Morphological characteristics of the acromion in Fosbury flop tears and their clinical outcomes after arthroscopic rotator cuff repair

Yukihiro Kajita^{a,b,*}, Yusuke Iwahori^c, Yohei Harada^a, Ryosuke Takahashi^b, Masataka Deie^a

^a Department of Orthopaedic Surgery, Aichi Medical University, Japan

^b Department of Orthopaedic Surgery, Ichinomiya Nishi Hospital, Japan

^c Department of Orthopaedic Surgery, Asahi Hospital, Japan

ARTICLE INFO

Keywords:

Acromion
Fosbury flop tears
Arthroscopic rotator cuff repair
Critical shoulder angle
Lateral acromial angle
Acromiohumeral distance

ABSTRACT

Background: Rotator cuff tears that have flipped upon itself and adhered medially have been recently described as Fosbury flop tears (FFT). However, there are no reports on the cause and clinical outcomes of FFT. We investigated the preoperative anatomical factors and clinical outcomes related to the occurrence of FFT.

Methods: Among patients with more than two years of follow-up, 33 patients with FFT who underwent arthroscopic rotator cuff repair (ARCR) for a small-to-medium sized tear of the supraspinatus tendon alone (Group F: mean age, 63.4 ± 8.9 years) and 52 patients without FFT who underwent ARCR (Group C: mean age, 62.1 ± 7.0 years) were included. Presence of diabetes mellitus, critical shoulder angle (CSA), lateral acromial angle (LAA), acromiohumeral distance (AHD), sagittal and coronal morphologies of the acromion, JOA score, and rate of rotator cuff re-tear were evaluated.

Results: There were significantly more males in Group F ($P = 0.017$). There were no significant differences in age or rate of diabetic complications. The mean CSA, LAA, and AHD in the Groups F and C were respectively as follows: CSA, 33.7 ± 4.0° and 34.5 ± 3.4°; LAA, 82.1 ± 9.9° and 82.1 ± 6.9°; AHD, 10.2 ± 1.4 mm and 9.8 ± 1.4 mm. There were no significant differences between groups. The acromial morphology showed no significant difference in the sagittal plane; however, significantly more double-floor type acromia were found in the coronal plane ($P < 0.001$). Although the JOA score significantly improved in both groups, there was no significant difference between groups. The re-rupture rate was significantly higher in Group F than Group C (15.2% versus 1.9%; $P = 0.02$).

Conclusions: Double-floor type acromia in the coronal plane was common in Group F. The location of osteophytes on the inferior surface of the acromion was believed to be associated with the occurrence of FFT. Furthermore, a high re-tear rate was observed in group F.

1. Introduction

Arthroscopic rotator cuff repair (ARCR) is widely known as a surgical method that can provide good improvement of pain and functional recovery. The popularization of ARCR has enabled the morphological evaluation of rotator cuff tears under arthroscopy, and various tear patterns of the rotator cuff have been reported in the literature.¹ Recently, Läderman et al.^{1,2} defined rotator cuff tears that have flipped upon itself and adhered medially as Fosbury flop tears (FFT) (Fig. 1). However, there are no reports on the morphological characteristics and mechanism of occurrence of this tear pattern. Moreover, there are no reports on the clinical outcomes of ARCR for Fosbury flop tears. Based

on our prior experience of performing ARCR for an FFT that was difficult to reduce due to osteophyte formation at the center of the acromion, we believe that the location of osteophytes on the inferior surface of the acromion may potentially be related to the occurrence of FFT. Therefore, the purpose of this study was to compare preoperative imaging findings of the shoulder joint with or without FFT prior to ARCR in order to investigate the preoperative anatomical factors associated with the occurrence of FFT. Furthermore, we investigated the treatment outcomes of ARCR. We hypothesized that the acromion in cases with FFT has distinct anatomical features and poor clinical outcomes.

* Corresponding author. Department of Orthopaedic Surgery, Aichi Medical University, 1 Yazakokarimata, Nagakute, Aichi, 480-1195, Japan.

E-mail address: yukihirokajita@gmail.com (Y. Kajita).

<https://doi.org/10.1016/j.jor.2020.11.003>

Received 29 September 2020; Accepted 1 November 2020

Available online 4 November 2020

0972-978X/© 2020 Professor P K Surendran Memorial Education Foundation. Published by Elsevier B.V. All rights reserved.

2. Methods

2.1. Patient selection

This retrospective study was approved by the ethics committee at our hospital, and consent was obtained from all patients for the research. We reviewed a database of all arthroscopic rotator cuff repairs performed by a single surgeon between 2015 and 2017. Of 418 patients who underwent ARCR, those with a small-to-medium tear of the supraspinatus tendon alone with a tear length of less than 3 cm (Cofield classification³) were included. Patients with partial tears were excluded. Patients with a supraspinatus tendon that was inverted (“flipped”) more than 90° under arthroscopy with morphological traits of FFT were categorized into Group F (Fig. 1), and

Those without an inverted tendon were used as a control (Group C) and were matched for age, sex, and diabetic complications. Surgeries were performed under general anesthesia with additional interscalene nerve block. Patients were positioned in the beach chair position. Arthroscopic rotator cuff repairs were performed by the suture-bridge technique. Medial anchors (Healix; DePuy-Mitek, Raynham, MA) were inserted just lateral to the cartilage of the humeral head. A suture from each anchor was passed through the tendon. Lateral anchors (Versalok Anchor; DePuy-Mitek, Raynham, MA) were placed approximately 5 mm distal to the lateral edge of the greater tuberosity.

The number of anchors was determined according to the size of the tear and repair configuration in terms of the suture-bridge repair. In Group F, the inverted tear was sufficiently removed, reduced, and repaired using the suture-bridge technique to the rotator cuff footprint. Subacromial decompression was also performed in patients with subacromial spurs.

2.2. Postoperative protocol

All patients followed the same rehabilitation regimen. The shoulder was immobilized for 4 weeks in a sling with an abduction pillow. Range of motion exercises for the elbow, wrist, and fingers were started immediately after surgery. Passive forward elevation exercises were initiated from postoperative day 1. An active-assisted motion exercise was initiated at 4 weeks postoperatively, active motion was allowed at 6 weeks postoperatively, and a strengthening exercise program was allowed at 8 weeks postoperatively.

2.3. Evaluation criteria

Presence of diabetes mellitus, critical shoulder angle (CSA),⁴ lateral acromial angle (LAA),⁵ acromiohumeral distance (AHD),⁶ sagittal and coronal morphologies of the acromion, Japanese Orthopaedic Association (JOA) scores, and rate of rotator cuff re-tear were evaluated and compared between Group F and Group C.

The CSA, LAA and AHD were measured on preoperative standard anteroposterior radiographs. The CSA is a radiologic measurement of the angle between a line connecting the superior and inferior aspects of

the glenoid fossa and another line connecting the inferior aspect of the glenoid with the most inferolateral point on the acromion (Fig. 2A). The LAA was assessed at the intersection of two lines representing the glenoid cavity and the inferior surface of the acromion (Fig. 2B). The AHD was measured by the method described by Ellman et al. (Fig. 2C).

The preoperative acromial morphology in the sagittal plane was categorized into Type 1 (flat), Type 2 (curve), and Type 3 (hook) on scapular Y radiographs according to the Bigliani classification.⁷ The preoperative acromial morphology in the coronal plane was classified by CT or MRI as follows: flat type, no osteophytes; beak type, lateral osteophytes; double-floor type, inferior osteophytes of the acromial center (Fig. 3). The minimum follow-up time for a clinical review to exclude infection was 24 months. JOA score were evaluated preoperatively and at 6, 12, and 24 months postoperatively. Rotator cuff re-tear was categorized into Type IV and V according to the Sugaya classification.⁸

2.4. Statistical analysis

All statistical analyses were performed using the SPSS software (ver. 18.0, SPSS Inc, Chicago, IL). T-test and Fisher’s exact test were used for statistical analysis, and the level of statistical significance was set as $P < 0.05$.

3. Results

Thirty-three patients in Group F and 52 patients in Group C were included in this study. The mean age of Groups F and C were 63.4 ± 8.9 years (SD) and 62.1 ± 7.0 (SD) years, respectively. There were 14 males and 19 females in Group F, and 29 males and 23 females in Group C. Diabetic complications were observed in 7 patients (21.4%) in Group F and 12 patients (23.1%) in Group C (Table 1). The mean CSA, LAA, and AHD in the Groups F and C were respectively as follows: CSA, $33.7 \pm 4.0^\circ$ and $34.5 \pm 3.4^\circ$ (SD); LAA, $82.1 \pm 9.9^\circ$ and $82.1 \pm 6.9^\circ$ (SD); AHD, 10.2 ± 1.4 mm and 9.8 ± 1.4 mm (SD). There was no significant difference between the two groups (Table 2).

The acromial morphology in the sagittal plane was categorized according to the Bigliani classification. In Group F, there were 10 cases of Type 1 acromia, 16 of Type 2, and 7 of Type 3. In Group C, there were 14 cases of Type 1, 30 of Type 2, and 8 of Type 3. There was no significant difference between the two groups ($P = 0.85$).

The acromial morphology in the coronal plane consisted of the flat, beak, and double-floor type. In Group F, there were 4 cases of the flat-type acromia, 2 of the beak-type, and 27 of the double-floor-type. In Group C, there were 26 flat-type, 14 beak-type, and 12 double-floor-type. There were significantly more double-floor acromia in Group F ($P < 0.001$) (Table 3). Although the JOA score was significantly improved after ARCR, there was no significant difference between the two groups (Fig. 4). The re-tear rate was significantly higher in the Group F compared to Group C ($P = 0.021$), with 5 patients in Group F (15.2%) and 1 in Group C (1.9%). Re-tear cases in Group F (mean age, 64.2 ± 10.1 years; no diabetic patients) obtained a JOA score of $59.8 \pm$

Fig. 1. Fosbury flop tear: a tear pattern wherein the stump of the rotator cuff is inverted more than 90° relative to the footprint.

Fig. 2. CSA, LAA, and AHD were measured on standard anteroposterior radiographs. A: The CSA is the angle between a line connecting the superior and inferior aspects of the glenoid fossa and another line connecting the inferior aspect of the glenoid with the most inferolateral point on the acromion. B: The LAA was assessed at the intersection of two lines representing the glenoid cavity and the inferior surface of the acromion. C: AHD was measured from the inferior surface of acromion to the apex of the humeral head.

Fig. 3. The acromial morphology in the coronal plane was classified as follows: A) flat type, no osteophytes; B) beak type, lateral osteophytes; C) double-floor type, inferior osteophytes of the acromial center.

Table 1
Patient demographics and surgical details.

	Group F	Group C	P-value
	<i>n</i> = 33	<i>n</i> = 52	
Age (year)	63.4 ± 8.9	62.1 ± 7.0	0.48*
Sex (male/female)	14/19	29/23	0.23 **
Diabetes	6 (18.2%)	12 (23.1%)	0.59 **
History of trauma	14/19	23/29	0.87 **
Capsular release	6 (18.2%)	15 (28.8%)	0.27**
LHB management (none/tenotomy/tenodesis)	18/12/3	22/25/5	0.53**

There was no significant difference between the groups in terms of age and complications of diabetes mellitus. *t-test. **chi-squared test.

Table 2
Results of CSA, LAA, and AHD.

	Group F	Group C	P-value
CSA (°)	33.7 ± 4.0	34.5 ± 3.4	0.38
LAA(°)	82.1 ± 9.9	82.1 ± 6.9	0.98
AHD (mm)	10.2 ± 1.4	9.8 ± 1.4	0.17

There was no significant difference between the groups in terms of CSA, LAA, and AHD. *t-test.

7.6 points preoperatively and 82.7 ± 5.4 points at 12 months postoperatively, and non-re-tear cases (mean age, 63.1 ± 8.5 years) obtained a JOA score of 62.9 ± 13.1 points preoperatively and 95.0 ± 5.3 points at 12 months postoperatively. There was no significant difference in the

Table 3
Results of acromial morphology.

		Group F	Group C	P-value
Acromial morphology of the sagittal plane (Bigliani classification)	Type 1	10 (30.3%)	14 (26.9%)	<i>P</i> = 0.85
	Type 2	16 (48.5%)	30 (57.7%)	
	Type 3	7 (21.2%)	8 (15.4%)	
Acromial morphology of the coronal plane	Flat type	4 (12.1%)	26 (50%)	<i>P</i> < 0.001
	Beak type	2 (6.1%)	14 (26.9%)	
	Double-floor type	27 (81.8%)	12 (23.1%)	

Although there was no significant difference between groups in terms of the Bigliani classification, significantly more double-floor type acromia were observed in the coronal plane for Group F.

preoperative JOA score, but the JOA score at 12 months postoperatively was significantly lower in patients with re-tears (*P* < 0.001).

4. Discussion

In 2015, Läderman et al.¹ introduced the Fosbury flop tear, a new tear pattern of the rotator cuff with an inverted tendon stump. However, based on our prior experience, we have previously observed tears with this morphology and believe that it is not a rare tear pattern. According to Läderman et al. the prevalence of Fosbury flop tears is 5% of rotator cuff tears that have undergone ARCR. In this study, we observed a

Fig. 4. In terms of the JOA score, both groups showed significant improvement at 6 months after surgery. There was no significant difference between groups from before surgery to 24 months postoperatively.

comparable prevalence rate of FFT at 7.9% among those who underwent ARCR. The tear pattern is relatively commonplace in ARCR surgery.

To the best of our knowledge, there are no reports on the mechanism of occurrence regarding FFT. The CSA, LAA, and Bigliani classification that were examined in this study have been reportedly associated with the occurrence of rotator cuff tears when the CSA is 35° or more, the LAA is less than 70° , and the Bigliani classification is Type 3.^{4–7} However, no consensus has been reached on these associations, as there are also reports that suggest that there is no association between the CSA, LAA, and Bigliani classification in relation to rotator cuff tears.^{9–11} In terms of AHD, it has been reported that the AHD can decrease as a result of rotator cuff tears.⁶ In this study, the CSA was less than 35° and the LAA was more than 70° in both groups, and there was no significant difference in the prevalence of Type 3 tears under the Bigliani classification. This may be due to the fact that the subjects that were examined in this study exhibited small-to-medium tears of the supraspinatus tendon alone, in addition to the effect of racial differences. Peter et al.¹¹ closely examined the relationship between acromial morphology and rotator cuff tears using CT, and reported that there was no association between acromial morphology and rotator cuff tears. We also believe that there is potentially no association between acromial morphology and the development of rotator cuff tears.

There are no reports in the literature that describe the morphological classification of acromial osteophytes in the coronal plane. Based on our experience, however, we have encountered FFT wherein the intra-operative findings during ARCR showed that the inverted tendon gets caught on osteophytes at the center of the acromion, thereby making it difficult to perform a reduction. Thus, we classified the acromial osteophytes in the coronal plane as flat, beak, or double-floor types in this study. From our evaluation, we observed that the prevalence of FFT was significantly higher in double-floor type acromia with osteophytes that protrude inferiorly from the acromial center, and that there is a potential association between this acromial morphology and FFT. However, we were unable to examine changes in osteophyte formation and FFT across time in order to determine which emerges first. In addition, since there was no difference between the two groups in terms of the rate of traumatic tears in this study, we believe that trauma was not related to the cause of FFT.

In recent years, rotator cuff repair using the suture-bridge technique has gained popularity in ARCR due to its superior contact area and contact pressure to the footprint of the rotator cuff.^{12,13} In this study, we evaluated the postoperative outcomes of ARCR using the suture-bridge technique in patients with FFT and compared the results to those

without an inverted tear. Although there was no significant difference in terms of the JOA score, the re-tear rate was significantly higher in Group F. The re-tear rate after ARCR using the suture-bridge technique has been reported to decrease as the tear size gets smaller.^{14,15} Old age, hyperlipidemia, diabetes mellitus, smoking, atrophy, and fatty infiltration of the muscle have been reported as risk factors for re-tears.^{16–19}

In this study, subacromial decompression was performed in cases with subacromial spurs in both groups. However, the re-tear rate of the rotator cuff was significantly higher in Group F. Considering the high number of double-floor type acromia in Group F, we believe that the decreased quality of the tendon due to recurrent impingement and wear can lead to the decreased regenerative ability of the tendon, which can potentially cause a re-tear of the rotator cuff. Rotator cuff tears were confirmed under arthroscopy when performing ARCR for patients with FTT, and some cases demonstrated tears that were either worn or frayed. Nho et al.²⁰ reported that the decreased quality of the rotator cuff stump due to recurrent impingement was at risk of re-tearing. Kumagai et al.²¹ reported that the collagen characteristics of the rotator cuff is altered when the rotator cuff is subject to repeated compression, and that double-floor type acromia was a risk factor for re-tears of the rotator cuff after ARCR. Prior to ARCR, CT or MRI should be performed to confirm the morphology of the acromial osteophytes in the coronal plane, and patients should be informed before surgery that those with double-floor type acromia are at high risk of re-tears.

There were several limitations to our research. First, the sample size was small. Second, the study was retrospective in nature. Third, risk factors of re-tears were not evaluated with the exception of diabetes mellitus. Fourth, we were unable to perform follow-up observations on the occurrence of FFT and the morphological changes of acromial osteophytes. Finally, we were also unable to perform a histological evaluation on the tendon stump of the rotator cuff.

5. Conclusion

The double-floor type acromial morphology in the coronal plane was common in Group F. The location of osteophytes on the inferior surface of the acromion was believed to be associated with the occurrence of Fosbury flop tears. In addition, a high re-rupture rate was observed following arthroscopic rotator cuff repair in those with Fosbury flop tears.

Study design

Retrospective clinical study.

Declaration of competing interest

None.

Acknowledgements

none.

References

- Lädermann A, Burkhart SS, Hoffmeyer P, et al. A new tear pattern of the rotator cuff and its treatment: Fosbury flop tears. *Int J Shoulder Surg.* 2005;9:9–12.
- Lädermann A, Burkhart SS, Hoffmeyer P, et al. Classification of full-thickness rotator cuff lesions: a review. *EFORT Open Rev.* 2017;1:420–430.
- Cofield RH. Subscapular muscle transposition for repair of chronic rotator cuff tears. *Surg Gynecol Obstet.* 1982;154:667–672.
- Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C. Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the glenohumeral joint?: a radiological study of the critical shoulder angle. *Bone Joint Lett J.* 2013;95-B:935–941.
- Banas MP, Miller RJ, Totterman S. Relationship between the lateral acromion angle and rotator cuff disease. *J Shoulder Elbow Surg.* 1995;4:454–461.
- Weiner DS, Macnab I. Superior migration of the humeral head. A radiological aid in the diagnosis of tears of the rotator cuff. *J Bone Joint Surg Br.* 1970;52:524–527.
- Bigliani Lu, Ticker JB, Flatow EL, Soslowsky LJ, Mow VC. The relationship of acromial architecture to rotator cuff disease. *Clin Sports Med*;10:823–838.
- Sugaya H, Maeda K, Matsuki K, Moriishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: single-row versus dual-row fixation. *Arthroscopy.* 2005;21:1307–1316.
- Bjarnason AO, Sørensen TJ, Kalleose T, Barfod KW. The critical shoulder angle is associated with osteoarthritis in the shoulder but not rotator cuff tears: a retrospective case-control study. *J Shoulder Elbow Surg.* 2017;26:2097–2102.
- Chalmers PN, Beck L, Miller M, et al. Acromial morphology is not associated with rotator cuff tearing or repair healing. *J Shoulder Elbow Surg.* 2020;29:2229–2239.
- Chalmers PN, Salazar D, Steger-May K, Chamberlain AM, Yamaguchi K, Keener JD. Does the critical shoulder angle correlate with rotator cuff tear progression? *Clin Orthop Relat Res.* 2017;475:1608–1617.
- Park MC, ElAttrache NS, Tibone JE, Ahmad CS, Jun BJ, Lee TQ. Part I: footprint contact characteristics for a transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. *J Shoulder Elbow Surg.* 2007;16:461–468.
- Park MC, Tibone JE, ElAttrache NS, Ahmad CS, Jun BJ, Lee TQ. Part II: biomechanical assessment for a footprint-restoring transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. *J Shoulder Elbow Surg.* 2007;16:469–476.
- Hein J, Reilly JM, Chae J, Maerz T, Anderson K. Retear rates after arthroscopic single-row, double-row, and suture bridge rotator cuff repair at a minimum of 1 Year of imaging follow-up: a systematic review. *Arthroscopy.* 2015;31:2274–2281.
- Hashiguchi H, Iwashita S, Sonoki K, Abe K, Yoneda M, Takai S. Clinical outcomes and structural integrity of arthroscopic double-row versus suture-bridge repair for rotator cuff tears. *J Orthop.* 2018;15:396–400.
- 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;87:1229–1240.
- Garcia GH, Liu JN, Wong A, et al. Hyperlipidemia increases the risk of retear after arthroscopic rotator cuff repair. *J Shoulder Elbow Surg.* 2017;26:2086–2090.
- Lee YS, Jeong JY, Park CD, Kang SG, Yoo JC. Evaluation of the risk factors for a rotator cuff retear after repair surgery. *Am J Sports Med.* 2017;45:1755–1761.
- Shimokobe H, Gotoh M, Honda H, et al. Risk factors for retear of large/massive rotator cuff tears after arthroscopic surgery: an analysis of tearing patterns. *J Orthop Surg Res.* 2017;12:140.
- Nho SJ, Yadav H, Shindle MK, Macgillivray JD. Rotator cuff degeneration: etiology and pathogenesis. *Am J Sports Med.* 2008;36:987–993.
- Kumagai J, Sarkar K, Uthoff HK. The collagen types in the attachment zone of rotator cuff tendons in the elderly: an immunohistochemical study. *J Rheumatol.* 1994;21:2096–2100.