The Radiohumeral Synovial Fold: Analysis with 3D Isotropic MR Imaging in 80 Asymptomatic Subjects

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Abstract

Purpose: To evaluate prospectively the size of the synovial fold protruding into the radiohumeral joint using 3D isovoxel MR imaging in asymptomatic volunteers, and to find a new reference value of the synovial fold on MR imaging.

Materials and methods: Eighty asymptomatic volunteers (36 women, 44 men; age range, 23–56 years; median age, 39; 20 patients in each decade from 20s to the 50s) were examined in this study. MR imaging of both sides of the elbow was performed using 3D isovoxel fast field-echo sequence with selective water excitation. The width of the synovial fold, which is defined as the distance between the tip of the synovial fold and the outer edge of the radial head, was measured at eight locations on the radiohumeral joint. We analyzed the relationship between the results and age, sex, and handedness.

Results: The posterior synovial fold was largest (range, 0.2–11.6 mm; median, 6.9 mm; 95th percentile, 10.0 mm). The width of the lateral synovial fold and posterolateral synovial fold was larger in patients in their 50s than in their 20s (p < 0.05 and p < 0.01, respectively).

Conclusion: Most normal synovial folds are smaller than 10.0 mm in width. Aging is a factor which influences the width of lateral to posterolateral synovial folds.

Key words

elbow, radiohumeral joint, synovial fold, synovial plica, MRI

Introduction

Lateral epicondylitis is the most common cause of lateral elbow pain. It is considered to be tendinosis, a degenerative process that is histopathologically characterized by the presence of active fibroblasts, vascular hyperplasia, and disorganized collagen at the origin of the extensor carpi radialis tendon. Synovial fold impingement occurring between the radial head and capitellum is considered to be a possible contributing pathological factor in recalcitrant lateral epicondylitis. The synovial fold of the radiohumeral joint may hypertrophy, resulting in not only snapping but also posterolateral elbow impingement syndrome. Radiohumeral joint synovial folds, also known as synovial fringe or plicae, are thought to be physiological remnants of embryonic septae that formed during development and are interposed within the radiohumeral joint space. Furthermore, both embryonic and cadaveric anatomical studies have demonstrated synovial folds to be attached to the annular ligament-joint capsule complex and presented with anterior and posterior folds. Lateral folds observed in adults usually appear to be hardened and hyalinized, most likely attributable to the repeated compression stress caused by radial head movements dur-
Several reports have documented the normal MR imaging features of the radiohumeral synovial fold\textsuperscript{3,10} and the 90th percentile for the craniocaudal dimension of the posterolateral fold was 2.6 mm\textsuperscript{9}. Since the synovial fold is interposed between the capitellum and radial head, we believe that its width, which is characterized by the distance between the articular capsule and tip of the fold, might represent a reference value that could potentially predict the risk of mechanical impingement. To our knowledge, there is no previous report in the literature documenting the normal range of width of synovial folds on MR imaging. However, the boundaries of the articular capsule and soft tissue around the radiohumeral joint are not always clearly delineated on MR imaging and may make accurate synovial fold width measurement a difficult task to perform. Therefore, we substituted the outer edge of the radial head with the articular capsule for a better and more accurate assessment of the synovial fold width. Synovial fold syndrome patients have reported pronounced lateral elbow pain during elbow extension and forearm pronation\textsuperscript{11}\textsuperscript{12} possibly due to the pronation-to-supination movement of the proximal radioulnar joint which may consequently affect synovial fold width. We utilized a 3D isovoxel fast field echo with water selective excitation (3D FFE WATS) sequence image acquisition to obtain multi-directional images of synovial fold with elbow extension and forearm pronation, and tried to search the location of the maximum width of synovial fold within the radiohumeral joint on MR imaging. Thus, the purpose of this study was to find an easy-to-use reference value of synovial fold of the radiohumeral joint on MR imaging. We also investigated the relationship between the width of the synovial fold and aging, sex, and handedness.

Materials and methods

Asymptomatic subjects

This study obtained institutional review board approval and informed consent from each volunteer (the approval number of 1453). Eighty asymptomatic volunteers (36 women, 44 men; age range, 23–56 years; mean age, 38; median age, 39) were prospectively examined in this study. In order to investigate and compare synovial fold sizes, all patients (n=80) were selected and categorized into 4 age groups of 10-year increments: 20 (n=20), 30 (n=20), 40 (n=20), and 50 (n=20) years of age. All eighty elbows underwent bilateral examination making a total of n=160 elbows for this present study. Two subjects were left-handed (2.5%) and 78 were right-handed (97.5%). The inclusion criteria were as follows: (1) no elbow pain, (2) no recent (less than 3 months) visit to healthcare professional for pain involving elbow and (3) never been involved in any sport activity beyond a recreational level. On physical examination, no subject reported either signs of tenderness at the elbow region or positive pain provocative tests for lateral epicondylitis after applying the Thomsen and middle finger extension test. Fringe impingement test for synovial impingement syndrome was also negative in all patients\textsuperscript{12}.

MR imaging

MR imaging was performed with a 1.5-T magnet (Gyrosan Intera/Achiva; Philips Medical Systems, Best, the Netherlands) using the Microscopy coil (inner diameter, 47 mm; Philips Medical Systems). The subjects were examined in the supine position with the elbow extended and forearm pronated. The Microscopy coil was placed on the lateral dorsal aspect of the radiohumeral joint. One side was examined, and then the other. Coronal T2-weighted images (repetition time, 3600 ms; echo time, 110 ms; field of view, 80 mm; number of averaging, 4; slice thickness, 2 mm; and matrix, 203 x 256) and 3D FFE WATS sequence (repetition time, 14.7 ms; echo time, 7.1 ms; flip angle, 40 degrees; field of view, 60 mm; number of averaging, 2; resolution, 0.5 x 0.5 x 0.5 mm; and matrix, 120 x 120) were obtained. No intravenous or intra-articular contrast was provided.

Quantitative analysis of MR image

Quantitative measurement of MR imaging was performed by a radiologist using 3D workstation (Ziosoft Inc, Tokyo, Japan). 3D FFE WATS imaging with multiplanar reformats was obtained for measurement of the width of the synovial fold of the radiohumeral joint. We measured the width of the synovial fold at eight locations; anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), lateral (L), and anterolateral (AL) (Fig. 1). To measure the width of the synovial fold, the outer edge of the radial head was used in substitution for the position of the articular capsule. We defined that the distance between the outer edge of the radial head and the tip of the synovial fold is the width of synovial fringe (Fig. 2). The width of the lateral synovial fold was measured on coronal T2-weighted image, which corresponds to the lateral
Figure 1. Coronal T2 weighted image (a) shows the reference line of reformatted axial 3D FFE WATS image at the level of proximal radioulnar joint (b). Four lines divide the articular surface of the radial head into eight equal areas (b). On these lines, the eight locations on the radial head are defined as anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), lateral (L), and anterolateral (AL). Reformatted oblique sagittal images of the radiohumeral joint demonstrate synovial folds at eight locations (arrows in c to f). **= biceps tendon, *= brachialis tendon.
For measuring the width of the synovial fold at eight locations, the outer edge of the radial head is used in substitution for the position of the articular capsule. We draw a projection line on the outer articular surface of the proximal radioulnar joint (solid line) perpendicular to the articular surface of the radiohumeral joint at the radial head (broken line). This projection line is considered the outermost edge of the radial head. The distance between the projection line and the tip of the synovial fold protruding articular cavity is regarded the width of the synovial fold (*). This is the same image as Fig. 1e.

The width of the synovial fold on reformatted coronal 3D FFE WATS image, to access intersequence reliability. All measurements were performed with electronic calipers.

Statistical analysis

Intersequence reliability was used to clarify that the measurement of the width of the synovial fold was not influenced by the sequence of MR imaging. Statistical correlation in measurement of the size of the lateral synovial fold between T2-weighted and 3D FFE WATS sequence imaging was analyzed by correlation coefficient. The frequency and width of the synovial fold in eight locations were noted. Means, medians, ranges, and 10th and 95th percentiles were calculated. The relationships between the width of the synovial fold and decade of age were analyzed using the Steel test. The Mann-Whitney U test was used to assess the relationship between the width of the synovial fold and sex and handedness. A p-value of less than 0.05 was considered to indicate a statistically significant difference. Statistical calculations were performed using JMP 9 (SAS Institute Inc.).

Results

Lateral synovial fold width measurement between T2-weighted and 3D FFE WATS sequence imaging displayed a strong correlation ($r = 0.890$). The anterior, anterolateral, lateral, posterolateral, posterior, and anteromedial synovial folds were present in all examined elbows. The medial synovial fold was identifiable only in 9 (5.6%) out of 160 elbows. The posteromedial synovial fold was observed in 102 (63.7%) elbows. The mean, median, minimum and maximum width, and 10th and 95th percentile of the synovial fold of the radiohumeral joint at eight locations (A, AM, M, PM, P, PL, L, and AL) are presented in Table 1. The posterior synovial fold is largest, with a median width of 6.9 mm (range, 0.2–11.6 mm), followed by the posterolateral fold, with a median width of 6.7 mm (range, 2.6–9.4 mm) and the lateral synovial fold, with a median width of 4.7 mm (range, 0.2–8.8 mm). The 95 percentile of the poste-

| Table 1. The Width of the Synovial Fold of the Radiohumeral Joint at Eight Locations |
|------------------------------------|---------------|---------------|----------------|----------------|---------------|---------------|---------------|---------------|
|                                   | A             | AM            | M             | PM            | P             | PL            | L             | AL            |
| Mean (mm)                         | 4.2           | 4.0           | 0.2           | 3.2           | 6.8           | 6.6           | 4.7           | 3.7           |
| Median (mm)                       | 4.0           | 3.8           | 0.0           | 2.7           | 6.9           | 6.7           | 4.7           | 3.6           |
| Range (mm)                        | 1.1 - 9.3     | 1.5 - 12.4    | 0 - 7.5       | 0 - 11.4      | 0.2 - 11.6    | 2.6 - 9.4     | 0.2 - 8.8     | 1.0 - 9.5     |
| 10 percentile (mm)                | 2.5           | 2.5           | 0.0           | 0.0           | 3.6           | 4.8           | 3.4           | 1.9           |
| 95 percentile (mm)                | 6.5           | 6.0           | 1.4           | 8.3           | 10.0          | 8.6           | 6.4           | 6.2           |

anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), lateral (L), anterolateral (AL)
rior fold was 10.0 mm.

Statistical analysis for the relationship between the width of the synovial fold and age group was performed at seven locations (A, AM, PM, P, PL, L, and AL) because of the small number of measurable medial synovial folds (3 in patients in their 20s, 3 in their 40s, and 3 in their 50s). Synovial folds exhibited a statistically significant difference in size between the 20 and 50 year-old groups with the lateral (p < 0.05) and posterolateral folds (p < 0.01) being considerably larger in the latter group (Fig. 3). Furthermore, no statistically significant difference between synovial fold size and sex or handedness was found (Table 2).

Discussion

In this study we evaluated 160 elbows, found the presence of synovial folds in the radiohumeral joint, and, also in accordance with previous reports\(^{(8,12,13)}\), revealed that the posterior and posterolateral folds were respectively the largest synovial fold detected on MR imaging. Cadaveric and embryonic investigation by Isogai et al. concluded that synovial folds were found to be attached to the annular ligament-joint capsule complex and to protrude within the radiohumeral interspace. Furthermore, the lateral folds were located on the proximal edge of the annular ligament and present in adults only while the posterior folds were generally longer, wider, extended more laterally, and were interposed more deeply within the radiohumeral joint than the anterior folds\(^{(8)}\). In a separate study on 49 fresh cadaveric elbows, Koh et al. reported the presence of radiohumeral synovial folds in all their specimens, with the posterior folds being larger than the anterior\(^{(13)}\). Similarly, Ando et al. documented the presence of synovial folds within the radiohumeral joint and, in 70% of all cases, found larger synovial folds in the posterolateral region\(^{(2)}\).

In this study, the 95 percentile of the posterior fold width measured 10.0 mm on MR imaging and represented the largest synovial fold. Hence, ‘normal’ synovial fold size commonly measures less than 10 mm in width. We believe that this is the first report of the width of the synovial fold being used for reference value of the size of the synovial fold on MR imaging and could be easily applied in clinical practice. The accurate measurement of the posterior synovial fold appears to vary widely, and some authors reported it as ranging from 2.1 to 11.0 mm (mean, 4.4 mm)\(^{(8)}\) while others stated 5.2 ± 1.3 mm\(^{(13)}\). Our results were slightly larger (range, 0.2–11.6 mm; mean, 6.8 mm). We attribute this discrepancy to the lack of a clear and easy method where the junction between the synovial fold and articular capsule could be precisely identified on MR imaging. However, anatomic\(^{(8,12)}\) and arthroscopic\(^{(14)}\) assessments showed continuity between the synovial fold and the articular capsule on the proximal edge of the annular ligament, which may not always be readily and accurately identifiable on MR imaging. To this end, during our measurement process, and for the purpose of practicality, we replaced the articular capsule by the articular surface of the radial head at the proximal radiohumeral joint as the outer edge of the synovial fold. In this way, the latter could be easily recognized on MR imaging and readily measurable, despite the fact that it may cause a slight overestimation of the synovial fold size.

Normal MR imaging reveals the synovial folds as a hypointense structure protruding within the radiohumeral articular cavity. There is a significant overlap in size between symptomatic and asymptomatic folds\(^{(9,15)}\). Husarik et al. assessed the size of the synovial fold in 60 asymptomatic subjects. They measured the size of the posterolateral fold in craniocaudal diameter on a sagittal image and in mediolateral diameter on a coronal image. The median size of the posterolateral plica was 4.3 x 1.9 x 3.9 mm (sagittal x craniocaudal x mediolateral dimensions). Because of high prevalence of the posterolateral fold in asymptomatic subjects, they speculated that the mere presence of a posterolateral fold may not explain clinical symptoms and that the size of the synovial fold should be considered. They proposed a cutoff value of 3 mm for thickened folds\(^{(9)}\). A recent study comparing synovial fold thickness between synovial fringe syndrome and control subjects revealed a significant correlation between the presence of plicae thicker than 2.6 mm and synovial fold syndrome\(^{(10)}\).

We performed MR imaging with the forearms in the pronated position and elbows fully extended under the assumption that this would increase the tension of the anterior articular capsule, hence displacing and trapping the synovial fold within the radiohumeral joint. Pronation of the forearm could produce tension in the muscles overlying the articular capsule at the radiohumeral joint\(^{(11)}\). We believe that this position would allow a larger protrusion of the synovial fold and better visualization on imaging since this study is intended to investigate and define the normal range, especially the upper limit of the normal range of the size of synovial folds.
Another notable result of this study is that the lateral and posterolateral synovial folds appeared to be larger in subjects in their 50s than in their 20s. Iso-gai et al. reported that, although the anterior and posterior folds could be identified in both embryos and adults, lateral folds could in no instance be identified in embryos. Furthermore, anterior folds were shorter and narrower in the adult population, while the posterior folds were generally longer and wider, extended more laterally, and interposed deeply into the radiocapitate joint than were anterior folds. The authors suggest that the lateral fold formation may be the result of repeated extension-compression stress exerted on the elbow as an adaptive mechanism allowing for full range joint movement, despite the alterations caused by aging elbow joint and surrounding supporting tissues. Our results concur with this theory.

Contrary to our expectations, neither handedness nor gender manifested any statistically significant difference in synovial fold size, although we speculated that a possible difference in size might exist due to the increased amount of mechanical stress sustained by the dominant side as opposed to the non-dominant side. However, Husaik et al. reported that the cranio-caudal dimension of the posterolateral plica was significantly larger in men than in women, and no rela-

Figure 3. Relationships between the width of the synovial fold and decade of age. The width of the anterior (a), anteromedial (b), posteromedial (c), posterior (d), posterolateral (e), lateral (f), and anterolateral (g) synovial folds in subjects in their 20s, 30s, 40s, and 50s are presented. The width of posterolateral (e) and lateral (f) synovial folds are larger in subjects in their 50s than in their 20s (*p < 0.01, *p < 0.05, Steel test).
tionship was found between age and the size of the synovial fold. The reason for the difference between their results and our results is unclear. However, the difference in size parameters might be part of the reason; Husaik used thickness while we used width.

Elbow synovial fringe syndrome occurs by impingement of the synovial fold in radiohumeral joint and can be clinically confused with lateral epicondylitis. Mullett et al. analyzed 30 patients who had recalcitrant symptoms of lateral epicondylitis and synovial fold impingement in radiohumeral joint at arthroscopic surgery. They observed a collar-like band of radiocapitellar capsular complex that subluxated into the radiocapitellar joint with manipulation under arthroscopy. Most of these patients experienced some pain relief due to resection of this collar-like band structure. The synovial fold is a distinct entity from the annular ligament and is contiguous with the joint capsule, which fuses with the common extensor tendon forming an enthesis at the lateral epicondyle. This explains the deteriorating effect caused by lateral epicondylitis of the common extensor tendon which may consequently involve the synovial fold and hence induce hypertrophic changes. Similarly, Ando et al. confirmed a histological congruity between synovial fold and the articular capsule, sug-
suggesting that synovial fold invagination may have a direct implication in the pathological conditions of lateral epicondylitis. Nerve fibers were found in the deep part of the synovial fold close to the attachment on the capsule, which accounts for the associated pain. Five synovial folds from five operated patients with lateral epicondylalgia showed hypertrophic and increased number of nerve fibers. Debridement of the extensor carpi radialis brevis tendon with synovial fold excision is the accepted treatment method for recalcitrant lateral epicondylitis. However, a recent report argues that the debridement of the extensor carpi radialis brevis tendon accompanied by posterior synovial fold excision does not provide any additional symptomatic improvement when compared with the debridement of only the extensor carpi radialis brevis tendon. The relationship between lateral epicondylitis and synovial fold syndrome has not yet been fully elucidated. If there is additional reference value other than the thickness of the synovial fold in the radiohumeral joint on MR imaging, it might be useful for further investigation of the clinical importance of synovial folds.

The current study was performed using 3D isotropic resolution MR sequence, allowing for the evaluation of the synovial fold of the radiohumeral joint in multiple directions. This method may potentially represent a novel MR imaging approach to obtaining a measurable reference for the larger synovial folds that protrude into the radiohumeral joint space. Within a single imaging acquisition, isovoxel 3D sequence imaging with secondary multiplanar reformation promptly produces all imaging planes, considerably reducing examination time. This technique includes gradient echo sequence and, more recently, fast spin echo sequences with variable flip-angle that have been successfully applied in evaluation of the musculoskeletal system, the ankle, and the foot. After the advent of 3T MR scanner, enhanced signal-to-noise ratio, higher spatial resolution, and the greater contrast-noise ratio of intrinsic joint structures at higher field strength are possible supplementary ways to improve the diagnostic ability of 3D isotropic resolution imaging.

There were limitations in this study. First, our measurements of the width of the synovial fold may not represent the actual width of the fold itself. There was slight overestimation of the synovial fold size on MR imaging, compared to the results from the cadaveric study. Second, we performed MR imaging with elbows fully extended and pronated forearms, which could not be the standard MR imaging positioning for the elbow. Performing elbow MR imaging with the elbow extended and the forearm in a neutral or supinate position may underestimate width of the synovial fold because the synovial fold might be pulled back from the radiohumeral joint space in this position. Lastly, if there had been capsular distension by fluid, the synovial fold may have been pushed out from the radiohumeral joint space, causing underesti-

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anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posteroslateral (PL), lateral (L), anterolateral (AL)
In conclusion, we measured the distance between the outer articular surface of the radial head in the proximal radioulnar joint and the tip of the synovial fold of the radiohumeral joint on MR imaging using 3D FFE WATS sequence. Most normal synovial folds measure 10.0 mm or less. This could be used as a new reference value of the size of the synovial fold for evaluation of lateral elbow pain. The lateral and posterolateral synovial folds become wider with age.

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References


