UNIVERSITE DE LAUSANNE - FACULTE DE BIOLOGIE ET DE MEDECINE

Département de radiologie médicale
et
Service de radiodiagnostic et radiologie interventionnelle

Dorsal Fractures of the Triquetrum: MRI Findings With an Emphasis on Dorsal Carpal Ligament Injuries

THESE

préparée sous la direction du Professeur Reto Meuli

et présentée à la Faculté de biologie et de médecine de l'Université de Lausanne pour l'obtention du grade de

DOCTEUR EN MEDECINE

par

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Lausanne

2013

Unil
UNIL | Université de Lausanne
Faculté de biologie
et de médecine

Ecole Doctorale
Doctorat en médecine

Imprimatur

Vu le rapport présenté par le jury d'examen, composé de

Directeur de thèse	*Monsieur le Professeur* **Reto Meuli**
Co-Directeur de thèse	
Expert	*Madame le Professeur* **Brigitte Jolles-Haeberli**
Directrice de l'Ecole doctorale	*Madame le Professeur* **Stephanie Clarke**

la Commission MD de l'Ecole doctorale autorise l'impression de la thèse de

Monsieur Fabio Becce

intitulée

Dorsal Fractures of the Triquetrum: MRI Findings with Emphasis on Dorsal Carpal Ligament Injuries

Lausanne, le 14 juin 2013

pour Le Doyen
de la Faculté de Biologie et de Médecine

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Résumé

Contexte et but de l'étude:

Les fractures du triquetrum sont les deuxièmes fractures des os du carpe en fréquence, après celles du scaphoïde. Elles représentent environ 3.5% de toutes les lésions traumatiques du poignet, et résultent le plus souvent d'une chute de sa hauteur avec réception sur le poignet en hyper-extension. Leur mécanisme physiopathologique reste débattu. La première théorie fut celle de l'avulsion ligamentaire d'un fragment osseux dorsal. Puis, Levy et coll. ainsi que Garcia-Elias ont successivement suggéré que ces fractures résultaient plutôt d'une impaction ulno-carpienne.

De nombreux ligaments (intrinsèques et extrinsèques du carpe) s'insèrent sur les versants palmaires et dorsaux du triquetrum. Ces ligaments jouent un rôle essentiel dans le maintien de la stabilité du carpe. Bien que l'arthro-IRM du poignet soit l'examen de référence pour évaluer ces ligaments, Shahabpour et coll. ont récemment démontré leur visibilité en IRM tridimensionnelle (volumique) après injection iv. de produit de contraste (Gadolinium). L'atteinte ligamentaire associée aux fractures dorsales du triquetrum n'a jusqu'à présent jamais été évalué. Ces lésions pourraient avoir un impact sur l'évolution et la prise en charge de ces fractures.

Les objectifs de l'étude étaient donc les suivants: premièrement, déterminer l'ensemble des caractéristiques des fractures dorsales du triquetrum en IRM, en mettant l'accent sur les lésions ligamentaires extrinsèques associées; secondairement, discuter les différents mécanismes physiopathologiques (i.e. avulsion ligamentaire ou impaction ulno-carpienne) de ces fractures d'après nos résultats en IRM.

Patients et méthodes:

Ceci est une étude rétrospective multicentrique (CHUV, Lausanne; Hôpital Cochin, AP-HP, Paris) d'examens IRM et radiographies conventionnelles du poignet. A partir de janvier 2008, nous avons recherché dans les bases de données institutionnelles les patients présentant une fracture du triquetrum et ayant bénéficié d'une IRM volumique du poignet dans un délai de six semaines entre le traumatisme et l'IRM. Les examens IRM ont été effectués sur deux machines à haut champ magnétique (3 Tesla) avec une antenne dédiée et un protocole d'acquisition incluant une séquence tridimensionnelle isotropique (« 3D VIBE ») après injection iv. de produit de contraste (Gadolinium). Ces examens ont été analysés par deux radiologues ostéo-articulaires expérimentés. Les mesures ont été effectuées par un troisième radiologue ostéo-articulaire. En ce qui concerne l'analyse qualitative, le type de fracture du triquetrum (selon la classification de Garcia-Elias), la distribution de l'œdème osseux post-traumatique, ainsi que le nombre et la distribution des lésions ligamentaires extrinsèques associées ont été évalués. Pour l'analyse quantitative, l'index du processus de la styloïde ulnaire (selon la formule de Garcia-Elias), le volume du fragment osseux détaché du triquetrum, et la distance séparant ce fragment osseux du triquetrum ont été mesurés.

Résultats:

Huit fractures de type 1, une de type 2, six de type 3, cinq de type 4 et une de type 5 ont été identifiées. Ces fractures étaient fréquemment associées à des lésions ligamentaires extrinsèques dorsales: 14 (67%) déchirures du ligament dorsal radio-carpien, 17 (81%) du ligament dorsal ulno-triquétral, et 16 (76%) lésions du ligament dorsal inter-carpien. Nous n'avons pas trouvé de corrélation entre la distribution de l'œdème osseux au sein du triquétrum et la présence d'une lésion ligamentaire extrinsèque associée. La taille moyenne (+/- l'écart-type) du fragment osseux était de 205 +/- 157 mm3, tandis que son déplacement moyen par rapport à l'os sous-jacent était de 1.0 +/- 1.1 mm. La valeur moyenne de l'index du processus de la styloïde ulnaire était de 0.21 +/- 0.10.

Conclusions:

Les fractures dorsales du triquetrum sont fréquemment associées à des lésions ligamentaires extrinsèques, dont l'impact sur la prise en charge clinique reste cependant à déterminer. La distribution de l'œdème osseux au sein du triquetrum n'est pas corrélée à la présence de lésions ligamentaires extrinsèques dorsales. D'après nos résultats, le mécanisme physiopathologique de ces fractures est vraisemblablement plus complexe qu'on ne le pensait.

Dorsal Fractures of the Triquetrum: MRI Findings With an Emphasis on Dorsal Carpal Ligament Injuries

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Keywords: carpal ligaments, fracture, MRI, triquetrum, wrist

DOI:10.2214/AJR.12.8736

Received February 10, 2012; accepted after revision May 15, 2012.

This work was partly supported by the Centre d'Imagerie BioMédicale (CIBM) of the University of Lausanne (UNIL), the Swiss Federal Institute of Technology Lausanne (EPFL), the University of Geneva (UniGE), the Centre Hospitalier Universitaire Vaudois (CHUV), the Hôpitaux Universitaires de Genève (HUG), and the Leenaards and Jeantet Foundations.

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AJR 2013; 200:608–617

0361–803X/13/2003–608

OBJECTIVE. The objective of our study was to report the MRI findings in dorsal fractures of the triquetrum, with an emphasis on dorsal carpal ligament injuries.

MATERIALS AND METHODS. A total of 21 patients (16 men, five women; mean age, 41.9 years) with acute or subacute (≤ 6 weeks) dorsal triquetral fractures on radiography and MRI were included in this two-center retrospective study. MRI of the wrist was performed on 3-T units with transverse T1-weighted, coronal or transverse (or both) fat-suppressed T2-weighted, transverse gadolinium-enhanced fat-suppressed T1-weighted turbo spin-echo, and 3D gadolinium-enhanced fat-suppressed T1-weighted gradient-recalled echo sequences. Three musculoskeletal radiologists evaluated the ulnar styloid process index (USPI) on radiographs and the following MRI features: fracture pattern (types 1–6), bone fragment size and displacement, bone marrow edema distribution, and dorsal carpal ligament tears.

RESULTS. Eight type 1, one type 2, six type 3, five type 4, and one type 5 fractures were identified. These fractures were associated with 14 (66.7%), 17 (81.0%), and 16 (76.2%) tears of the dorsal radiocarpal, ulnotriquetral, and intercarpal ligaments, respectively. There was no correlation between bone marrow edema distribution and dorsal carpal ligament injuries (all $p > 0.05$). The mean (± SD) bone fragment volume and displacement were 205 ± 157 mm^3 and 1.0 ± 1.1 mm, respectively. The mean USPI was 0.21 ± 0.10.

CONCLUSION. Dorsal fractures of the triquetrum are frequently associated with dorsal carpal ligament injuries. Bone marrow edema distribution is not correlated with these ligament tears.

Carpal bone fractures are quite common and their relative incidence has been reported to range from 8% to 18% [1]. Their prevalence is probably underestimated because they may be occult or overlooked on conventional radiographs and consequently undiagnosed or misdiagnosed as wrist sprain. CT and MRI have proven to be helpful in directing clinical management of acute or chronic wrist injuries [2, 3]. However, these imaging techniques are used only in selected cases because of practical and cost considerations.

Fractures of the triquetrum account for up to 3.5% of all wrist injuries [4]. Triquetrum fractures represent the second most common form of carpal bone fractures, far behind those of the scaphoid [1, 4]. Most triquetral fractures result from falls from standing height onto the outstretched hand [1, 4]. Three types have been described: cortical dorsal, by far the most common; body; and cortical palmar [1, 5]. More than 7 decades after triquetral fractures were first reported in the literature [6], their pathologic mechanism remains controversial. Two major theories have been suggested: first, ligament avulsion fracture [4, 5]; and second, ulnocarpal impaction [7, 8]. Other less common theories include direct trauma to the dorsum of the hand or sudden resistance against twisting motion of the wrist [9].

The main dorsal carpal ligaments insert on the dorsum of the triquetrum. These ligaments consist of extrinsic (dorsal radiocarpal, dorsal ulnotriquetral) and intrinsic (dorsal intercarpal) ligaments that attach to distinct areas [10, 11] (Fig. 1). The dorsal intercarpal ligament, also called the "dorsal scaphotriquetral ligament," is an intrinsic capsular ligament because it does not originate from the distal radius or ulna [12, 13]. Although MR arthrography is the examination of choice to assess these ligaments, 3D MRI of the wrist, especially using thin sections and IV gadolinium administration, can also show these ligaments [14–16].

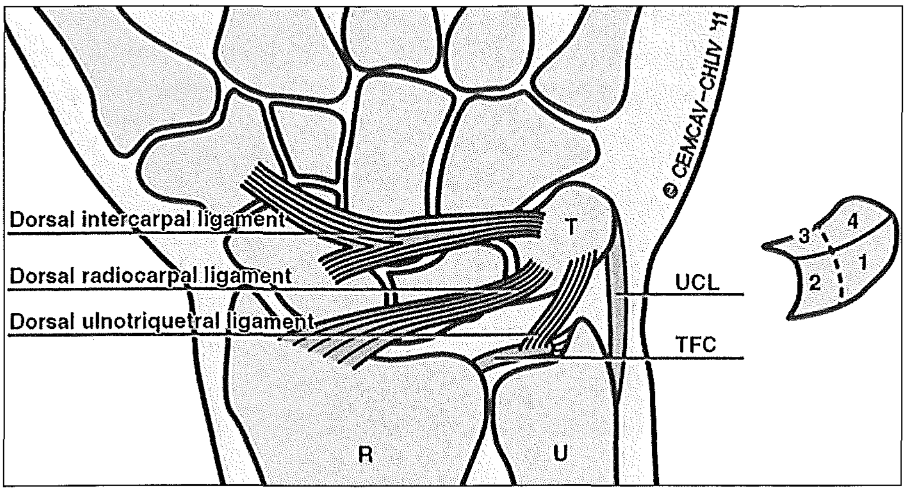


Fig. 1—Schematic drawing of wrist with three dorsal carpal ligaments inserting on dorsal aspect of triquetrum. Dorsal radiocarpal and dorsal ulnotriquetral ligaments are extrinsic ligaments that insert proximal to dorsal ridge of triquetrum on area 2 (proximal lateral) and area 1 (proximal medial), respectively. In contrast, dorsal intercarpal ligament is intrinsic ligament that inserts distal to ridge on area 3 (distal lateral). There is no ligament insertion on area 4 (distal medial). R = radius, U = ulna, TFC = triangular fibrocartilage, UCL = ulnar collateral ligament. (Reprinted with permission from Philippe Clavel, Lausanne, Switzerland)

To our knowledge, the MRI findings in dorsal fractures of the triquetrum have not yet been described in the literature. Thus, the purpose of our study was to report the MRI features of those fractures, with an emphasis on the associated dorsal carpal ligament tears.

Materials and Methods

This two-center retrospective study was approved by the institutional ethics committees at both institutions, with waivers of informed consent.

Patients

Twenty-nine patients with fractures of the triquetrum on MRI were first identified by searching the radiologic databases (search terms: triquetrum or triquetral, fracture, MRI, wrist or hand) of two university hospitals from January 2008 to October 2011. Exclusion criteria were the following: high-velocity trauma (n = 1), interval between trauma and MRI of more than 6 weeks (n = 2), fractures of triquetrum body or palmar cortical (n = 2), and no thin-section MR images (n = 3). Hence, the final study population consisted of 21 patients (16 men, five women; mean age, 41.9 years; age range, 22–75 years) with acute or subacute (≤ 6 weeks) triquetral fractures.

On review, all patients had a displaced osseous fragment identified on either conventional radiographs or MR images with bone marrow edema changes. MRI of the wrist (12 right, 9 left) was performed at an average of 2.8 weeks (range, 2–6 weeks) after trauma. Sixteen patients (76.2%) sustained their injury in falls from standing height on the outstretched hand, 14 (66.7%) with the wrist in extension and two (9.5%) with the wrist in flexion. One patient (4.8%) reported direct trauma to the dorsum of the hand, and four (19%) presented with symptoms after sudden resistance against twisting motion of the wrist. All patients were managed conservatively, and clinical follow-up at a minimum of 3 months was available in 15 cases. Functional recovery was evaluated from physical examination findings (swelling and tenderness, range of motion, grip strength) and subjective complaints retrieved in patients' medical records.

Control Group

Thirty consecutive patients (14 men, 16 women; mean age, 35.5 years; age range, 18–63 years) who underwent MRI of the wrist (11 right, 19 left) at institution 1 between January 2011 and June 2011 were included as control subjects. They all met the following inclusion criteria: no ulnar-sided wrist pain, no history of trauma or surgery of the hand or wrist, and thin-section MR images after IV gadolinium administration. The indications for MRI were as follows: arthritis (n = 23), ganglion cysts (n = 3), carpal tunnel syndrome (n = 2), flexor and extensor tendon disorders (n = 1), and soft-tissue infection (n = 1).

MRI Protocol

All MRI studies were performed on one of two 3-T units (Magnetom Trio or Verio, Siemens Healthcare). Patients were positioned prone, with the arm extended over the head and the wrist in neutral position and placed at the center of a four-channel dedicated wrist coil (α III Tx/Rx Quadrature Wrist Coil, Siemens Healthcare). In both institutions, the minimum protocol consisted of the following MR pulse sequences: transverse T1-weighted turbo spin-echo (TSE), coronal or transverse (or both) fat-suppressed T2-weighted TSE, transverse contrast-enhanced (0.2

TABLE 1: Parameters of the Reviewed MR Pulse Sequences

Parameter	Transverse T1-Weighted TSE	Transverse Fat-Suppressed T2-Weighted TSE	Coronal Fat-Suppressed T2-Weighted TSE	Transverse Gadolinium-Enhanced Fat-Suppressed T1-Weighted TSE	3D Gadolinium-Enhanced Fat-Suppressed T1-Weighted GRE VIBE
TR (ms)	788	4990	5180	600	16.6
TE (ms)	26	80	99	28	4.8
Echo-train length	6	14	19	6	1
Receiver bandwidth (Hz/pixel)	260	250	230	260	130
Flip angle (°)	150	150	120	150	10
FOV (mm)	90 × 90	100 × 100	100 × 100	90 × 90	105 × 98
Matrix size	384 × 269	384 × 230	256 × 256	384 × 230	320 × 300
No. of signal averages	2	2	1	3	1
Section thickness (mm)	3	3	3	3	0.3
Gap (%)	10	10	10	10	NA

Note—TSE = turbo spin-echo, GRE = gradient-recalled echo, VIBE = volumetric interpolated breath-hold examination, NA = not applicable.

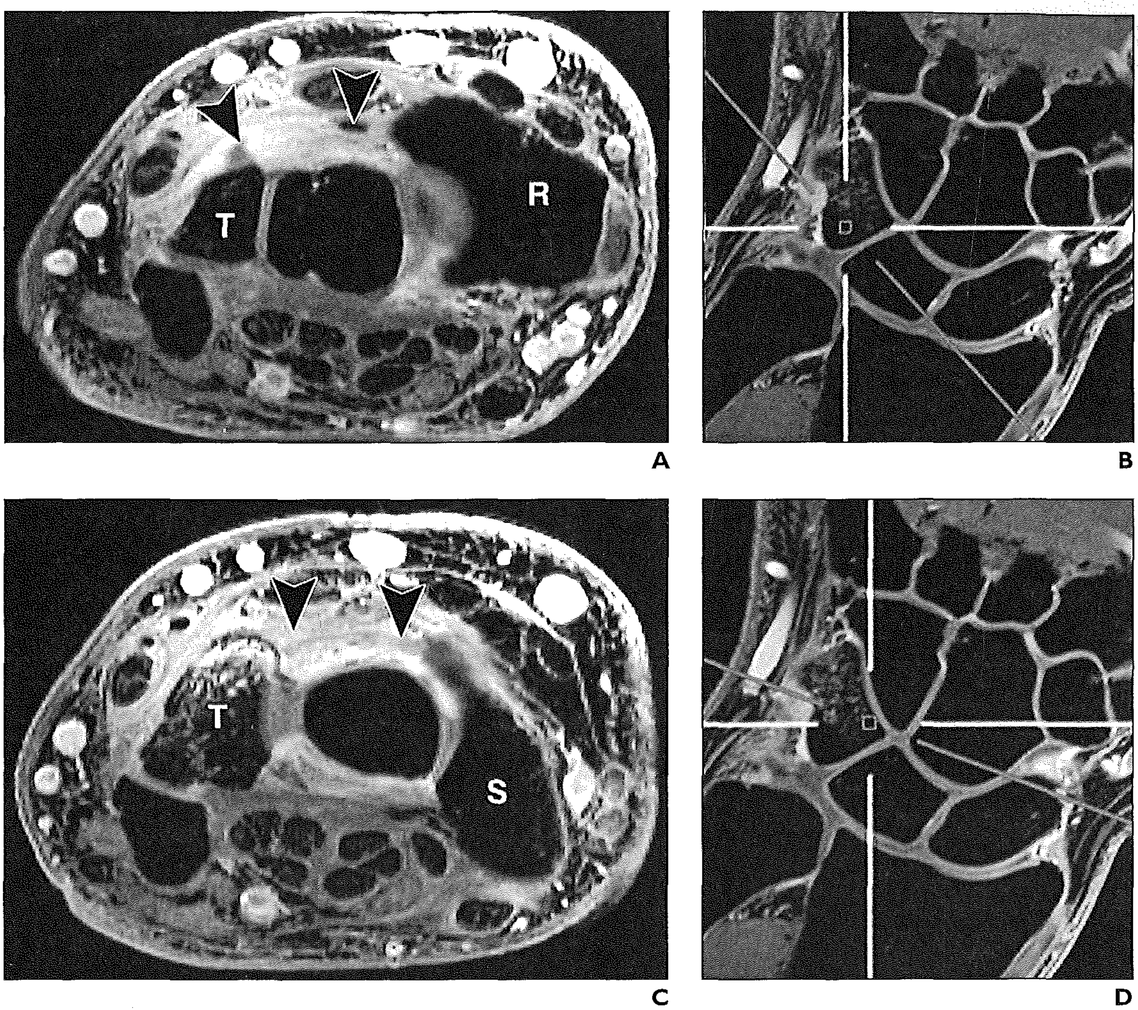
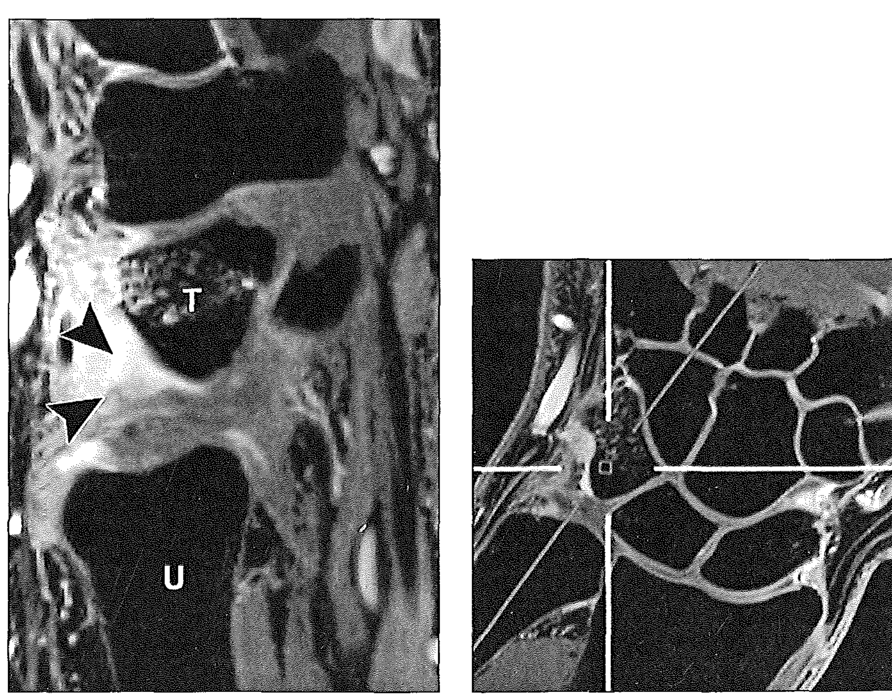


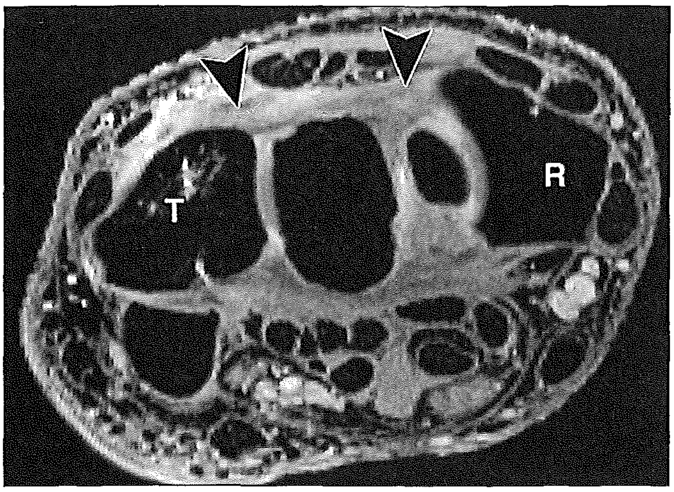
Fig. 2—40-year-old man with dorsal fracture of triquetrum sustained by suddenly resisting against twisting motion of his left wrist. Gadolinium-enhanced fat-suppressed T1-weighted volumetric interpolated breath-hold examination MR images (**A**–**F**) of left wrist are shown. R = radius, S = scaphoid, U = ulna.

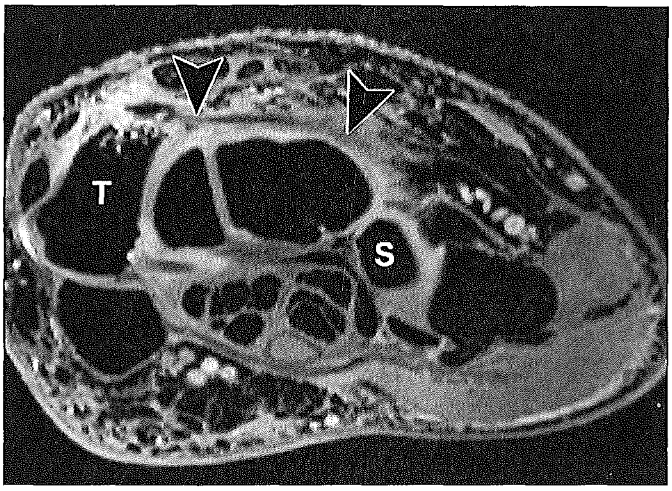
A and **B**, Transverse oblique reformatted view (**A**) obtained in plane of dorsal radiocarpal ligament (*diagonal lines* and □, **B**) and coronal view (**B**) show completely torn dorsal radiocarpal ligament (*right arrowhead*, **A**) with wavy stump (*left arrowhead*, **A**) on dorsal aspect of triquetrum (T, **A**).

C and **D**, Transverse oblique reformatted view (**C**) obtained in plane of dorsal intercarpal ligament (*diagonal lines* and □, **D**) and coronal view (**D**) reveal slightly displaced dorsal cortical fracture with bone marrow edema changes in underlying triquetrum body (T). Dorsal intercarpal ligament insertion on bone fragment (*left arrowhead*, **C**) has thickened appearance with abnormal signal intensity suggestive of partial tear. Right arrowhead in **C** shows normal origin of dorsal intercarpal ligament.

E and **F**, Sagittal reformatted view (**E**) obtained in plane of dorsal ulnotriquetral ligament (*diagonal lines* and □, **F**) and coronal view (**F**) display completely torn dorsal ulnotriquetral ligament (*arrowheads*, **E**), with bone marrow edema in underlying triquetrum body (T) and posttraumatic changes in soft tissues on dorsal aspect of wrist.







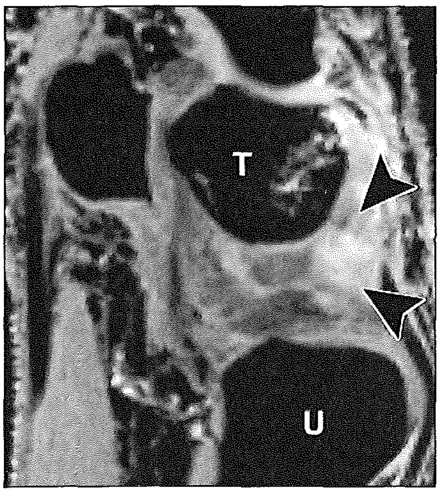


Fig. 3—33-year-old woman with dorsal fracture of triquetrum sustained in fall on left hand with wrist in extension. Gadolinium-enhanced fat-suppressed T1-weighted volumetric interpolated breath-hold examination MR images of left wrist are shown. R = radius, S = scaphoid, U = ulna.
A and **B**, Transverse oblique reformatted views show preserved dorsal radiocarpal ligament (**A**) and preserved dorsal intercarpal ligament (**B**) (*arrowheads*) inserting on dorsum of triquetrum (**A**) and on slightly displaced dorsal cortical fracture (**B**), respectively. Moderate bone marrow edema is seen in underlying triquetrum body (T).
C, Sagittal reformatted view reveals completely torn dorsal ulnotriquetral ligament (*arrowheads*), with bone marrow edema in underlying triquetrum body (T), and posttraumatic changes in soft tissues on dorsal aspect of wrist.

mL/kg IV gadoteric acid [Dotarem, Guerbet]) fat-suppressed T1-weighted TSE, and 3D contrast-enhanced fat-suppressed T1-weighted gradient-recalled echo free-breathing volumetric interpolated breath-hold examination (VIBE). The VIBE sequence was customized by removing all interpolations in slice-encoding and phase-encoding directions, without changing its contrast parameters. The detailed parameters of the reviewed sequences are presented in Table 1. Any additional MR sequence was not considered for the purpose of our study.

Image Analysis

Two musculoskeletal radiologists (observers 1 and 2 with 20 and 11 years' experience, respectively) jointly reviewed all conventional radiographs and MRI studies on a commercial DICOM viewer (Kodak Carestream, Carestream Health), with consensus agreement. Measurements, obtained to the nearest tenth of millimeter, were performed by a third musculoskeletal radiologist (observer 3 with 3 years' experience) on a similar workstation.

The observers assessed wrist radiographs to determine whether the dorsal fracture of the triquetrum was visible. Using anteroposterior wrist radiographs, the observers calculated the ulnar styloid process index (USPI) using the following formula described by Garcia-Elias [8]: (length of the ulnar styloid process – ulnar variance) / width of the ulnar head.

All other imaging features were evaluated on MR images. The coronal, sagittal reformatted, and transverse oblique reformatted views were assessed when the 3D VIBE images were reviewed (Figs. 2–5).

The pattern of dorsal triquetral fracture was determined according to the classification system proposed by Garcia-Elias [8]: type 1, undisplaced fracture; types 2 and 3, partially displaced (proximal or distal end, respectively); type 4, completely displaced; type 5, multiple bone fragments; and type 6, verticofrontal fracture (i.e., involving the entire dorsal aspect of the triquetrum).

The size of the triquetral bone fragment was measured in all three planes on the 3D VIBE images. Its volume was subsequently calculated using the ellipsoid formula:

$$4/3 \cdot \varpi \cdot x \cdot y \cdot z,$$

where x is mediolateral, y is anteroposterior, and z is craniocaudal.

The largest gap between the bone fragment and the triquetrum was measured in the sagittal plane on the 3D VIBE images.

The presence of bone marrow edema changes in the wrist was evaluated on T2-weighted images. Bone marrow edema distribution in the dorsal triquetrum was further subcategorized into four areas corresponding to insertions of the dorsal carpal ligaments (area 1 = dorsal ulnotriquetral, area 2 = dorsal radiocarpal, area 3 = dorsal intercarpal, area 4 = no ligament) (Fig. 1).

When present, injuries to the dorsal carpal ligaments were graded as partial or complete on the 3D VIBE images. A partial tear was considered when the ligament exhibited abnormal signal intensity or a thickened or wavy appearance (Figs. 2C, 4A, and 4B). In contrast, identification of a ligamentous stump corresponded to a complete tear (Figs. 2A, 2E, 3C, and 4C). When intact, the ligament's thickness was measured at its insertion.

All imaging features in patients with a history of avulsion (i.e., fall on the outstretched hand with the wrist in extension) were compared to those with a history of impaction (i.e., fall on the outstretched hand with the wrist in flexion or sudden resistance against twisting motion of wrist).

In control subjects, the following features were evaluated: The visibility of each of the three dorsal carpal ligaments inserting on the dorsum of the triquetrum was determined on the 3D VIBE images. Each ligament was further graded as partially visible, completely visible, or not visible (Fig. 5).

When a ligament was completely visible, the ligament's thickness was measured at its insertion.

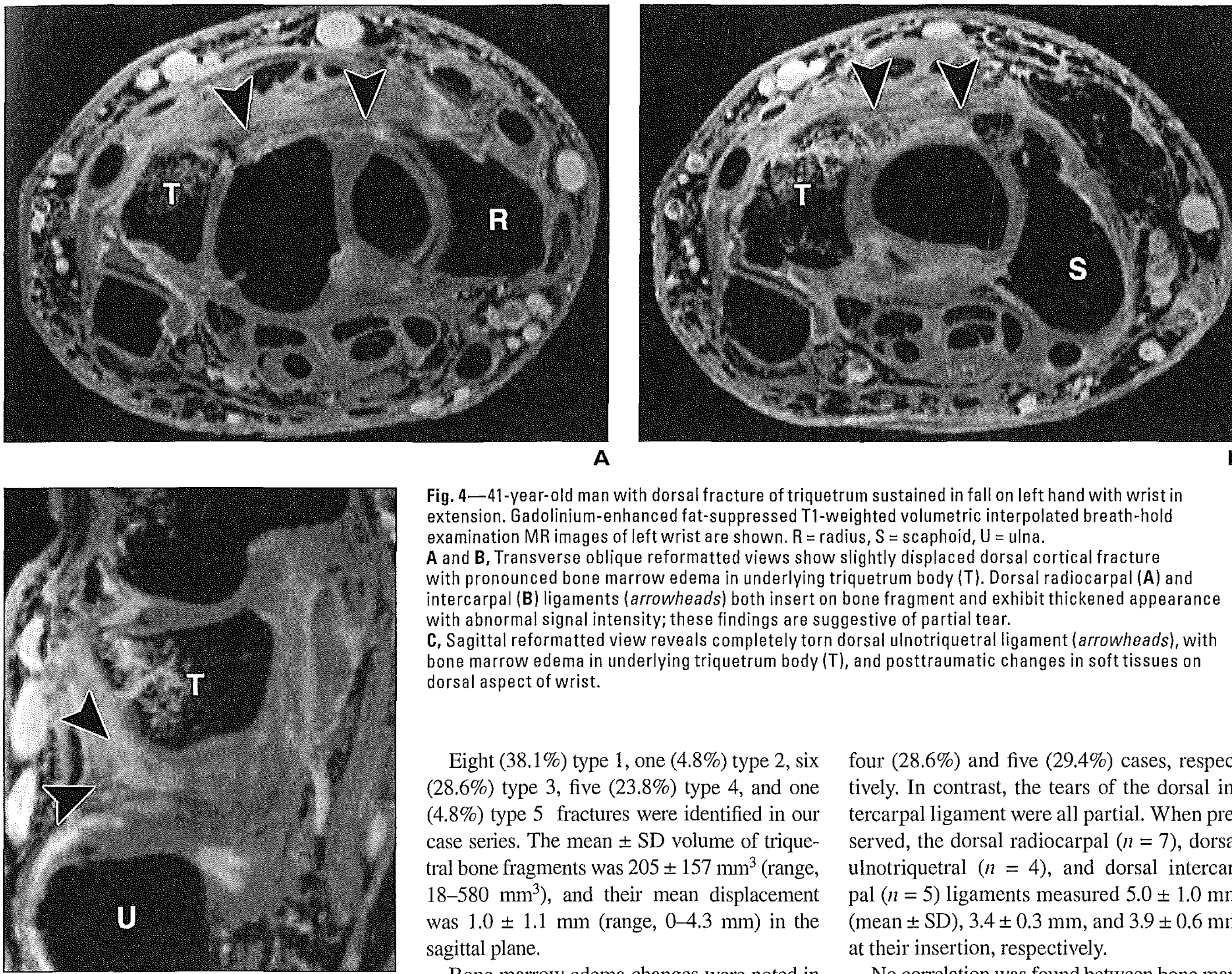


Fig. 4—41-year-old man with dorsal fracture of triquetrum sustained in fall on left hand with wrist in extension. Gadolinium-enhanced fat-suppressed T1-weighted volumetric interpolated breath-hold examination MR images of left wrist are shown. R = radius, S = scaphoid, U = ulna.
A and **B**, Transverse oblique reformatted views show slightly displaced dorsal cortical fracture with pronounced bone marrow edema in underlying triquetrum body (T). Dorsal radiocarpal (**A**) and intercarpal (**B**) ligaments (*arrowheads*) both insert on bone fragment and exhibit thickened appearance with abnormal signal intensity; these findings are suggestive of partial tear.
C, Sagittal reformatted view reveals completely torn dorsal ulnotriquetral ligament (*arrowheads*), with bone marrow edema in underlying triquetrum body (T), and posttraumatic changes in soft tissues on dorsal aspect of wrist.

Statistical Analysis

All data were processed using statistical software (MedCalc, version 12.0, MedCalc Software). Patients' characteristics in both groups were compared using the chi-square and Student t test for independent samples. Continuous variables were assessed using the Mann-Whitney U test for independent samples. Categoric variables were assessed using the chi-square test. Two-tailed p values < 0.05 were considered to be statistically significant.

Results

There was no significant difference in sex ($p = 0.06$) and age ($p = 0.11$) between the patients and control subjects.

Patients

The main MRI findings in the 21 patients with dorsal fractures of the triquetrum are summarized in Table 2.

Eight (38.1%) type 1, one (4.8%) type 2, six (28.6%) type 3, five (23.8%) type 4, and one (4.8%) type 5 fractures were identified in our case series. The mean ± SD volume of triquetral bone fragments was 205 ± 157 mm^3 (range, 18–580 mm^3), and their mean displacement was 1.0 ± 1.1 mm (range, 0–4.3 mm) in the sagittal plane.

Bone marrow edema changes were noted in all fractured triquetrum bones ($n = 21$). These changes were most frequent in area 1 ($n = 18$, 85.7%), followed by area 3 ($n = 14$, 66.7%) and area 2 ($n = 12$, 57.1%). They were least common in area 4 ($n = 6$, 28.6%). Bone marrow edema was never observed in the ulnar styloid process, whereas it was found in the hamate and other bones of the hand and wrist in five (23.8%) and four (19%) cases, respectively. Among those cases, the distal end of the radius, the scaphoid, and the lunate were involved in two cases each and the pisiform, in one case.

Overall, 47 dorsal carpal ligament injuries were identified and 20 (95.2%) patients presented at least one associated ligament injury. These injuries consisted of 14 (66.7%) tears of the dorsal radiocarpal, 17 (81.0%) tears of the dorsal ulnotriquetral, and 17 (76.2%) tears of the dorsal intercarpal ligaments. The tears of the dorsal radiocarpal and dorsal ulnotriquetral ligaments were partial in 10 (71.4%) and 12 (70.6%) cases, and they were complete in four (28.6%) and five (29.4%) cases, respectively. In contrast, the tears of the dorsal intercarpal ligament were all partial. When preserved, the dorsal radiocarpal ($n = 7$), dorsal ulnotriquetral ($n = 4$), and dorsal intercarpal ($n = 5$) ligaments measured 5.0 ± 1.0 mm (mean ± SD), 3.4 ± 0.3 mm, and 3.9 ± 0.6 mm at their insertion, respectively.

No correlation was found between bone marrow edema distribution in the four triquetrum areas and the corresponding dorsal carpal ligament injury: bone marrow edema in area 1 and dorsal ulnotriquetral tear ($p = 0.07$), in area 2 and dorsal radiocarpal tear ($p = 0.29$), and in area 3 and dorsal intercarpal tear ($p = 0.19$).

On review of standard wrist radiographs, four (19%) fractures involving the dorsum of the triquetrum were not visible. The mean USPI was 0.21 ± 0.10 (range, 0.05–0.44).

The radiographic and MRI findings in patients with a history of avulsion versus those with a history of impaction are presented in Table 3. All characteristics did not significantly differ between the two subgroups except bone fragment displacement and bone marrow edema distribution in other bones, which were both greater in patients with impaction ($p = 0.04$ and $p < 0.001$, respectively).

Functional recovery was excellent ($n = 14$) or good ($n = 6$) in all patients except one (patient 2 in Table 2) who had persistent symptoms

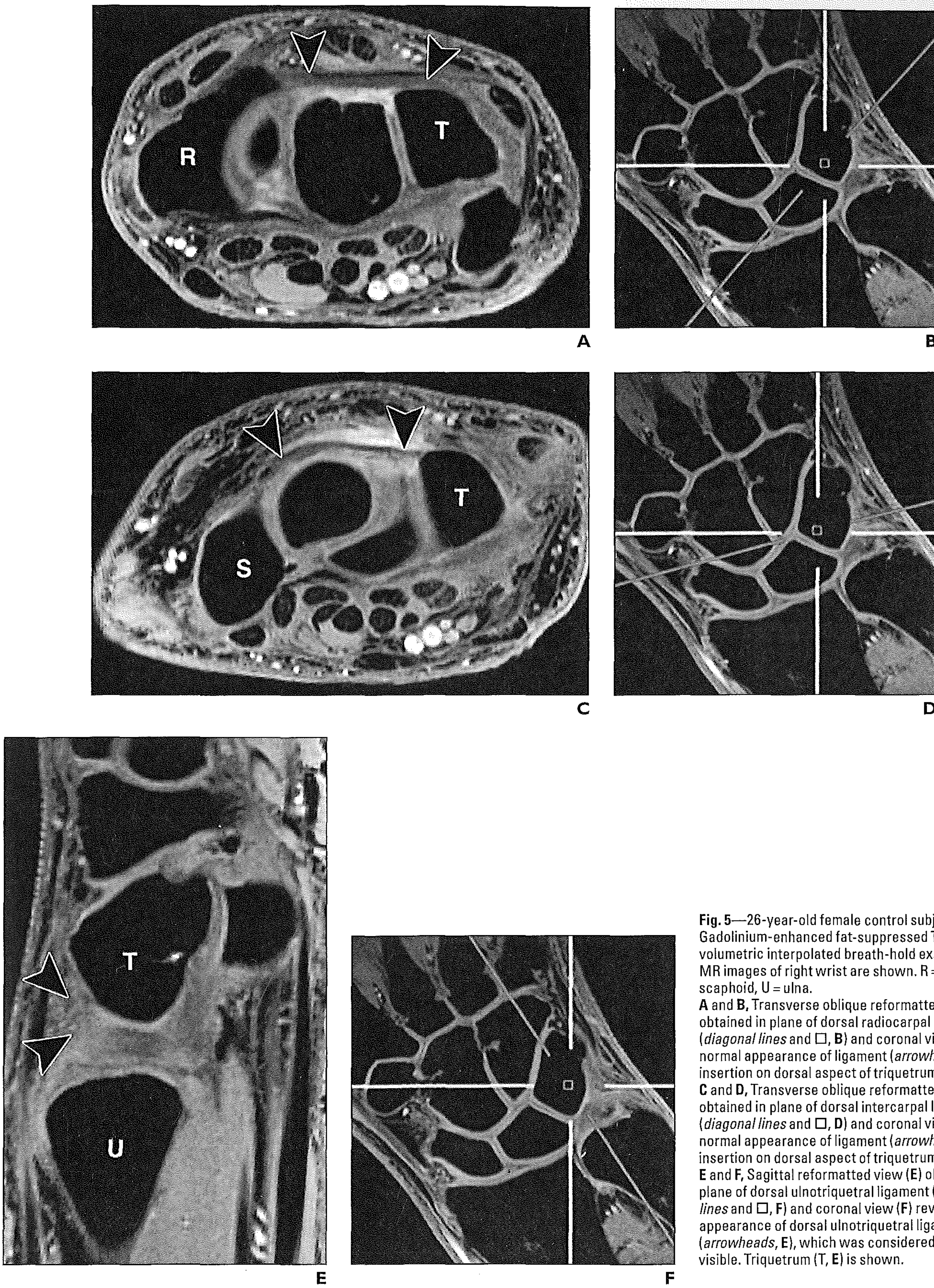


Fig. 5—26-year-old female control subject. Gadolinium-enhanced fat-suppressed T1-weighted volumetric interpolated breath-hold examination MR images of right wrist are shown. R = radius, S = scaphoid, U = ulna.
A and **B**, Transverse oblique reformatted view (**A**) obtained in plane of dorsal radiocarpal ligament (*diagonal lines* and □, **B**) and coronal view (**B**) show normal appearance of ligament (*arrowheads*, **A**) with insertion on dorsal aspect of triquetrum (T, **A**).
C and **D**, Transverse oblique reformatted view (**C**) obtained in plane of dorsal intercarpal ligament (*diagonal lines* and □, **D**) and coronal view (**D**) reveal normal appearance of ligament (*arrowheads*, **C**) with insertion on dorsal aspect of triquetrum (T, **C**).
E and **F**, Sagittal reformatted view (**E**) obtained in plane of dorsal ulnotriquetral ligament (*diagonal lines* and □, **F**) and coronal view (**F**) reveal blurred appearance of dorsal ulnotriquetral ligament (*arrowheads*, **E**), which was considered as partially visible. Triquetrum (T, **E**) is shown.

TABLE 2: Radiographic and MRI Findings in the 21 Patients With Dorsal Fractures of the Triquetrum

Patient						Triquetrum Fragment		Bone Marrow Edema Distribution				Dorsal Carpal Ligament Injuries[e]		
No.	Sex	Age (y)	Mechanism of Injury[a]	USPI[b]	Fracture Pattern (Types 1–6)[c]	Volume (mm^3)	Displacement (mm)	Triquetrum (Areas 1–4)[d]	Ulnar Styloid Process	Hamate	Other Bones	RC	UT	IC
1	M	40	4	0.31	3	189	1.2	1, 3, 4	–	–	–	2	2	1
2	M	29	1	0.24	4	107	3.3	1, 3, 4	–	+	+	2	1	1
3	F	75	1	0.06	3	260	1.5	1, 3, 4	–	–	–	1	1	1
4	M	59	2	0.31	1	246	0	3	–	–	–	0	1	1
5	M	41	1	0.20	3	580	0.6	1, 2, 3	–	+	–	1	2	1
6	F	33	1	0.29	4	81	1	1, 3	–	+	–	0	2	0
7	M	60	1	0.28	3	401	0.9	1, 2, 3, 4	–	–	+	1	1	1
8	M	29	1	0.22	1	212	0	1, 2, 3, 4	–	–	–	0	0	1
9	M	58	2	0.29	1	206	0	1, 2, 3	–	+	–	1	1	1
10	M	61	1	0.10	3	313	1.4	2, 3	–	–	–	1	0	1
11	F	33	1	0.09	1	418	0	1, 3	–	–	–	0	1	1
12	M	47	1	0.05	3	50	1.2	1, 2	–	–	–	1	1	1
13	M	41	4	0.23	1	18	0	1, 2	–	–	–	2	1	0
14	M	22	3	0.25	1	44	0	1	–	–	–	1	2	0
15	M	49	1	0.17	2	459	1.1	1, 2, 3, 4	–	+	+	2	1	1
16	M	35	4	0.10	1	76	0	1, 2	–	–	+	0	0	0
17	M	32	1	0.44	4	152	4.3	1, 2	–	–	–	1	0	1
18	F	37	1	0.22	4	50	2.2	3	–	–	–	0	2	1
19	M	46	1	0.19	1	41	0	1	–	–	–	0	1	1
20	F	24	1	0.18	5	250	1.2	1, 2, 3	–	–	–	1	1	0
21	M	28	4	0.24	4	160	0.8	1, 2	–	–	–	1	1	1

Note—Minus sign (–) indicates absent, plus sign (+) = present. USPI = ulnar styloid process index, RC = radiocarpal, UT = ulnotriquetral, IC = intercarpal.
[a]Mechanism of injury: 1 = fall on the outstretched hand with the wrist in extension, 2 = fall on the outstretched hand with the wrist in flexion, 3 = direct trauma, 4 = sudden resistance against twisting motion of the wrist.
[b]USPI [8] was calculated on anteroposterior wrist radiographs as follows: (length of the ulnar styloid process – ulnar variance) / width of the ulnar head.
[c]Fracture pattern [8]: 1 = undisplaced, 2 and 3 = partially displaced (proximal or distal end, respectively), 4 = completely displaced, 5 = multiple fragments, 6 = verticofrontal.
[d]Triquetrum area (Fig. 1): 1 = proximal medial, 2 = proximal lateral, 3 = distal lateral, 4 = distal medial.
[e]Dorsal carpal ligament injuries: 0 = no injury, 1 = partial tear, 2 = complete tear.

in activities of daily living and diminished grip strength at his 3-month follow-up examination.

Control Group

The visibility of each of the three dorsal carpal ligaments in the 30 control patients is reported in Table 4.

Overall, 83 of the 90 (92.2%) dorsal carpal ligaments were identified: 30 (100%) dorsal radiocarpal, 23 (76.7%) dorsal ulnotriquetral, and 30 (100%) dorsal intercarpal ligaments. The dorsal radiocarpal, dorsal ulnotriquetral, and dorsal intercarpal ligaments were completely visible in 24 (80%), 16 (53.3%), and 29 (96.7%) cases, whereas these ligaments were only partially visible in six (20%), seven (23.3%), and one (3.3%), respectively. When completely visible, the dorsal radiocarpal (n = 24), dorsal ulnotriquetral (n = 16), and dorsal intercarpal (n = 29) ligaments measured 4.5 ± 0.9 (mean ± SD), 3.6 ± 0.5, and 3.5 ± 0.6 mm at the insertion, respectively.

Discussion

The triquetrum, named after its roughly pyramidal shape, is a bone of the first carpal row. Unlike the scaphoid and the lunate, the triquetrum is not involved in the radiocarpal joint but is part of the midcarpal joint [4, 17]. It has three articular facets for the pisiform, the lunate, and the hamate on its palmar, lateral, and distal aspects, respectively [4, 17]. In contrast, its dorsomedial aspect is extraarticular and divided in two surfaces by a transverse ridge, also called the posterior tubercle [4, 17] (Fig. 1). Two dorsal extrinsic carpal ligaments (dorsal radiocarpal and dorsal ulnotriquetral) insert proximal to this ridge, and one intrinsic ligament (dorsal intercarpal) inserts distal to it [4, 10, 17] (Fig. 1). Because anatomic variations exist [11], we considered only the most common forms of these ligaments for simplicity's sake. Furthermore, the dorsal portion of the lunotriquetral interosseous ligament also attaches to the dorsolateral aspect of the triquetrum. All those ligaments have proven to be visible on MR arthrography [10] and high-resolution ultrasound of the wrist [12, 18]. Moreover, they were recently reported to be also visible on 3D gadolinium-enhanced MRI [14]. However, the diagnostic accuracy of that imaging technique has not yet been established in the literature.

In agreement with Shahabpour et al. [14], we found that the dorsal carpal ligaments inserting on the triquetrum were visible in up to 92.2% of control patients on 3D VIBE images (Table 4). Interestingly, although the dorsal

TABLE 3: Comparison of Imaging Findings in Patients With a History of Avulsion Versus Those With a History of Impaction

Parameter	Avulsion ($n = 6$ Patients)	Impaction ($n = 14$ Patients)	p
USPI[a], median (95% CI)	0.27 (0.13–0.31)	0.20 (0.10–0.24)	0.09[b]
Fracture pattern[c], no. of patients			0.40[d]
Type 1	4	3	
Type 2	0	1	
Type 3	1	5	
Type 4	1	4	
Type 5	0	1	
Triquetrum fragment			
Volume (mm^3), median (95% CI)	174.4 (29.3–238.3)	231.1 (77.5–402.5)	0.25[b]
Displacement (mm), median (95% CI)	0 (0–1.1)	1.2 (0.5–1.6)	0.04[b]
Bone marrow edema distribution			
Triquetrum[e]	2.17	2.57	0.27[d]
Ulnar styloid process	0	0	NA[d]
Hamate, no. (%)	1 (16.7)	4 (28.6)	0.99[d]
Other bones, no. (%)	1 (16.7)	3 (21.4)	< 0.001[d]
Dorsal carpal ligament injuries			
Dorsal radiocarpal tear, no. (%)	4 (66.7)	9 (64.3)	0.70[d]
Dorsal ulnotriquetral tear, no. (%)	5 (83.3)	10 (71.4)	0.99[d]
Dorsal intercarpal tear, no. (%)	4 (66.7)	12 (85.7)	0.72[d]

Note—USPI = ulnar styloid process index, NA = not applicable.
[a]USPI [8] was calculated on anteroposterior wrist radiographs as follows: (length of the ulnar styloid process – ulnar variance) / width of the ulnar head.
[b]Mann-Whitney U test.
[c]Fracture pattern [8]: 1 = undisplaced, 2 and 3 = partially displaced (proximal or distal end, respectively), 4 = completely displaced, 5 = multiple fragments, 6 = verticofrontal.
[d]Chi-square test.
[e]Bone marrow edema triquetrum: average number of the four areas (Fig. 1) for each patient.

radiocarpal and dorsal intercarpal ligaments were completely visible in most cases (80% and 96.7%, respectively), the dorsal ulnotriquetral ligament was completely visible in only about half of the cases (53.3%) and was not visible in 23.3% of the cases (Table 4). This difference in visibility could be explained at least partly by magic angle effect artifact related to the curved course of this ligament and the short TE (4.8 ms) of the 3D VIBE sequence [19]. This artifact should also be kept in mind when interpreting the results of dorsal ulnotriquetral ligament tears, which are therefore probably overestimated. The dorsal ulnotriquetral ligament has been inconsistently reported in the literature to date [10–18, 20], but this point goes beyond the scope of our study.

Over the past 40 years, the pathologic mechanism of dorsal triquetral fractures has drawn some attention in the orthopedics literature. The traditional view first pointed to avulsion as the primary mechanism of injury [4, 6, 21]. Then, successive works by Levy et al. [7] and Garcia-Elias [8] suggested that the pathologic mechanism involved chisel action (i.e., impaction) of the ulnar styloid process on the dorsal aspect of the triquetrum rather than avulsion. Garcia-Elias also defined the USPI as follows: [(length of the ulnar styloid process – ulnar variance) / width of the ulnar head]. According to this formula, patients with a long ulnar styloid process and positive or neutral ulnar variance would be more likely to sustain impaction of the ulnar styloid process against the dorsal aspect of the triquetrum when falling on the outstretched hand, particularly when the wrist is in extension. Later, Höcker and Menschik [17] argued that chisel action of the dorsoproximal edge of the hamate striking against the fully extended and ulnar-deviated wrist might instead be the major cause of dorsal triquetral fractures. To date, although fractures of the triquetrum body are recognized to be caused by compressive forces [22], the pathologic mechanism of dorsal triquetral fractures remains controversial.

On the basis of our radiographic and MRI findings, we believe that this mechanism may be complex.

Contrary to the theory of impaction, we found a mean USPI (0.21) within the normal range and not as high as previously reported (0.29) [8]. When we compared the patients from the two subgroups (i.e., avulsion and impaction), the median USPI was found to be even higher in patients with a history of avulsion than in those with a history of impaction (0.27 vs 0.20, respectively) (Table 3). Moreover, we did not find any patient with a fracture or bone marrow edema of the ulnar styloid process (Table 2), which should virtually exclude the mechanism of impaction. However, a few patients presented bone marrow edema changes in the hamate, which still supports the theory of impaction between the hamate and the extended and ulnar-deviated wrist [17].

Furthermore, Garcia-Elias [8] hypothesized that patients with type 3 fracture patterns sustained their injury by avulsion rather than im-

TABLE 4: Visibility of Each of the Three Dorsal Carpal Ligaments in the 30 Control Patients

Visibility	Dorsal Carpal Ligament			Total
	Radiocarpal	Ulnotriquetral	Intercarpal	
No. of ligaments / total no. of ligaments (%)				
Complete	24/30 (80)	16/30 (53.3)	29/30 (96.7)	69/90 (76.7)
Partial	6/30 (20)	7/30 (23.3)	1/30 (3.3)	14/90 (15.6)
None	0/30	7/30 (23.3)	0/30	7/90 (7.8)
Ligament's thickness at insertion on triquetrum (mm), mean ± SD	4.5 ± 0.9	3.5 ± 0.6	3.6 ± 0.5	

paction because the mean USPI for patients with the type 3 fracture pattern was significantly lower (0.24) than that for patients with other types of fracture patterns. Interestingly, we also noted a lower mean USPI (0.17) in patients with the type 3 fracture pattern. However, this fracture pattern was found to be much more common in the impaction subgroup than in the avulsion subgroup (5 vs 1), which is somehow contrary to its presumed avulsion by the dorsal radiocarpal or dorsal ulnotriquetral ligament (Table 3). Although it is certainly not possible to draw wide conclusions from our small patient population, we believe that tears of the various dorsal carpal ligaments might still be correlated to specific fracture patterns (e.g., a dorsal ulnotriquetral ligament tear associated with proximal tilt of bone fragment by avulsion). However, although we expected to find more dorsal carpal ligament injuries in patients with a history of avulsion, no significant difference was noted between the two subgroups with regard to the prevalence of these ligament tears (Table 3). The poor correlation between ligament injury and bone marrow edema pattern may be because of anatomic variations in ligament insertions on the triquetrum.

Several studies have reported the radiographic [4–9, 17, 21, 22] and CT [23] features of triquetral fractures. To our knowledge, the MRI findings have not been described in the literature to date. MRI has proven to have a clinical impact in acute wrist injuries, particularly when radiographic findings are inconclusive [2, 3]. Triquetral fractures were recently reported to be radiographically occult in up to 80% of cases [23, 24]. They are also known to be associated with injuries to the other bones of the wrist in 20–50% of cases [17, 24]. Interestingly, Lee et al. [25] lately reported a small series of six patients with persistent ulnar-sided wrist pain after treatment of dorsal triquetral fracture. They concluded that associated triangular fibrocartilage complex injuries were the cause of symptoms. In our series, only four (19%) fractures were found to be radiographically occult. In addition, 20 (95.2%) patients had at least one associated ligament injury.

We acknowledge several limitations of our study. First, owing to its retrospective nature, the study has an inherent patient selection bias. Second, a relatively small number of patients were included even though two university hospitals were involved. This small number is primarily because most patients in this setting are not examined on MRI but still recover well. Third, the mechanism of injury may not be precisely remembered by patients. Fourth, CT would be more accurate for measuring bone fragment volume. However, dorsal carpal ligament injuries may not be assessed with this imaging technique. Fifth, control patients were not asymptomatic volunteers and may have had previous injuries to their wrist ligaments despite our inclusion criteria. Finally, we were unable to correlate our MRI findings with arthroscopy or surgery. However, all examinations were analyzed by musculoskeletal radiologists with experience in hand and wrist imaging.

In conclusion, we presented the MRI findings in patients with dorsal fractures of the triquetrum. These fractures are frequently associated with dorsal carpal ligament tears. According to our preliminary findings, their pathologic mechanism may be more complicated than previously thought. Further studies are needed to evaluate the clinical significance of those associated injuries.

Acknowledgment

We gratefully thank Philippe Clavel for his computer graphics work.

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