center. A second line was drawn through the most cranial and caudal points of the glenoid rim. Angle γ was measured between the axes of these two lines in the caudal direction. From this, the glenoid inclination angle (α) was calculated using the formula, α = 90° – γ. In the same way as described above, the scapular axis was defined as the line connecting the tip of the trigonum scapulae and the center of the glenoid line. Glenoid version was calculated as the angle between the glenoid line (the most posterior and anterior points of the glenoid rim) and the line perpendicular to the scapular axis. This was calculated in both preoperative and postoperative scapular bone models, and the changes before and after surgery were measured (Fig. 7).

To measure the humerus osteophyte change, we first placed the best-fit sphere on the articular surface of the humeral head. The midcoronal CT scan provides a 2D method for fitting of a circle and would correlate with a 2D anterior-to-posterior radiographic image of the proximal humerus in the axial, coronal, and sagittal views of the scapula. The maximum distance difference between the center of the circle formed by the sphere and the osteophyte was measured. The difference between the two preoperative and postoperative humeri was calculated (Fig. 8).

**Statistical Analysis**

A specialized statistician at Inje University Busan Paik Hospital (BHK) performed statistical evaluation using IBM SPSS ver. 25.0 (IBM Corp., Armonk, NY, USA). Chi-square test was used to evaluate the occurrence of glenoid...
bone change between the healing and retear groups. Wilcoxon rank-sum test was used to evaluate the degree of glenoid bone change, glenoid inclination change, retroversion change, and glenoid center, as well as the degree of humerus head change between the healing and retear groups. A $p$-value of $< 0.05$ was considered statistically significant.

**RESULTS**

Among 49 patients in the rotator cuff repair group, 15 had postoperative rotator cuff tendon retears (retear group) and 34 patients had no rotator cuff tendon retear (healing group). The period from the date of operation to final CT was $63.60 \pm 25.16$ months in the healing group and $60.16 \pm 37.9$ months in the retear group ($p = 0.709$). Patients’ characteristics are listed in Table 1.

**Comparison of the Occurrence of Glenoid Bone Change between the Healing and Retear Groups**

In the healing group, 1 patient (2.9%) showed glenoid bone change and 33 patients (97.1%) showed no glenoid bone change. Among the 15 patients in the retear group, 4 patients (26.7%) showed glenoid bone change and 11 patients (73.3%) showed no glenoid bone change. There was a statistically significant difference in the occurrence of glenoid bone change between the healing and retear groups ($p = 0.026$) (Table 2).
Comparison of the Occurrence of Glenoid Bone Change in Specific Clockwise Planes between the Healing and Retear Groups

With regard to the occurrence of glenoid bone change in specific clockwise planes, there was a statistically significant difference between the healing and retear groups in the 11–1 o’clock axial plane and 10–8 o’clock, 11–7 o’clock, and 12–6 o’clock coronal plane (p = 0.026, p = 0.026, p = 0.026, and p = 0.026, respectively) (Table 3).

Comparison of the Degree of Glenoid Bone Change in Specific Clockwise Planes between the Healing and Retear Groups

In the retear group, the degree of glenoid bone change was 1.01 ± 1.85 mm in the 11–1 o’clock axial plane, 0.99 ± 1.82 mm in the 10–8 o’clock coronal plane, 0.73 ± 1.3 mm in the 11–7 o’clock coronal plane, and 0.99 ± 1.82 mm in the 12–6 o’clock coronal plane. In the healing group, the degree of glenoid bone change was 0.16 ± 0.93 mm in the
Fig. 7. Measurement of glenoid inclination and retroversion. (A) Sagittal computed tomography (CT) view of the scapula. Measurement of glenoid inclination. Line 1 was drawn from the trigonum scapulae to the glenoid center. Line 2 was drawn through the most cranial and caudal points of the glenoid rim. Angle $\gamma$ was measured between the axes of these two lines in the caudal direction. Glenoid inclination (angle $\alpha$) was calculated using the formula, $\alpha = 90^\circ - \gamma$. (B) Axial CT view of the scapula. Measurement of glenoid retroversion. The red dotted line represents the scapular axis. Line 1 was drawn by connecting the tip of the trigonum scapulae and the center of the glenoid line (the most posterior and anterior points of the glenoid rim). Line 2 was drawn perpendicular to the scapular axis. (C) Angle measurement module of three-dimensional Slicer.

Fig. 8. Measurement of the humerus head bone change. The yellow circle represents the best-fit sphere of the humeral head. The red arrow represents the distance between the center of the sphere and the farthest point of the humerus bone. The red straight line represents the radius of the sphere, and $r$ represents the radius of the sphere. (A) Preoperative conventional four-panel view of three-dimensional (3D) Slicer. (B) Postoperative conventional four-panel view of 3D Slicer.
Kim et al. Bone Change after Rotator Cuff Tendon Retear
Clinics in Orthopedic Surgery • Vol. 14, No. 4, 2022 • www.ecios.org

11–1 o’clock axial plane, 0.06 ± 0.93 mm in the 10–8 o’clock coronal plane, 0.1 ± 0.58 mm in the 11–7 o’clock coronal plane, and 0.16 ± 0.93 mm in the 12–6 o’clock coronal plane. The retear group showed significant difference in the degree of glenoid bone change in the axial 11–1 o’clock plane, coronal 10–8 o’clock plane, coronal 11–7 o’clock plane, and coronal 12–6 o’clock compared with the healing group (p = 0.014, p = 0.012, p = 0.014, and p = 0.014, respectively) (Table 4).

**Comparison of the Degree Of Humeral Head Change between the Healing and Retear Groups**
The mean humeral head change was 1.27 ± 2.02 mm in the healing group and 5.69 ± 3.67 mm in the retear group. The retear group showed statistically significantly increased humeral head change compared with the healing group (p < 0.001) (Table 6).

**DISCUSSION**
In the current study, the occurrence of glenoid bone change was more common in the retear group than the healing group, and the degree of glenoid bone change and glenoid inclination change were greater in the retear group than the healing group. These differences were statistically significant. With regard to the occurrence of glenoid bone change in specific clockwise planes between the healing
and retear groups, there was a statistically significant difference in the 11–1 o’clock axial plane and 10–8 o’clock, 11–7 o’clock, and 12–6 o’clock coronal plane ($p = 0.026$, $p = 0.026$, $p = 0.026$, respectively); the retear group showed more glenoid bone change in these planes compared with the healing group.

Previous studies have shown that retears after rotator cuff repair lead to the progression of glenohumeral degenerative bone changes because of instability of the glenohumeral joint caused by rotator cuff retears and that the maintenance of cuff integrity is correlated with the degree of OA progression after rotator cuff repair.\(^{18}\) Neer et al.\(^{21}\) reported that the loss of rotator cuff function may lead to superior translation of the humeral head during arm elevation. Based on these studies, a tendon retear after ARCR can result in rotator cuff dysfunction, which leads to glenohumeral instability and humerus and glenoid bone change. However, in most of the previous studies, gleno-humeral OA was evaluated using only simple radiographs that are influenced by the scapular position, patient position, beam angle, and cassette position and was graded by measuring humeral head osteophytes and joint space narrowing (SP classification).\(^{5,23-25}\) Therefore, there are few studies that evaluated the change in the glenoid bone after rotator cuff repair.

In the current study, we evaluated glenoid bone change after repair of small- to medium-sized RCTs by

![Table 3. Comparison of the Occurrence of Glenoid Bone Change at Specific Clockwise Planes between Healing and Retear Groups](image)

| Clockwise plane of glenoid | Cuff healing state | Healing (n = 34) | Retear (n = 15) | $p$-value* |
|---------------------------|------------------|-----------------|----------------|----------|
| Axial view (11–1 o’clock) | Bone change      | 1 (2.9)         | 4 (26.7)       | 0.026    |
|                           | No change        | 33 (97.1)       | 11 (73.3)      |          |
| Axial view (10–2 o’clock) | Bone change      | 1 (2.9)         | 1 (6.7)        | 0.523    |
|                           | No change        | 33 (97.1)       | 14 (93.3)      |          |
| Axial view (9–3 o’clock)  | Bone change      | 0               | 0              | 1.000    |
|                           | No change        | 34 (100)        | 15 (100)       |          |
| Axial view (8–4 o’clock)  | Bone change      | 0               | 0              | 1.000    |
|                           | No change        | 34 (100)        | 15 (100)       |          |
| Axial view (7–5 o’clock)  | Bone change      | 0               | 0              | 1.000    |
|                           | No change        | 34 (100)        | 15 (100)       |          |
| Coronal view (10–8 o’clock) | Bone change     | 1 (2.9)         | 4 (26.7)       | 0.026    |
|                           | No change        | 33 (97.1)       | 11 (73.3)      |          |
| Coronal view (11–7 o’clock) | Bone change    | 1 (2.9)         | 4 (26.7)       | 0.026    |
|                           | No change        | 33 (97.1)       | 11 (73.3)      |          |
| Coronal view (12–6 o’clock) | Bone change     | 1 (2.9)         | 4 (26.7)       | 0.026    |
|                           | No change        | 33 (97.1)       | 11 (73.3)      |          |
| Coronal view (1–5 o’clock) | Bone change     | 1 (2.9)         | 1 (6.7)        | 0.523    |
|                           | No change        | 33 (97.1)       | 14 (93.3)      |          |
| Coronal view (2–4 o’clock) | Bone change     | 0               | 0              | 1.000    |
|                           | No change        | 34 (100)        | 15 (100)       |          |

Values are presented as number (%).
*Chi-square test, $p < 0.05$.\(^{18}\) Neer et al.\(^{21}\) reported that the loss of rotator cuff function may lead to superior translation of the humeral head during arm elevation. Based on these studies, a tendon retear after ARCR can result in rotator cuff dysfunction, which leads to glenohumeral instability and humerus and glenoid bone change. However, in most of the previous studies, gleno-humeral OA was evaluated using only simple radiographs that are influenced by the scapular position, patient position, beam angle, and cassette position and was graded by measuring humeral head osteophytes and joint space narrowing (SP classification).\(^{5,23-25}\) Therefore, there are few studies that evaluated the change in the glenoid bone after rotator cuff repair.

In the current study, we evaluated glenoid bone change after repair of small- to medium-sized RCTs by
Comparing preoperative and postoperative 3D CT. Using CT DICOM data, glenoid and humerus were 3D reconstructed. Then, we could evaluate the specific glenoid bone changes according to the fiducial registration method that overlaps two images with the same landmarks being placed on two different images. With regard to the occurrence of glenoid bone change and the degree of glenoid bone change, statistically significant differences between healing and retear groups were found in the current study. Moreover, in the 11–1 o’clock axial plane and 10–8 o’clock, 11–7 o’clock, and 12–6 o’clock coronal plane, which represent the posterosuperior quadrant area of the glenoid surface, the occurrence of glenoid bone defect showed significant difference between the healing and retear groups. However, the average value of glenoid bone change at midterm follow-up in the retear group was within the range of 0.14 to 1.01 mm for each plane, which are all within the measurement bias range.

This result implies that healing after repair of a small- to medium-sized RCT may decrease glenoid bone change in the midterm follow-up but a retear may not increase large glenoid bone change at midterm follow-up. It is difficult to clarify the specific reason for this minimal glenoid bone change in the retear group after rotator cuff repair in this study. We speculate that the preserved force couple despite retears after repair of small- to medium-sized tears and midterm follow-up may have led to the minimal bone change.

Regarding the comparison of the degree of glenoid inclination change, glenoid version change, and glenoid center change between the healing and retear groups, there was a significant difference only in the glenoid inclination change between the two groups and no significant difference in the glenoid version and glenoid center change; the retear group showed increased glenoid inclination. The change of glenoid inclination seems to be related to the glenoid bone change at the posterosuperior site, and thus, superior glenoid inclination may occur. However, the degree of glenoid inclination change was also minimal.

In this study, we also evaluated the exact humeral head change by comparing preoperative and postoperative 3D-reconstructed humeri with the extraction of the same size best-fit sphere. Then, we could measure the increase of the humeral head bone by measuring the maximum diameter of the extracted 3D model. There was a statistically significant difference in the degree of humeral head bone change between the healing and retear groups ($p < 0.001$). The mean humeral head change in the healing group was $1.27 \pm 2.02$ mm, which corresponds to the SP grade 1, whereas it was $5.69 \pm 3.67$ mm in the retear group, which corresponds to the SP grade 2.

There are several limitations of this study. First, our study design was a retrospective review and did not include consecutive patients. To select subjects who had

| Clockwise plane of glenoid | Cuff healing state | p-value* |
|---------------------------|------------------|----------|
|                           | Healing (n = 34) | Retear (n = 15) |
| Axial view (11–1 o’clock) | 0.16 ± 0.93     | 1.01 ± 1.85     | 0.014     |
| Axial view (10–2 o’clock) | 0.06 ± 0.36     | 0.62 ± 1.07     | 0.012     |
| Coronal view (10–8 o’clock) | 0.07 ± 0.38     | 0.14 ± 0.56     | 0.569     |
| Coronal view (11–7 o’clock) | 0.10 ± 0.58     | 0.73 ± 1.30     | 0.014     |
| Coronal view (12–6 o’clock) | 0.16 ± 0.93     | 0.99 ± 1.82     | 0.014     |
| Coronal view (1–5 o’clock) | 0.10 ± 0.58     | 0.25 ± 0.96     | 0.527     |

Values are presented as mean ± standard deviation. *Wilcoxon rank-sum test, $p < 0.05$.

| Variable               | Cuff healing state | p-value* |
|------------------------|--------------------|----------|
|                        | Healing (n = 34)   | Retear (n = 15) |
| Glenoid inclination change (°) | 0.11 ± 0.65     | 0.85 ± 1.48     | 0.014     |
| Retroversion change (°)  | -0.11 ± 0.67     | -0.34 ± 1.08    | 0.274     |
| Glenoid center change (mm) | 0.00 ± 0.02     | 0.01 ± 0.03     | 0.548     |

Values are presented as mean ± standard deviation. *Wilcoxon rank-sum test, $p < 0.05$. | Cuff healing state | p-value* |
|------------------------|------------------|----------|
| Healing (n = 34)       | Retear (n = 15)  |
| Bone change (mm)       | 1.27 ± 2.02      | 5.69 ± 3.67 | < 0.001 |
taken both preoperative CT and postoperative CT at minimum 3 years after rotator cuff repair, a number of patients had to be excluded. Furthermore, the number of final subjects was small, and there may have been selection bias in this study. Second, this study did not control several factors that cause postoperative bone change. Until recently, there was no consensus on the factors that cause postoperative glenohumeral OA. In particular, the initial tear size or fatty degeneration of the rotator cuff may influence glenohumeral bone changes. However, in this study, we simply evaluated bone change depending on whether a retear or healing occurred. Third, the fiducial registration technique, which is overlapping the preoperative and postoperative scapulae by referring to an anatomical bony landmark, has a limitation of not perfectly matching two different scapulae of the same patient. Thus, in this study, we used three registration points, which had barely changed, and the RMS distance between homologous fiducials after registration was measured. We considered the less than the highest RMS value (a bone change less than 2 mm) as measurement bias. Fourth, we simply compared preoperative CT and postoperative CT at minimum 3 years after operation. In our institution, not all patients have taken postoperative shoulder CT or chest CT at the exact time routinely, and therefore, we inevitably selected patients retrospectively. Thus, postoperative CT was not taken in the same period for the included patients. In addition, there was no interval CT between preoperative and postoperative CT, and we could not examine when the bone change occurred. Fifth, the clinical outcome after ARCR was not considered in this study. Thus, we could not define clinical outcomes of bone change according to the number of rotator cuff tendons. Sixth, healing of the rotator cuff tendon was evaluated 6 months after the operation, and therefore, there may have been a difference in the healing state between the last CT evaluation and the CT taken 6 months after the operation. Finally, this study is not based on long-term follow-up results. Therefore, we could not conclude if this pathologic condition of the rotator cuff would affect bone change in the long term.

In the comparison of preoperative and postoperative midterm shoulder CT images between the retear and healing groups after repair of small- to medium-sized tears, statistically significant differences in the glenoid and humeral head bone changes were noted; more increased glenoid and humeral head bone changes were found in the retear group in the midterm follow-up. However, the difference in the quantitative value of glenoid bone change between the healing group and the retear group, considering the measurement bias, was within the measurement error range. Healing after repair of small- to medium-sized RCTs may decrease glenoid bone change at midterm follow-up but retears may not increase glenoid bone change at midterm follow-up.

**CONFLICT OF INTEREST**

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

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**REFERENCES**

1. Moore KL, Dalley AF. Upper limb. In: Moore KL, Dalley AF, eds. Clinically oriented anatomy. Philadelphia: Lippincott Williams and Wilkins; 2006. 704-5.
2. Milgrom C, Schaffler M, Gilbert S, van Holsbeeck M. Rotator-cuff changes in asymptomatic adults: the effect of age, hand dominance and gender. J Bone Joint Surg Br. 1995;77(2):296-8.
3. Minagawa H, Yamamoto N, Abe H, et al. Prevalence of symptomatic and asymptomatic rotator cuff tears in the general population: from mass-screening in one village. J Orthop. 2013;10(1):8-12.
4. Colvin AC, Egorova N, Harrison AK, Moskowitz A, Flatow EL. National trends in rotator cuff repair. J Bone Joint Surg Am. 2012;94(3):227-33.
5. Collin P, Betz M, Herve A, et al. Clinical and structural outcome 20 years after repair of massive rotator cuff tears. J Shoulder Elbow Surg. 2020;29(3):521-6.
6. Berenbaum F. Osteoarthritis as an inflammatory disease (osteoarthritis is not osteoarthrosis!). Osteoarthritis Cartilage. 2013;21(1):16-21.
7. Chalmers PN, Salazar DH, Steger-May K, et al. Radiographic
progression of arthritic changes in shoulders with degenerative rotator cuff tears. J Shoulder Elbow Surg. 2016;25(11):1749-55.

8. Liem D, Lengers N, Dedy N, Poetzi W, Steinbeck J, Marquardt B. Arthroscopic debridement of massive irreparable rotator cuff tears. Arthroscopy. 2008;24(7):743-8.

9. Cole BJ, McCarty LP 3rd, Kang RW, Alford W, Lewis PB, Hayden JK. Arthroscopic rotator cuff repair: prospective functional outcome and repair integrity at minimum 2-year follow-up. J Shoulder Elbow Surg. 2007;16(5):579-85.

10. Kim CW, Kim JH, Kim DG. The factors affecting pain pattern after arthroscopic rotator cuff repair. Clin Orthop Surg. 2014;6(4):392-400.

11. Yang J Jr, Robbins M, Reilly J, Maerz T, Anderson K. The clinical effect of a rotator cuff retear: a meta-analysis of arthroscopic single-row and double-row repairs. Am J Sports Med. 2017;45(3):733-41.

12. Yoo JH, Cho NS, Rhee YG. Effect of postoperative repair integrity on health-related quality of life after rotator cuff repair: healed versus retear group. Am J Sports Med. 2013;41(11):2637-44.

13. McElvany MD, McGoldrick E, Gee AO, Neradilek MB, Matsen FA 3rd. Rotator cuff repair: published evidence on factors associated with repair integrity and clinical outcome. Am J Sports Med. 2015;43(2):491-500.

14. Bishop J, Klepps S, Lo IK, Bird J, Gladstone JN, Flatow EL. Cuff integrity after arthroscopic versus open rotator cuff repair: a prospective study. J Shoulder Elbow Surg. 2006;15(3):290-9.

15. Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am. 2005;87(6):1229-40.

16. Galatz LM, Ball CM, Teeffey SA, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. J Bone Joint Surg Am. 2004;86(2):219-24.

17. Wieser K, Joshy J, Filli L, et al. Changes of supraspinatus muscle volume and fat fraction after successful or failed arthroscopic rotator cuff repair. Am J Sports Med. 2019;47(13):3080-8.

18. Paxton ES, Teeffey SA, Dahiya N, Keener JD, Yamaguchi K, Galatz LM. Clinical and radiographic outcomes of failed repairs of large or massive rotator cuff tears: minimum ten-year follow-up. J Bone Joint Surg Am. 2013;95(7):627-32.

19. Fedorov A, Beichel R, Kalpathy-Cramer J, et al. 3D Slicer as an image computing platform for the Quantitative Imaging Network. Magn Reson Imaging. 2012;30(9):1323-41.

20. Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C. The clinical and structural long-term results of open repair of massive tears of the rotator cuff. J Bone Joint Surg Am. 2008;90(11):2423-31.

21. Neer CS 2nd, Craig EV, Fukuda H. Cuff-tear arthropathy. J Bone Joint Surg Am. 1983;65(9):1232-44.

22. Konno N, Itoi E, Kido T, Sano A, Urayama M, Sato K. Glenoid osteophyte and rotator cuff tears: an anatomic study. J Shoulder Elbow Surg. 2002;11(1):72-9.

23. Gazielly DF, Gleyze P, Montagnon C. Functional and anatomical results after rotator cuff repair. Clin Orthop Relat Res. 1994;(304):43-53.

24. Knudsen HB, Gelineck J, Sojbjerg JO, Olsen BS, Johanssen HV, Sneppen O. Functional and magnetic resonance imaging evaluation after single-tendon rotator cuff reconstruction. J Shoulder Elbow Surg. 1999;8(3):242-6.

25. Sugaya H, Maeda K, Matsuji K, Morishii J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: single-row versus dual-row fixation. Arthroscopy. 2005;21(11):1307-16.