Fosbury Flop Tear of the Rotator Cuff:

Diagnostic Assessment with Magnetic Resonance Arthrography

Running Title: Fosbury Flop Tears

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Abstract

Objectives

The aim was to assess the diagnostic performance of magnetic resonance arthrography (MRA) of the shoulder for the detection of "Fosbury flop" tears.

Methods

All patients undergoing arthroscopic rotator cuff repair were considered as potentially eligible for inclusion in this prospective case series. Preoperative MRAs were consecutively performed and compared with intraoperative findings being the gold standard control. Two experienced musculoskeletal radiologists, blinded to the arthroscopic findings, independently analyzed all MRAs for the presence of typical signs of Fosbury flop tears.

Results

423 patients were included. Among this group, 11 presented a Fosbury flop tear with a prevalence of 2.6 %. Inter-observer agreement was considered as excellent for thickened tendon, tendon stump, fluid accumulation, abnormal fibers orientation, and adherences between tendon and bursa. The most sensitive and specific criterion was the tendon thickness (90.9%; CI: 62.3-98.4% and 97.1% CI: 95.0-98.3%, respectively).

Conclusions

Fosbury flop tear is an uncommon condition that should be recognized to allow optimal anatomic repair. MRA is a valuable tool in making the diagnosing of this lesser recognized type of rotator cuff tear. An abnormally thickened supraspinatus tendon tear should especially raise suspicion for a Fosbury flop tear of the posterosuperior rotator cuff.

Advances in knowledge

MRA is a valuable tool in making the diagnosing of Fosbury flop tears. An abnormally thickened supraspinatus tendon tear should especially raise suspicion for such lesion.

Keywords:

Shoulder arthroscopy; Magnetic resonance arthrography (MRA); Rotator cuff lesion; Fosbury flop tear; New tear pattern.

Abbreviations and acronyms:

None

Introduction

Shoulder pain and dysfunction is a common musculoskeletal problem with rotator cuff tears being one of the most common causes [1]. Rotator cuff lesions have substantial variability in location, tear pattern, functional impairment, and reparability. They can be categorized into four major groups based on involvement of the bone (Type A), tendon (Type B), musculotendinous junction (Type C) and muscle (Type D) [2]. Tearing of the tendon from the bone is the most common [2]. Full-thickness tears come in a variety of patterns often classified as crescent tears, L-shaped tears, reverse L-shaped tears, and U-shaped tears [3]. Recognizing the tear pattern is important in understanding the pathology in order to propose an adapted treatment and repair plan. A new full thickness tear pattern of the posterosuperior rotator cuff associated with reversal healing of the supraspinatus on its bursal side has been recently recognized [4, 5] and described as B3 lesions according to Lädermann et al. [2]. This unusual avulsion of the posterosuperior rotator cuff has been termed the "Fosbury flop" tear (Figure 1) [4]. The two series that analyzed specifically "Fosbury flop" tears both found a prevalence of 5% [4, 5]. Nevertheless, other large series of MRI or MRA analysis on the prevalence of posterosuperior rotator cuff lesions did not reported this particular pattern [6].

The purpose of this study was to assess the diagnostic performance of magnetic resonance arthrography (MRA) of the shoulder for the detection of Fosbury flop tear pattern of the rotator cuff with an arthroscopic correlation. The hypothesis was that MRA was a valuable tool in making the diagnosis of this lesser recognized type of rotator cuff tear.

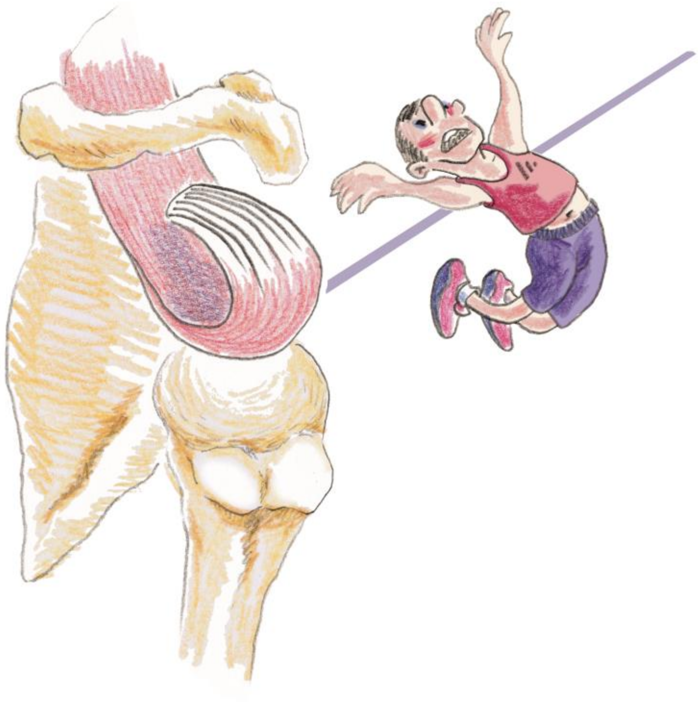

Figure 1: Illustration of a Fosbury flop tear.

Material and methods

Patients' selection

Between March 2012 and September 2015, all patients undergoing arthroscopic rotator cuff repair by an experienced orthopedic shoulder surgeon (AL) were considered as potentially eligible for inclusion in this prospective case series. The only exclusion criterion was whether the patients in which diagnosis was performed without MRA. Some patients have been previously reported [4]. This prior article dealt with the description of this new full-thickness tear pattern, the associated specific radiological signs and the arthroscopic rotator cuff repair technique, whereas in this manuscript we report on the diagnostic performance of MRA for the detection of Fosbury flop tear pattern. The study protocol was approved by our institutional Ethics Committee (AMG: 12-26) and all patients gave written informed consent.

MRA procedure

After local anesthesia, 2 ml (300 mg iodine per milliliter) of ionic contrast media (Lopamiro 300, Bracco, Plan-les-Ouates, Switzerland), followed by 10 ml of diluted gadopentate dimeglumine (Magnevist, Bayer, Basel, Switzerland) with a concentration of 2 mmol/l were injected inside the shoulder joint under fluoroscopic guidance. MRAs were performed with a 1.5T system (MR450 W, General Electrics, Milwaukee, USA) or a 3T system (Philips Achieva, Eindhoven, Netherlands). A dedicated shoulder coil was used. Imaging parameters are detailed in Tables 1 and 2.

Image analysis

Preoperative MRAs were consecutively performed and compared with intraoperative findings being the gold standard control. All MRAs were independently analyzed by two experienced musculoskeletal radiologists (KFC and KA). They were blinded to the arthroscopic findings. The rotator cuff morphology was assessed qualitatively. The presence of MRA findings that seem to typically describe the Fosbury flop tear [4] were systematically evaluated by each reader: the maximum thickness of the full torn tendon was measured in millimeters in the coronal plane (Figure 2), the presence of adherences between the bursal tendon side and the wall of the subacromial bursa (Figure 3), the presence of fluid accumulation in the superomedial part of the subacromial bursa and the visualization of a tendon stump with superomedial orientation (Figure 4) were reported. Finally, the presence of an abnormal orientation of the fibers in the tendon stump in the coronal plane (see Figures 3 and 4) was also reported.

Figure 2: Coronal T2 weighted MRA image with fat saturation of a right shoulder. A complete tear and retracted supraspinatus tendon is observed. The tendon stump is abnormally thickened (9 mm) which should raise suspicion for a Fosbury flop tear.

Figure 3: Coronal T1 weighted MRA image with fat saturation of a right shoulder demonstrates adhesions between the bursal side of the tendon and the wall of the subacromial bursa (red arrow), and abnormal orientation of the fibers stump (yellow arrow).

Sample size calculation

Because a Fosbury flop tear is a rare condition described with a prevalence of 5% [4], the sample size will be important for specificity, but quite low for sensitivity. An expected sensitivity of 80% was estimated from a pilot analysis (unpublished results). The sample size was thus estimated upon the determination of the acceptable width of the confidence interval of sensitivity, which was fixed at 12% for each arm. A sample size of 11 patients with a Fosbury flop tear was calculated with epitools online calculator (*epitools.ausvet.com.au/*). It was therefore decided to stop the patient's recruitment when the quota of 11 was reached.

Figure 4: Coronal intermediate weighted MRA image without fat saturation of a right shoulder demonstrates the tendon stump projecting on the top of the superomedial part of the subacromial bursa (arrow). A two-layered structure and the stump is readily identifiable.

Statistical analysis

Statistical analysis was performed with R v3.2.2 Portable (Free Software Foundation Inc, Vienna, Austria). Agreement between the two experienced radiologists verifying the presence of radiological signs was assessed using Cohen's Kappa (*K*) and intraclass correlation coefficients, which were interpreted as described by Landis and Koch [7]. In the case of a discordant observation, consensus was made between the two radiologists. Then, the sensitivity, specificity, positive predictive value, negative predictive value and accuracy were calculated for each radiological criterion, as well as their corresponding confidence intervals. ROC curve was plotted for each combination of radiological criteria.

Results

From the 500 patients meeting inclusion criteria, 77 were excluded because MRA was not performed (i.e., rotator cuff tear evaluation was performed with MRI, ultrasound or computed tomography arthrogram). Therefore, 423 patients (202 females and 221 males) with a mean age of 56 ± 10 years old (range, 21 to 82 years) were selected for analysis. The median timing between MRA and surgery was 82 days (range, 2 to 337 days). Among this group, 11 presented a Fosbury flop tear with a prevalence of 2.6 ± 1.5 %. Two of the 11 patients have been previously reported [4].

Inter-observer agreement

Inter-observer agreement was considered as excellent for tendon thickness (K=0.81), tendon stump (K=0.93), fluid accumulation (K=0.89), fiber orientation (K=0.89), and adhesion between tendon and bursa (K=0.87). While reviewing the 423 patients, consensus was necessary in 12 cases for tendon thickness, 4 cases for tendon stump, 22 cases for fluid accumulation, 6 cases for fiber orientation, and 22 cases for adhesion between tendon and bursa.

Prevalence of radiological criteria

Table 3 shows the prevalence of Fosbury signs in the whole patients' sample, as well as in the subgroups of patients with and without arthroscopically recognized Fosbury flop tear. Mean tendon thickness for the patients without Fosbury flop tear was 5.4 ± 1.3 mm, mean thickness in patients with a Fosbury flop tear was 9.1 ± 2.2 mm.

Sensitivity analysis

In the sensitivity analysis of the five described radiological criteria, most sensitive isolated criteria for diagnosing a “Fosbury flop tear” were tendon thickness (90.9%; CI: 62.3-98.4%) and tendon stump (90.9%; CI: 62.3-98.4%) (Table 4). Note that the sensitivities are equivalent because the proportion of those two criteria are identical into the “Fosbury flop tear” subgroup (see Table 3). However, the most specific criterion was tendon thickness (97.1% CI: 95.0-98.3%). Even if the presence of one of the five criteria showed a sensitivity of 100% (CI: 74.1-100%) and the presence of five of the five criteria showed a specificity of 98.5% (CI: 96.9-99.3%), no combination of radiological criteria showed both sensitivity and specificity as performant as the tendon thickness. Indeed, as illustrated in the ROC curve (Figure 5), the tendon thickness criterion is closest to the upper left corner of the plot than the presence of any other criteria.

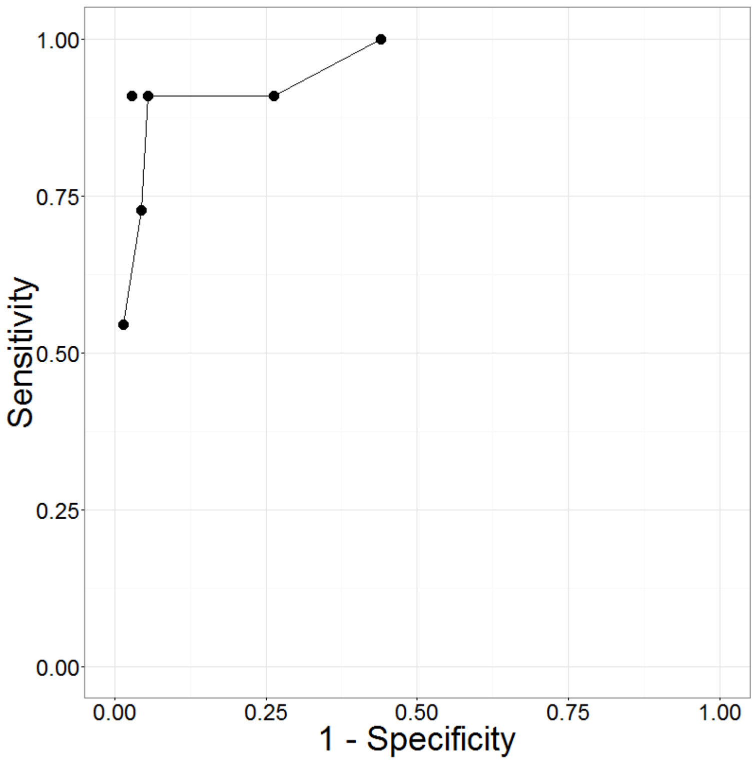

Figure 5: ROC curve, depending on the number of positive radiological criteria. *Single point*, tendon thickness ≥ 9 mm. *Curve*, combination of the five radiological signs.

Discussion

While the Fosbury flop tear is an uncommon rotator cuff tear, radiologists and orthopedic surgeons must be aware of this tear pattern. Failure to recognize this type of tear will lead to a non-anatomic repair or even the inability to achieve repair. Among the five different radiological criteria reviewed by the two musculoskeletal radiologists, the sensitivity analysis showed that tendon thickness is the most accurate MRA sign for diagnosing a Fosbury flop tear.

In the present study, the mean tendon thickness for the patients without Fosbury flop tear was 5.4 ± 1.3 mm. Similar values have been found in other studies. Aktuk et al. found a mean supraspinatus thickness of 4.9 ± 0.4 mm in a control group [8]. In our study, the mean thickness in patients with a Fosbury flop tear was 9.1 ± 2.2 mm. The effect of pathologies on tendon thickness is not well known. Theoretically, it could be related to tear, tendinopathy, diabetes in relation to retraction, edema or structural changes in tendon collagen. Meyer et al. demonstrated that musculotendinous retraction in chronic tears results mainly from shortening without thickening [9]. Another study reported that diabetes increased tendon thickness up to 6.6 ± 1.2 mm compared to a control group [8]. To our best knowledge, Fosbury flop tears are consequently the only condition that creates such an increase in tendon thickness.

Compared to tendon thickness only, the most efficient combination of radiological signs, including the presence of all five signs, allows an increase of specificity from 97.8 to 98.5, but the cost is a decrease of sensitivity from 90.9 to 54.5 (Figure 5). The sensitivity analysis shows an excellent sensitivity (90.9, CI: 95.0-98.3) and an excellent negative predictive value (99.8, CI: 98.6-100) for tendon thickness. However, falsepositive events are not uncommon, as the positive predictive value (45.5, CI: 26.9-65.3) is quite low. The excellent interobserver reliability shows that all radiological signs of interest are reproducible, especially tendon thickness.

Strength and limitations

The major strength of this study is the prospective design comparing patients with and without Fosbury flop tear with arthroscopic correlation. Furthermore, it has been shown that MRA is highly accurate in the diagnosis of full-thickness rotator cuff tears using arthroscopy as the gold standard [1]. Moreover, the sample size is relatively large in relation to an uncommon pathology. However, we acknowledge several limitations in our study. First, the confidence intervals for sensitivity remain quite wide due to the limited number of patients having a Fosbury flop tear. Second, MRIs were performed with arthrography and with different systems (1.5T vs. 3T). Conventional MRI [1, 10] and particularly 3D MRI may improve the accuracy of rotator cuff tear shape characterization. [11] Nonethess, MRI remains a sensitive and specific tool for the diagnosis of full-thickness tear of the rotator cuff and in our experience Fosbury flop tears can be diagnosed accurately without arthrography. Third, nearly one year could have passed between the MRA and the surgery, leading to a potential evolution of the rotator cuff tears.

Conclusion

Fosbury flop tear is an uncommon rotator cuff tear pattern that should be recognized to achieve anatomic rotator cuff repair. MRA is a valuable tool in the preoperative recognition of this tear pattern. An abnormally thickened supraspinatus tendon tear should especially raise suspicion for a Fosbury flop tear of the posterosuperior rotator cuff.

Source of funding

None

Conflict of interest

None

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Table 1: MRI sequences with their imaging parameters acquired on the 1.5T system (GE MR450W).

MRI Sequences	Imaging Parameters
Coronal T2 weighted propeller fast spin-echo with fat saturation	Section thickness 3.5 mm; gap 0.5 mm; TR/TE msec 4045/103; field of view, 16x16 cm; matrix 320 × 320; 3 signal acquired
Sagittal T2 weighted propeller fast spin-echo with fat saturation	Section thickness 3.5 mm; gap 0.5 mm; TR/TE msec 4934/96; field of view, 16x16 cm; matrix 288 × 288; 3 signal acquired
Coronal intermediate weighted propeller fast spin-echo with fat saturation	Section thickness 3.5 mm; gap 0.5 mm; TR/TE msec 2099/47; field of view 16x16 cm; matrix 288 × 288; 3 signals acquired
Coronal T1 weighted fast spin echo with fat saturation	Section thickness 3.5 mm; TR/TE msec 643/9; field of view, 16x16 cm; matrix 320 × 224; 2 signal acquired
Transverse T1 weighted fast spin echo with fat saturation	Section thickness 3.5 mm; gap 0.5 mm; TR/TE msec 641/9; field of view, 16x16 cm; matrix 320 × 224; 2 signal acquired
Sagittal T1 weighted fast spin-echo without fat saturation	Section thickness 3.5mm; TR/TE msec 562/10; field of view 16x16 cm; matrix 320 × 224; 1 signal acquired
Transverse 3D MERGE*	Section thickness 2 mm; no intersection gap; TR/TE msec 40/18; flip angle 7°; field of view, 19x19 cm; matrix 288 × 224; 2 signal acquired

* Multiple Echo Recombined Gradient Echo

Table 2: MRI sequences with their imaging parameters acquired on the 3T system (Philips Achieva).

MRI Sequences	Imaging Parameters
Coronal intermediate weighted fast spin-echo with fat saturation	Section thickness 3 mm; gap 0.8 mm; TR/TE msec 2679/35; field of view, 13x13 cm; matrix 528 × 528; 4 signal acquired
Transverse intermediate weighted fast spin echo with fat saturation	Section thickness 3 mm; gap 0.8mm; TR/TE msec 3613/30; field of view, 13x13 cm; matrix 512 × 512; 3 signal acquired
Sagittal T1 weighted fast spin-echo without fat saturation	Section thickness 3 mm; gap 0.8 mm; TR/TE msec 694/20; field of view, 14x14 cm; matrix 640 × 640; 2 signal acquired
Coronal T1 fast spin-echo with fat saturation	Section thickness 3 mm; gap 0.7 mm; TR/TE msec 687/8,9; field of view 13x13 cm; matrix 672x672; 3 signals acquired
Ultrafast isovoxel spoiled gradient echo (Thrive)	Section thickness 0.7 mm; TR/TE msec 11,2/5; field of view 18x18 cm; matrix 256 × 256; 1 signal acquired

Table 3: Prevalence of Fosbury flop tear MRA signs.

	Patients diagnosed with Fosbury flop tear (n = 11)	**Patients with other rotator cuff tears (n = 412)**	**Whole patients sample (n = 423)**
Thickened tendon (> 9mm)	10 (91%)	8 (2%)	18 (4%)
Tendon Stump	10 (91%)	15 (4%)	25 (6%)
Fluid accumulation	9 (82%)	111 (27%)	120 (28%)
Abnormal fibers orientation	9 (82%)	14 (3%)	23 (5%)
Adherences between tendon and bursa	7 (64%)	78 (19%)	85 (20%)

Table 4: Sensitivity analysis for the radiologic assessment of supraspinatus Fosbury tear.

	Sensitivity	**Specificity**	**PPV**	**NPV**	**Accuracy**
Thickened tendon (> 9mm) (A)	90.9 (62.3 98.4)	97.1 (95 98.3)	45.5 (26.9 65.3)	99.8 (98.6 100)	96.9 (94.8 98.2)
Tendon stump (B)	90.9 (62.3 98.4)	94.7 (92 96.4)	31.2 (18 48.6)	99.7 (98.6 100)	94.6 (92 96.3)
Fluid accumulation (C)	81.8 (52.3 94.9)	58.5 (53.7 63.2)	5 (2.7 9.2)	99.2 (97 99.8)	59.1 (54.4 63.7)
Abnormal fibers orientation (D)	81.8 (52.3 94.9)	94.9 (92.3 96.6)	30 (16.7 47.9)	99.5 (98.2 99.9)	94.6 (92 96.3)
Adherences between tendon and bursa (E)	63.6 (35.4 84.8)	70.6 (66.1 74.8)	5.5 (2.7 10.9)	98.6 (96.6 99.5)	70.4 (65.9 74.6)
One of A, B, C, D, and E	100 (74.1 100)	54.9 (50 59.6)	5.6 (3.1 9.7)	100 (98.3 100)	56 (51.3 60.7)
Two of A, B, C, D, and E	90.9 (62.3 98.4)	72.1 (67.6 76.2)	8 (4.4 14.1)	99.7 (98.1 99.9)	72.6 (68.1 76.6)
Three of A, B, C, D, and E	90.9 (62.3 98.4)	94.4 (91.8 96.3)	30.3 (17.4 47.3)	99.7 (98.6 100)	94.3 (91.7 96.2)
Four of A, B, C, D, and E	72.7 (43.4 90.3)	95.9 (93.5 97.4)	32 (17.2 51.6)	99.2 (97.8 99.7)	95.3 (92.8 96.9)
All of A, B, C, D, and E	54.5 (28 78.7)	98.5 (96.9 99.3)	50 (25.4 74.6)	98.8 (97.2 99.5)	97.4 (95.4 98.5)

In parenthesis: 95% confidence intervals. *PPV*, positive predictive value; *NPV*, negative predictive value.