ORIGINAL ARTICLE

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Evaluation of the Triangular Fibrocartilage in Cadaveric Wrists by Means of Arthrography, Magnetic Resonance (MR) Imaging, and MR Arthrography

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Purpose: To evaluate the diagnostic accuracy of arthrography, magnetic resonance (MR) imaging, and MR arthrography in the detection and localization of defects of the triangular fibrocartilage (TFC) in cadaveric wrists, using arthroscopy as a reference standard.

Material and Methods: Twenty-four specimen wrists were evaluated. The different imaging modalities were blinded to reviewers and were interpreted independently. A classification of TFC defects was used for the evaluation of images in the different imaging modalities, thus permitting a more uniform correlation. Two cases were excluded from the MR imaging study because of poor image quality. Contingency tables with the chi-square test and Fisher's exact test were used for statistical analysis.

Results: Defects of the TFC were identified in 17 of the 24 specimen wrists by means of arthroscopy, and 16 defects were observed when arthrography was carried out. With MR imaging 14 defects of the TFC were detected in the 22 specimen wrists evaluated, and with MR arthrography 16 defects were observed. Most defects were central or combined (two or more defects). In comparison to arthroscopy, the accepted diagnostic gold standard, the following results were found for arthrography in the detection of TFC defects: sensitivity 95%, specificity 100%, and accuracy 95% ($P<0.0005$); for MR imaging: sensitivity 86%, specificity 85%, and accuracy 70% ($P<0.002$); and for MR arthrography: sensitivity 100%, specificity 85%, and accuracy 95% ($P<0.0005$).

Conclusion: The results of the study seem to indicate that both arthrography and MR arthrography have high accuracy, and either would be useful for evaluation of the TFC. The combined approach using both techniques would have a very high accuracy equivalent to that resulting from arthroscopy.

Key words: Arthrography; arthroscopy; hand; magnetic resonance arthrography; magnetic resonance imaging; triangular fibrocartilage

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The diagnostic evaluation of patients with chronic wrist pain is a challenge for both radiologists and hand surgeons. Ulnar-side wrist pain is frequently caused by tears of the triangular fibrocartilage (TFC) (2, 14). For the detection of these lesions, several different imaging modalities are used: single, two-, or three-compartmental arthrography, magnetic resonance imaging (MRI), MR arthrography, and arthroscopy. Numerous studies using these diagnostic procedures have shown varying results (4, 6, 8, 9, 12, 13, 16, 17, 19–22, 24). Wrist arthroscopy is considered by many surgeons to be the gold reference standard (8, 12). However, the continuing controversy over the diagnostic management of this clinical problem, the choice of the imaging modality most appropriate for TFC evaluation, still presents a diagnostic dilemma. The classification of TFC lesions most often used is that described by PALMER (14), based on the localization and the cause of the lesion. The localization of the

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tear is useful in determination of the therapeutic option. Accordingly, for central or radial tears debriding is used, and for ulnar-peripheral tears reinsertion or sutures are recommended (14, 15, 20). In these localizations, arthrography is considered to be a procedure that often does not show the exact localization of the site of tear (10, 17). Likewise, MR imaging has its limitations for the definition of the exact site of the lesion, especially in the ulnar-peripheric area (7, 16). In all events, it is essential to be able to establish a reliable diagnostic protocol that will provide the useful information that will enable the clinician to make the most appropriate choice of treatment. The objective of this study was to determine the diagnostic accuracy of arthrography, MR imaging, and MR arthrography in the detection and precise localization of TFC defects, using arthroscopy of the wrist as a reference standard. We describe a simple classification of TFC defects to enable the uniform correlation of findings between the different imaging methods employed in this study.

Material and Methods

Cadaver specimens

After approval of the study by the Institutional Review Board, 24 specimen wrists, deep frozen at –40℃, harvested from different anonymous non-embalmed cadavers, were obtained. No information on age or clinical history was available. The specimens were allowed to thaw for 24 hours at room temperature. All specimens were examined with MR imaging, then radiocarpal arthrography, and finally MR arthrography. Arthroscopy was performed 12–24 hours after the imaging procedures.

Arthrographic procedure

All arthrographic procedures were carried out using the technique described by BERNÁ-SERNA et al. (1). An adhesive marker-plate with radiopaque coordinates was placed on the area of the wrist to determine the site for puncture (Fig. 1). Insertion of a 22-gauge or 25-gauge needle was carried out through the hole selected on the marker-plate. Between 2 and 4 ml of gadopentate dimeglumine (Magnevist; Schering, Berlin, Germany) were diluted in a 100-ml mixture containing 50 ml of sterile saline and 50 ml of iopramide (Ultravist 330; Schering, Berlin, Germany). Initially, we injected only a small amount of contrast material, and then progressively injected a volume of between 3 and 5 ml. During the procedure, appropriate spot

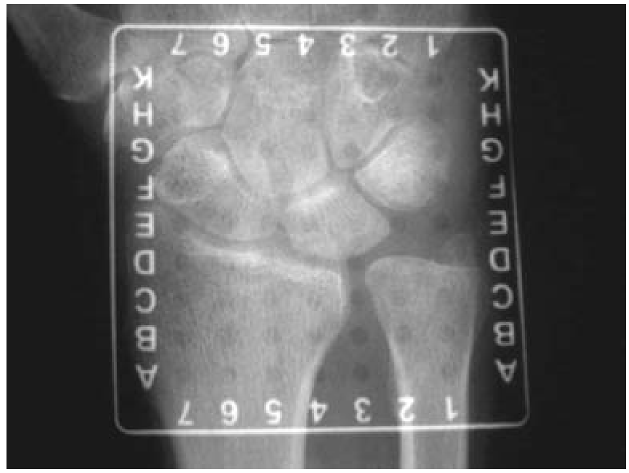

Fig. 1. The radiopaque coordinates in the area of the wrist.

fluoroscopic images were made, particularly in the early stages of the injection, to evaluate in detail any possible communication with the midcarpal joint and/or distal radioulnar joint. The arthrographic procedure was performed in 15 cases by a radiologist with 5 years' experience in wrist arthrography, and in the remaining nine cases by a resident who was learning the technique and who had observed the first 15 cases. Procedural times were recorded for each arthrography. Procedure time was defined as the time interval between the placement of the adhesive marker-plate on the skin of the wrist and the withdrawal of the needle.

MR imaging

MR imaging studies were performed using a 1.5T MR system (Signa; General Electric Medical Systems, Milwaukee, Wisc., USA) and a 3-inch (7.62-cm) surface coil. The protocol of conventional MR imaging comprises the following parameters: coronal spin-echo (SE) T1-weighted images (TR/TE 360/13, number of excitations (NEX) 3, matrix 256×192, echo-train length 16, field of view (FOV) 10×10 cm, 2.0 mm thickness/0.2 mm interspace); axial fast spin-echo (FSE) T2-weighted images (TR/TE 2640/102, NEX 4, matrix 256×192, echo-train length 16, FOV 10×10 cm, 2.0 mm thickness/0.2 mm interspace); and coronal FSE T2-weighted images with fat suppression (TR/TE 3000/103, NEX 4, matrix 256×192, echo-train length 16, FOV 10×10 cm, 2.0 mm thickness/0.2 mm interspace). The mean imaging time was 20 min.

The parameters used for MR arthrography were as follows: coronal SE T1-weighted images (TR/TE 360/13, NEX 4, matrix 256×192, echo-train length 16, FOV 10×10 cm, 2.0 mm thickness/0.2 mm interspace); coronal FSE T2-weighted images (TR/

TE 3000/104, NEX 4, matrix 256 × 192, echo-train length 16, FOV 10 × 10 cm, 2.0 mm thickness/0.2 mm interspace); and coronal FSE T2-weighted images with fat suppression (TR/TE 3000/104, matrix 256 × 192, FOV 10 × 10 cm, 2.0 mm thickness/0.2 mm interspace). The MR arthrographic examination was performed within 30 min of completion of the injection of contrast material. A musculoskeletal radiologist (J. A.) with 10 years' experience in the technique was responsible for both the MR imaging and the MR arthrographic examinations. Two cases were excluded because of poor image quality and failure to identify the TFC, probably as a result of problems with specimen conservation. Mean time for MR arthrography was 25 min, including the time taken for performing conventional arthrography.

Arthroscopy

All specimen wrists were subjected to standard radiocarpal arthroscopy by a hand surgeon (F. M.) with 10 years' experience in arthroscopy. All the arthroscopic examinations were recorded by means of videotape. Mean procedure time was approximately 15 min.

Image analysis

Findings observed in the different imaging methods were blinded among the observers. All MR imaging studies were evaluated by one observer (J. A.); the arthrograms were evaluated by one radiologist (J. D. B.); and the arthroscopic images were evaluated by the same surgeon who carried out the arthroscopy (F. M.). Based on the classification of the TFC lesions described by PALMER (14), the modified classification of PALMER (2), and a study of the characterization and localization of TFC defects by ZANETTI et al. (23), the following arthrographic classification of the defects of the TFC was established by consensus of the authors of the present study, with due regard to the morphology of the TFC and to any evidence of communication between the radiocarpal joint (RCJ) and the distal radioulnar joint (DRUJ).

This classification is made up of the following categories (Fig. 2):

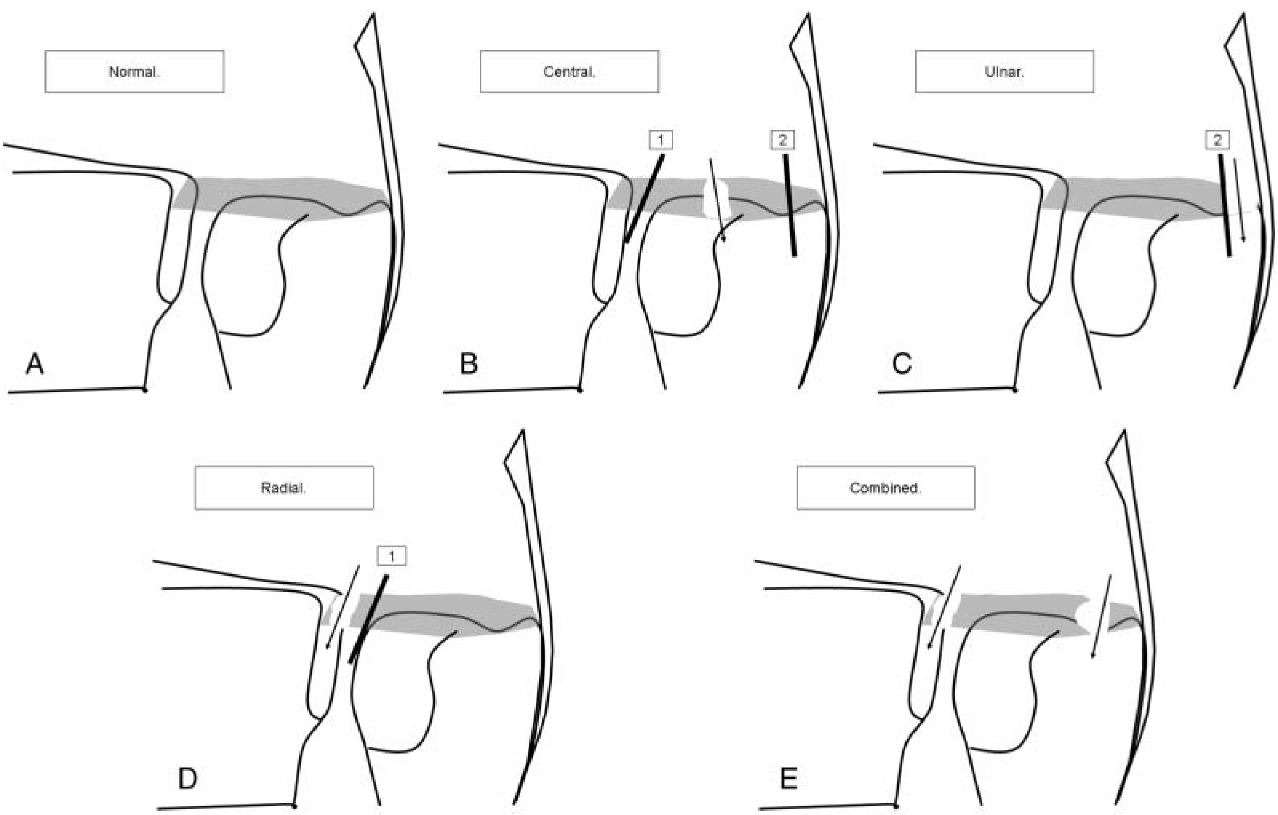

Fig. 2. Drawing illustrating the classification of arthrographic findings for the evaluation of the TFC. A. Normal TFC. Complete defect: central (B), ulnar (C), radial (D), and combined (E).

1) Normal: when the imaging reveals a TFC with smooth edges and when no communication is observed between the RCJ and the DRUJ.
2) Complete defect: when the imaging reveals a disruption of the TFC and/or communication is seen between the RCJ and DRUJ.

Additionally, to determine the localization of the defect, three portions of the TFC (ulnar, central, and radial) were established by tracing two imaginary lines at 3 mm distance both from the radial area of insertion (line 1) and the ulnar area of insertion (line 2). Based on the evidence of the localization of the defect observed in the TFC, the following types of defect were proposed:

- Central: when the defect is seen in the segment of the TFC between lines 1 and 2.
- Ulnar: when the defect is seen between the ulnar area of insertion and line 2.
- Radial: when the defect is seen between the radial area of insertion and line 1.
- Combined: when there is evidence of more than one type of defect (e.g., radial-central or ulnar-central).

The three observers (the two radiologists and the surgeon) evaluated the images using the criteria described above.

Statistical analysis

The statistical analysis was carried out with SPSS, version 12.0 (SPSS, Chicago, Ill., USA). The correlation between the imaging modalities was carried out using contingency tables with chi-square tests and Fisher's exact test. The sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of arthrography, MR imaging, and MR arthrography were assessed, using arthroscopy as the reference standard. $P<0.05$ was considered to be statistically significant.

Results

Tables 1 and 2 list the findings observed in the different imaging modalities employed in the present study and the statistical analysis, using wrist arthroscopy as the reference standard.

Arthroscopic findings

Arthroscopic findings showed TFC defects in 17 (70.8%) of the 24 specimen wrists under study. Distribution of defects was as follows: six central, one radial, one ulnar, and nine combined. The classification of the defects of the TFC employed in this study was a simple tool to establish the localization of the TFC defects. All tears identified by means of arthroscopy were confirmed on anatomic examination carried out by the same orthopedic surgeon.

Arthrographic findings

The arthrographic studies were satisfactory in all 24 specimen wrists. No extravasation of contrast material was seen in any of the cases. Mean procedure time was 4 min (range 3–7 min).

Findings seen in the arthrograms revealed TFC defects in 16 (66.6%) of the 24 specimen wrists. These defects were confirmed by arthroscopy. It was usually possible to determine the exact site of defects during the early phases of the examination (Fig. 3A). Using the classification described above,

Table 1. Detection of TFC defects with four different imaging modalities

TFC defects	Arthrography	MR imaging*	MR arthrography*	Arthroscopy
Normal	8	8	6	7
Central	7	7	8	6
Radial	2	2	1	1
Ulnar	0	0	0	1
Combined	7	5	7	9
Total	24	22	22	24

* Two cases excluded because of artifacts.

Table 2. Sensitivity, specificity, accuracy, and positive and negative predictive values for the detection of TFC defects in three imaging modalities, with arthroscopy as the reference standard

Imaging modality	Sensitivity, %	Specificity, %	Accuracy, %	PPV, %	NPV, %
Arthrography	94 (16/17)	100 (7/7)	95 (23/24)	100 (16/16)	87 (7/8)
MR imaging	86 (13/15)	85 (6/7)	86 (19/22)	92 (13/14)	75 (6/8)
MR arthrography	100 (15/15)	85 (6/7)	95 (21/22)	93 (15/16)	100 (6/6)

Numerators and denominators are in parentheses. PPV: positive predictive value; NPV: negative predictive value.

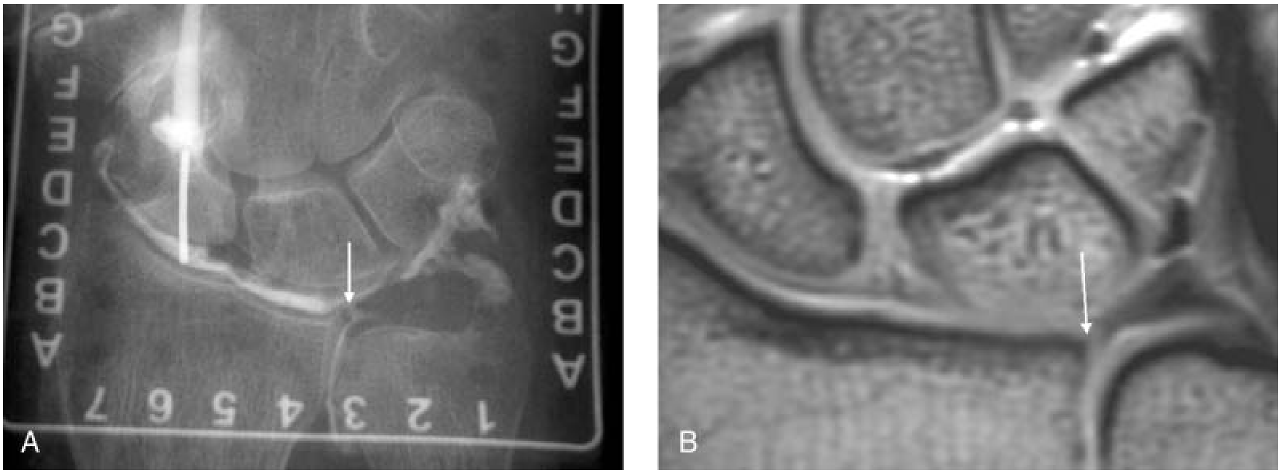

Fig. 3. Radial defect of TFC confirmed by arthroscopy. A. Early-phase arthrogram showing complete radial defect (arrow). Communication is observed between the radiocarpal joint and the distal radioulnar joint by evidence of the passage of contrast material. B. Coronal spin-echo arthrogram (TR/TE 360/13) showing radial defect (arrow).

findings observed in the arthrograms were as follows: TFC normal in eight cases, central defect in seven cases (Fig. 4), radial defect in two cases, and in seven cases combined defects were observed.

There was close correlation of the types of defect detected by arthrography and those observed by arthroscopy. Sensitivity, specificity, and diagnostic accuracy of radiocarpal arthroscopy for the detection of TFC defects were 94%, 100%, and 95%, respectively. Only one false negative was observed. Statistical analysis showed statistically significant differences ($P < 0.0005$).

MR imaging findings

Examinations of two specimen wrists were excluded because of artifacts. Defects of the TFC were detected in 14 (63.6%) of the 22 wrist specimens evaluated. These defects were: seven central, two radial, and five combined. Using arthroscopy as a reference standard, sensitivity, specificity, and accuracy were 86%, 85%, and 70%, respectively, when using MR imaging for detection of TFC defects, and showed statistically significant differences ($P < 0.002$).

By means of MR arthrography, 16 defects (72.7%) were seen in the 22 specimen wrists. The distribution of these defects was: eight central, one radial, and seven combined. Using arthroscopy as a reference standard, sensitivity, specificity, and accuracy of MR arthrography in the detection of TFC defects were 100%, 85%, and 95%, respectively, and showed statistically significant differences ($P < 0.0005$).

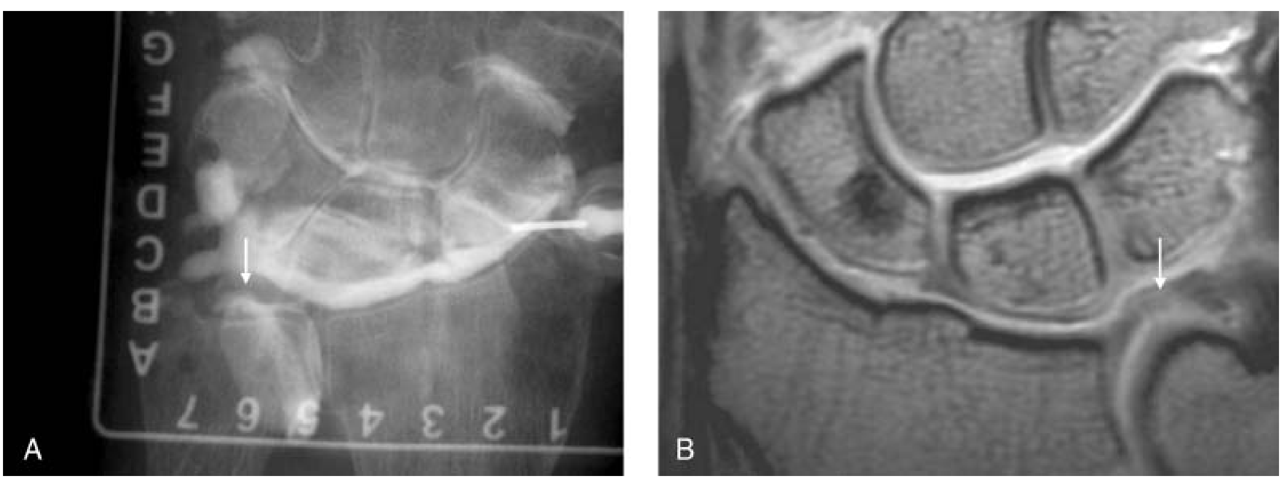

Fig. 4. Central defect of TFC confirmed by arthroscopy. A. Arthrogram of the radiocarpal joint showing communication into the distal radioulnar joint through a central defect of the TFC (arrow), and communication into the midcarpal joint through a defect of the lunotriquetral. B. Coronal spin-echo arthrogram (TR/TE 360/13) showing central defect (arrow).

Discussion

The diagnostic management of patients with suspected TFC pathology is the subject of some controversy. Wrist arthroscopy is routinely used for diagnosis and/or treatment of lesions of wrist TFC. However, although it is very sensitive and specific, it is also more invasive than other available diagnostic techniques (2, 10). Diagnostic accuracy is variable between imaging modalities used for TFC study, such as conventional arthrography, MR imaging, and MR arthrography (3–9, 12, 13, 16–24). Arthrography of the wrist, specifically three-compartment arthrography, has traditionally been recommended for the investigation of tears within the TFC (4, 5, 9, 19, 21, 23). SHIANOVA et al. (19) reported that arthrography is superior to MR imaging for the evaluation of TFC injuries: sensitivity 85%, specificity 100%, and accuracy 92% with arthrography, and sensitivity 73%, specificity 72%, and accuracy 73% with MR imaging. In another study (5), lower sensitivity (74%) and lower specificity (56%) were seen with arthrography. Nevertheless, imaging modalities should be fundamental as guides to therapeutic planning. With regard to this, YIN et al. (21) stressed that the results of bilateral three-compartment wrist arthrography in patients with chronic wrist pain play an important role in the therapeutic decision-making of the surgeon, and tend to lead to more conservative management and less invasive treatment. Additionally, ZANETTI et al. (23) reported that the description of noncommunicating defects of the TFC could improve the sensitivity of arthrography, although it is always essential to bear in mind that TFC defects may be evidenced in asymptomatic contralateral-side wrists (21, 23).

Published reports as to the diagnostic value of MR imaging for the detection of TFC abnormalities vary widely, with results showing sensitivity ranging between 44% and 100% (4, 6, 8, 12, 13, 16, 17, 20, 22, 24). CEROFOLINI et al. (4) and PEDERZINI et al. (16) found MR imaging superior to arthrography. Other studies (13, 16, 17) observed that MR imaging is a useful procedure for the detection of tears of the TFC, especially central and radial tears. However, MR imaging is of limited utility in the detection of ulnar-side abnormalities (7, 13). SCHMIT et al. (18) described very good results with MR arthrography in the detection of TFC lesions, with a sensitivity of 97.1%, a specificity of 96.4%, and an accuracy of 96.8%. MR images were difficult to interpret in 8.3% of cases (2/24) in the present study. In all specimen wrists, both arthrography and arthroscopy were carried out satisfactorily. The results using arthrography were similar to those obtained using MR arthrography. Moreover, the results obtained by combining arthrographic findings and MR arthrography findings were equivalent to the arthroscopy findings. Of the methods used in this study, arthrography was the quickest and the most economical. MR imaging and MR arthrography were more time consuming. Arthroscopy was the most expensive of the three procedures.

The Palmer classification (14) is generally employed for determining the localization of the TFC tear and for establishing its cause (degenerative or traumatic). MR imaging has the advantage that indirect signs of chronicity may be seen in the ulnar corners of the lunate, as a sign of ulnocarpal abutment, as opposed to arthrography, which does not have this advantage. However, it is difficult to differentiate between a degenerative tear and a traumatic tear using MR imaging (3, 11). Moreover, it has been reported in the literature that both MR imaging and conventional arthrography are of limited value for the localization of TFC defects, particularly those of the ulnar side (7, 10, 13, 16). In this respect, CEREZAL et al. (3) pointed out that the appearance of the lesions may be similar both in symptomatic and asymptomatic patients.

Traumatic tears are more common in younger patients, whilst degenerative tears are more common as age advances. Lesions of the TFC at the ulnar and radial attachment sites, including partial avulsions, are more likely to be a clinically relevant finding than central perforations (10). A large number of TFC abnormalities have been recorded in patients with asymptomatic wrist. For this reason, we believe that it is important to evaluate carefully the lesions of the TFC, their localization, and the age and clinical history of the patient, in order to be able to determine the nature of the tear. In order to optimize the management of TFC lesions, we consider both the availability of an adequate infrastructure and the close collaboration between radiologist and clinician as essential.

In the present study, we describe a system of classification of TFC defects, which we have used in the different imaging modalities employed in this work, thus permitting a more uniform correlation. To our knowledge, there are no reports in the imaging literature that correlate the detection and localization of TFC defects using the four modalities employed in this study—conventional arthrography, MR imaging, MR arthrography, and arthroscopy. The results obtained in our series show good correlation of the localization of the defects between the imaging techniques, using arthroscopy as a reference standard. The defects of the TFC detected by means of arthroscopy were seen on anatomic examination of the specimens. There was a high level of agreement between arthroscopy findings and conventional arthrography and MR arthrography findings combined concerning the localization of the TFC defect. Nevertheless, as described in previous imaging literature, it was found that the evaluation of the ulnar side presented a difficulty, as both conventional arthrography and the combination of MR imaging and MR arthrography failed to reveal one ulnar-sided defect seen with arthroscopy.

For the clinician, it is essential to receive a correct diagnosis of the TFC pathology in order to establish the most appropriate plan of treatment. Even though most surgeons still prefer diagnostic arthroscopy, which is a more invasive procedure requiring anesthesia and is more expensive (2, 10), we feel that it is important to use imaging methods that provide accurate diagnosis and serve to filter out unnecessary diagnostic arthroscopy.

Both conventional arthrography and MR arthrography are imaging modalities that provide high diagnostic accuracy. We consider that the two examinations are not exclusive but complementary, as the findings seen in this study show that, by using both together, diagnostic accuracy similar to that of arthroscopy is achieved. For this reason, both modalities should be included in the diagnostic protocol of patients with suspected tears of the TFC. At present, we are using a combination of conventional arthrography and MR arthrography for the evaluation of patients with ulnar-side wrist pain.

In conclusion, arthrography is a semi-invasive procedure that is more efficient and less costly than conventional MR imaging for the detection of TFC lesions. Both arthrography and MR arthrography are less invasive than arthroscopy, and the efficiency of a combination of the two procedures is very similar to that of diagnostic arthroscopy. We recommend a combination of the two examinations for the evaluation of suspicious lesions of the TFC as an alternative to diagnostic arthroscopy. Using this combination, arthroscopic studies could be reduced to a minimum and surgical intervention or arthroscopy could be employed for therapeutic means only.

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