Diagnostic performance of high-resolution ultrasound in the evaluation of intrinsic and extrinsic wrist ligaments after trauma

Diagnostische Leistung des hochauflösenden Ultraschalls bei der Beurteilung von intrinsischen und extrinsischen Bändern des Handgelenks nach einem Trauma

Authors
Salvatore Gitto[1, 2], Domenico Albano[2], Francesca Serpi[1], Pierino Spadafora[2], Roberta Colombo[2], Carmelo Messina[1, 2], Alberto Aliprandi[3], Luca Maria Sconfienza[1, 2]

Affiliations
1 Department of Biomedical Sciences for Health, University of Milan, Milan, Italy
2 Diagnostic and Interventional Radiology Unit, IRCCS Galeazzi Orthopaedic Institute, Milan, Italy
3 Radiology Unit, Zucchi Clinical Institutes Spa, Monza, Italy

Key words
carpal ligament, magnetic resonance arthrography, magnetic resonance imaging, ultrasound, wrist

received 14.05.2022
accepted after revision 31.03.2023
accepted manuscript online 31.03.2023
published online 07.06.2023

Bibliography
Ultraschall in Med 2024; 45: 54–60
DOI 10.1055/a-2066-9230
ISSN 0172-4614

Georg Thieme Verlag KG, Rüdigerstraße 14,
70469 Stuttgart, Germany

Correspondence
Dr. Salvatore Gitto
Department of Biomedical Sciences for Health, University of Milan and IRCCS Galeazzi Orthopaedic Institute, Via Cristina Belgioioso 173, 20157 Milan, Italy
sal.gitto@gmail.com

ABSTRACT

Purpose To investigate the role of ultrasound (US) in the evaluation of intrinsic and extrinsic ligaments of the wrist with magnetic resonance arthrography (MRA) as the reference standard.

Materials and Methods This prospective study included patients referred for MRA after wrist trauma. US examination was performed just before MRA. On the dorsal and palmar sides of the wrist, the intrinsic interosseus and midcarpal, extrinsic, and collateral ligaments were evaluated. MRA was performed on a 1.5-T unit. In the first 20 patients included, ligament thickness was independently assessed using US and MRA and thickness reproducibility was calculated. Ligament integrity was evaluated in all patients.

Results 38 patients (22 men, 16 women; mean age: 38 years) were included. Ligament thickness reproducibility ranged between 44 % for the palmar ulnocapitate ligament and 71 % for the palmar scaphotriquetral ligament. US had a sensitivity, specificity, positive and negative predictive values, and accuracy of 100 % in the identification of tears of the palmar (n = 8) and dorsal (n = 3) bands of the scapholunate ligament and the ulnar collateral ligament (n = 3). It had a sensitivity of 100 %, specificity of 97 %, positive predictive value of 50 %, negative predictive value of 100 %, and accuracy of 97 % in the identification of tears of the palmar ulnolunate ligament (n = 1).

Conclusion Compared to MRA, US showed good reproducibility in the assessment of wrist ligament thickness and similar accuracy with respect to identifying tears of the scapholunate, palmar ulnolunate, and ulnar collateral ligaments.

ZUSAMMENFASSUNG

Ziel Es sollte die Rolle des Ultraschalls (US) bei der Beurteilung der intrinsischen und extrinsischen Bänder des Handgelenks untersucht werden, wobei die Magnetresonanz-Arthrografie (MRA) als Referenzstandard diente.

Material und Methoden Diese prospektive Studie umfasste Patienten, die nach einem Handgelenktrauma zur MRA überwiesen wurden. Die US-Untersuchung wurde unmittelbar vor der MRA durchgeführt. Auf der dorsalen und palmaren Seite des Handgelenks wurden die intrinsischen interossären und mediokarpalen, die extrinsischen und die kollateralen Bänder bewertet. Die MRA wurde mit einem 1,5-T-Gerät durchgeführt. Bei den ersten 20 eingeschlossenen Patienten wurde die Dicke der Bänder unabhängig voneinander mittels US und MRA beurteilt und die Reproduzierbarkeit der Dicke berechnet. Die Integrität der Bänder wurde bei allen Patienten untersucht.

Ergebnisse 38 Patienten (22 Männer, 16 Frauen; Durchschnittsalter: 38 Jahre) wurden eingeschlossen. Die Reproduzierbarkeit der Ligamentdicke lag zwischen 44 % beim palmaren Ligamentum ulnocapitatum und 71 % beim palmaren Ligamentum scaphotriquetral. Die US-Untersuchung hatte eine

100 %ige Sensitivität, Spezifität, positive und negative Vorhersagewerte und Genauigkeit bei der Identifizierung von Rissen der palmaren (n = 8) und dorsalen (n = 3) Bänder des Ligamentum scapholunatum und des Ligamentum collaterale ulnare (n = 3). US hatte eine Sensitivität von 100 %, eine Spezifität von 97 %, einen positiven Vorhersagewert von 50 %, einen negativen Vorhersagewert von 100 % sowie eine Genauigkeit von 97 % bei der Erkennung von Rissen des palmaren Ligamentum ulnolunatum (n = 1).

Schlussfolgerung Im Vergleich zur MRA zeigte der US eine gute Reproduzierbarkeit bei der Beurteilung der Banddicke des Handgelenks und eine ähnliche Genauigkeit bei der Identifizierung von Rissen des Ligamentum scapholunatum, des palmaren Ligamentum ulnolunatum und des Ligamentum collaterale ulnare.

Introduction

Wrist ligaments stabilize the carpal bones during movement, transmit motion, and act as a guide with respect to the radius, ulna, and metacarpals [1]. Intrinsic ligaments connect the carpal bones between each other within the same carpal row (interosseous) or passing over the midcarpal joint (midcarpal). Extrinsic ligaments connect the carpal bones to the distal radius or ulna [2]. In the setting of wrist trauma, the prevalence of extrinsic and intrinsic ligament injuries has been reported as 75 % and 60 %, respectively [3]. Clinical presentation includes discomfort, grip weakness, and click phenomena, which may progress to restriction of range of motion and finally osteoarthritis [4]. Early diagnosis and prompt treatment are of paramount importance to prevent long-term complications. Imaging, including X-ray assessment of bone structures as first-level and magnetic resonance imaging, computed tomography arthrography, or magnetic resonance arthrography (MRA) as second-level modalities, helps with diagnosis [5, 6, 7]. Particularly, MRA is the best imaging method to visualize wrist ligaments and assess related injuries [6, 7], although it is expensive and often unavailable in the setting of acute trauma. Preliminary results have been published on ultrasound (US) of wrist ligaments, which is cost-effective, noninvasive, and largely available [8, 9, 10, 11, 12, 13]. Additionally, latest-generation US systems allow for the visualization of small superficial structures of the wrist with high resolution [14, 15]. However, most US studies to date have focused on the evaluation of wrist ligaments in normal subjects [8, 9, 10, 11, 12, 13] or cadavers [16].

The aim of this study is to investigate the role of US in the evaluation of intrinsic and extrinsic ligaments of the wrist in patients with a history of trauma, using MRA as the reference standard.

Materials and methods

Study design and population

This prospective study included a consecutive series of patients with a history of wrist trauma, who were referred for MRA between 2018 and 2021 at a tertiary orthopedic institution. All patients were older than 18 years of age and provided written consent to undergo MRA and preliminary US, which served as a guide for intra-articular injection of contrast medium, as per routine protocol. All patients also provided written consent for anonymized data use for research purposes, which is accepted by Institutional Review Board as informed consent for data publication. Exclusion criteria were: (i) prior wrist surgery and (ii) chronic arthritides, such as rheumatoid arthritis, in which a decrease in ligament detectability has previously been reported [17].

US examination

US examination of the symptomatic wrist was performed on the same day as MRA, just before injecting intra-articular contrast medium, by one of two musculoskeletal radiologists with respectively 10 and 5 years of experience in musculoskeletal US. A commercially available US system (HI VISION Preirus, Hitachi Medical Systems, Tokyo, Japan; or MyLab Alpha, Esaote, Genoa, Italy) equipped with a high-resolution linear probe (14–6 MHz or 13–3 MHz, respectively) was used. The patient sat opposite the radiologist with the hand and forearm lying on the examination table. A large amount of gel was used. Either a rolled towel or a cylindrical US gel tube allowed proper wrist positioning, namely mild palmar flexion and mild dorsal flexion for dorsal and palmar ligaments, respectively. Wrist ligaments were imaged along their longitudinal axis using the distal radius, distal ulna, and carpal bones as anatomical landmarks [13, 18], according to a previously described imaging protocol which also included dynamic evaluation and comparison with the contralateral healthy side (▶ **Table 1**) [19]. Schematic drawings of intrinsic and extrinsic wrist ligaments are shown in ▶ **Fig. 1**.

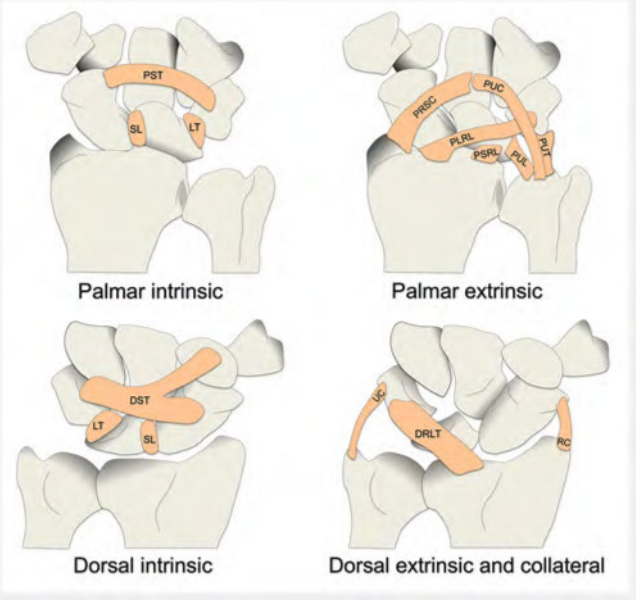
In the first 20 patients included in the study, a preliminary analysis was conducted to evaluate thickness reproducibility between US and MRA. Maximum ligament thickness was measured on US. Healthy ligaments appeared as fibrillar echogenic structures in the expected anatomic location, according to their origin and insertion sites, deeper than the wrist tendons [20, 21]. In all patients included in the study, the US criteria for ligament tears were: (i) ligament disruption or fiber discontinuity and (ii) loss of normal echogenic appearance of the ligament, which was not visualized in contiguity with its attachment site.

MRA examination

MRA of the symptomatic wrist was performed immediately after US examination. The radiocarpal joint was injected in a standard sterile fashion, under US guidance, using a dorsal approach between the radius and scaphoid [22]. A 23-gauge needle was used to inject gadopentetate dimeglumine 1.88 mg/ml (Magnevist, Bayer Healthcare Pharmaceuticals, Wayne, NJ) until joint distension was achieved. MRA studies were performed on a 1.5-T unit (Magnetom Espree or Magnetom Avanto, Siemens Medical Sys-

▶ **Table 1** Sequential imaging protocol to assess the intrinsic and extrinsic ligaments of the wrist, according to a previously published study [19].

Steps	Ligaments	US scans	Wrist positioning
1	Palmar radioscaphocapitate, long radiolunate, and short radiolunate	Longitudinal-to-oblique (from radial to ulnar)	Supination ± dorsal flexion
2	Palmar ulnotriquetral, ulnocapitate, and ulnolunate	Longitudinal-to-oblique (from ulnar to radial)	Supination ± dorsal flexion
3	Palmar scaphotriquetral	Transverse	Supination ± dorsal flexion
4	Scapholunate and lunotriquetral palmar bands	Transverse	Supination ± dorsal flexion
5	Dorsal radiolunotriquetral	Oblique	Pronation ± palmar flexion
6	Dorsal scaphotriquetral	Transverse-to-oblique	Pronation ± palmar flexion
7	Scapholunate and lunotriquetral dorsal bands	Transverse	Pronation ± palmar flexion
8	Radial collateral	Longitudinal	Pronation ± ulnar deviation
9	Ulnar collateral	Longitudinal	Pronation ± radial deviation



▶ **Fig. 1** Schematic drawings of intrinsic and extrinsic wrist ligaments. DRLT = dorsal radiolunotriquetral; DST = dorsal scaphotriquetral; LT = lunotriquetral; PLRL = palmar long radiolunate; PRSC = palmar radioscaphocapitate; PSRL = palmar short radiolunate; PST = palmar scaphotriquetral; PUC = palmar ulnocapitate; PUL = palmar ulnolunate; PUT = palmar ulnotriquetral; RC = radial collateral; SL = scapholunate; UC = ulnar collateral.

tems, Erlangen, Germany) equipped with a dedicated wrist coil. The imaging protocol included coronal and sagittal T1-weighted, coronal and axial fat-suppressed T1-weighted, coronal and axial fat-suppressed proton density-weighted, and sagittal T2-weighted sequences.

MRA evaluation of wrist ligaments for the purpose of this study was performed beyond our clinical schedule. After a delay of 2–3 months aimed at minimizing the recall of specific cases, the musculoskeletal radiologist with 5 years of experience reviewed all MRA scans and assessed the maximum thickness and integrity of the same ligaments that were previously evaluated by means of US. MRA criteria for ligament tears were: (i) ligament disruption or fiber discontinuity and, (ii) in case of scapholunate or lunotriquetral ligament tear, leak of radiocarpal joint contrast into the midcarpal joint.

Data analysis

Anonymous data were analyzed using SPSS 26.0 (SPSS Inc., Armonk, NY, USA). Ligament thickness reproducibility between MRA and US was assessed using the Bland-Altman method. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated for each ligament. A two-sided p-value <0.05 was defined as statistically significant. Continuous variables were reported as mean value ± standard deviation (SD), and categorical variables were reported as absolute value and percentage.

Results

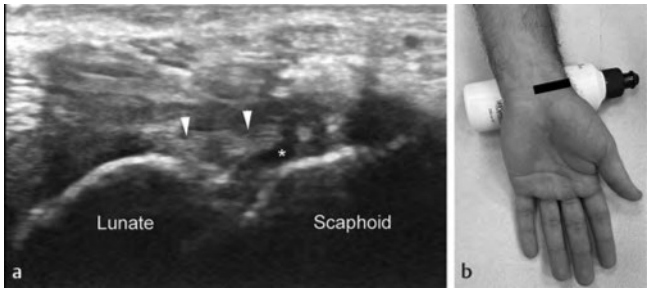
Forty patients with a history of wrist trauma were referred for MRA of the wrist between 2018 and 2021. Two of them underwent prior wrist surgery and were excluded. None of them had chronic arthritis. A total of 38 patients (22 men, 16 women; 38 ± 18 years of age) were included in this study. Trauma occurred between 1 and 12 months before MRA examination. All patients were referred to rule out injuries to the scapholunate and lunotriquetral ligaments or triangular fibrocartilage complex.

Ligament thickness reproducibility between US and MRA ranged between 44 % of the palmar ulnocapitate ligament and 71 % of the palmar band of the scaphotriquetral ligament. ▶ **Table 2** details ligament thickness assessed using both MRA and US, as well as thickness reproducibility for each ligament. Tears of the palmar (▶ **Fig. 2**) and dorsal bands of the scapholunate ligament, ulnar collateral ligament (▶ **Fig. 3**), and palmar ulnolunate ligament (▶ **Fig. 4**) were detected on US. US accuracy ranged between 97 % and 100 %, as detailed in ▶ **Table 3**. A false-positive palmar ulnolunate ligament tear was detected (▶ **Fig. 5**),

▶ **Table 2** Thickness of the carpal ligaments assessed using MRA and US, and thickness reproducibility for each ligament.

Ligament	Thickness by US (mean ± SD)	Thickness by MRA (mean ± SD)	Reproducibility	Repeatability coefficient/bias
SL (palmar band)	1.8 ± 0.3 mm	1.9 ± 0.4 mm	53 %	0.7/–0.16
SL (dorsal band)	2.0 ± 0.4 mm	2.2 ± 0.3 mm	58 %	0.7/–0.20
LT (palmar band)	1.9 ± 0.5 mm	1.9 ± 0.7 mm	58 %	0.8/0.03
LT (dorsal band)	1.6 ± 0.3 mm	1.7 ± 0.3 mm	62 %	0.5/–0.09
PST	1.8 ± 0.4 mm	1.8 ± 0.4 mm	71 %	0.5/–0.01
PRSC	2.0 ± 0.4 mm	2.3 ± 0.7 mm	52 %	0.8/–0.23
PLRL	2.3 ± 1.1 mm	2.7 ± 0.9 mm	60 %	0.6/–0.36
PSRL	1.7 ± 0.4 mm	2.0 ± 0.5 mm	51 %	0.7/–0.27
PUL	2.2 ± 0.9 mm	2.3 ± 0.8 mm	53 %	1.0/–0.10
PUT	1.9 ± 0.4 mm	2.0 ± 0.5 mm	53 %	0.9/–0.06
PUC	2.1 ± 0.7 mm	2.5 ± 0.7 mm	44 %	0.9/–0.38
DST	1.7 ± 0.2 mm	1.8 ± 0.4 mm	47 %	0.8/–0.15
DRLT	2.2 ± 0.5 mm	2.2 ± 0.5 mm	67 %	0.7/–0.02
UC	1.7 ± 0.3 mm	1.6 ± 0.3 mm	55 %	0.7/0.08
RC	1.8 ± 0.3 mm	1.6 ± 0.3 mm	61 %	0.5/0.16

DRLT = dorsal radiolunotriquetral; DST = dorsal scaphotriquetral; LT = lunotriquetral; PLRL = palmar long radiolunate; PRSC = palmar radioscaphocapitate; PSRL = palmar short radiolunate; PST = palmar scaphotriquetral; PUC = palmar ulnocapitate; PUL = palmar ulnolunate; PUT = palmar ulnotriquetral; RC = radial collateral; SL = scapholunate; UC = ulnar collateral



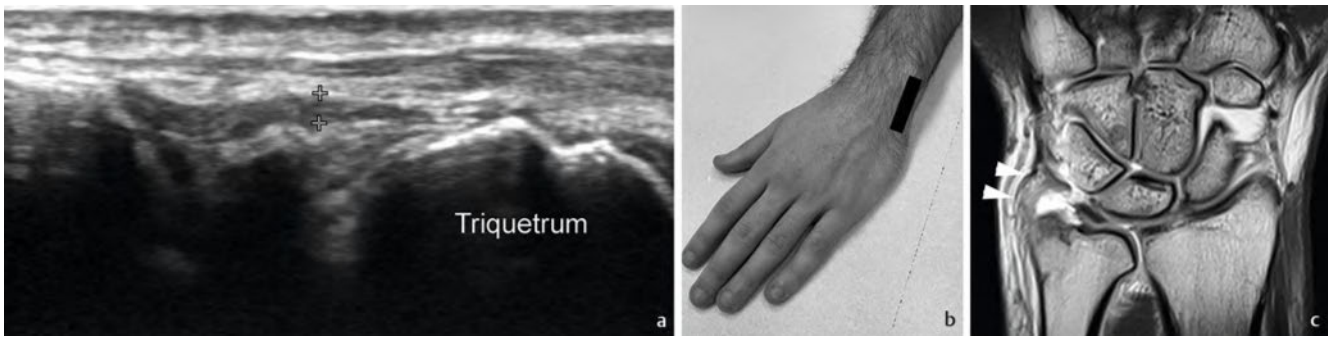
▶ **Fig. 2** Scapholunate ligament tear in a 28-year-old male. **a** The palmar band of the scapholunate ligament (arrowheads) is discontinuous and shows an anechoic cleft (asterisk) consistent with a tear. **b** US probe positioning on the volar wrist with the wrist in supination and slight extension.

namely the ligament appeared torn on US but was intact on MRA. No false-negative cases were reported.

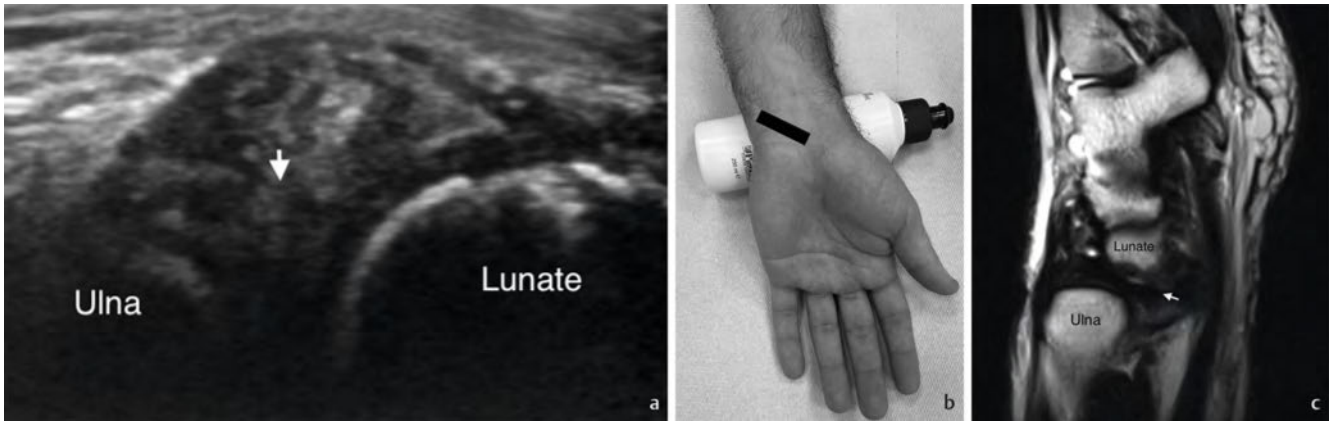
Discussion

The main finding of our study was that US showed good performance in the assessment of intrinsic and extrinsic ligaments of the wrist, including good reproducibility rates in thickness evaluation and high accuracy in tear detection, compared to MRA. Although a limited number of tears was found, our results are encouraging and support the use of US in patients with a history of trauma. These findings open the possibility for US to be implemented in clinical practice, for instance as a first-level imaging modality, which is ideally suited for the assessment of superficial structures such as the carpal ligaments.

In our study, good reproducibility rates were found between MRA and US in the evaluation of ligament thickness, ranging between 44 % and 71 % for the palmar ulnocapitate and palmar scaphotriquetral ligaments, respectively. Additionally, US showed similar diagnostic performance to MRA in the assessment of tears of dorsal and palmar bands of the scapholunate ligament, ulnar collateral ligament, and palmar ulnolunate ligament. Our results agreed with preliminary studies dealing with US of intrinsic interosseous ligaments of the proximal carpal row [23, 24]. Particularly, in our study, US achieved a sensitivity, specificity, accuracy, PPV and NPV of 100 % in identifying scapholunate ligament tears, as also shown by Finlay et al. [23]. In the same paper, the specificity was 100 % and the sensitivity was low (25 %) when evaluating the lunotriquetral ligament [23]. As we did not find any lunotriquetral ligament injuries, the latter result could not be compared with our findings. Regarding extrinsic ligaments, in our study, US had an accuracy of 97–100 % when assessing tears of ulnocarpal ligaments, namely the palmar ulnolunate and ulnar collateral ligaments. We found no case of radiocarpal ligament tear using both US and MRA. This seems surprising, as high rates of palmar long radiolunate (referred to as palmar radiolunotriquetral ligament), palmar radioscaphocapitate, and dorsal radiolunotriquetral (referred to as dorsal radiotriquetral ligament) ligament tears were previously reported in the setting of wrist trauma [3]. However, in



▶ **Fig. 3** Ulnar collateral ligament tear in a 45-year-old male. **a** On US, the ulnar collateral ligament (calipers) is inhomogeneously hypoechoic and not contiguous with the distal ulna, suggesting a ligament tear. **b** US probe positioning on the ulnar wrist, with the wrist in pronation and radial deviation. **c** On MRA, a coronal T1-weighted image shows the ulnar collateral ligament (arrowheads) that is ruptured at its ulnar attachment.



▶ **Fig. 4** Palmar ulnolunate ligament tear in a 55-year-old male. **a** On US, no definite ligament is seen in the expected anatomic location between palmar ulna and lunate (arrow). **b** US probe positioning on the volar wrist, with the wrist in supination and slight extension. **c** On MRA, irregular capsular thickening is noted as a result of previous trauma, with no definite ligament in the expected location (arrow).

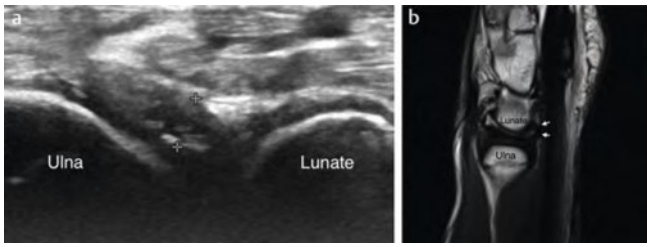
▶ **Table 3** Accuracy, sensitivity, specificity, positive (PPV) and negative (NPV) predictive values in US detection of ligament tears.

Ligament	Tears (n)	Sensitivity	Specificity	Accuracy	PPV	NPV
SL (palmar band)	8	100 %	100 %	100 %	100 %	100 %
SL (dorsal band)	3	100 %	100 %	100 %	100 %	100 %
PUL	1	100 %	97 %	97 %	50 %	100 %
UC	3	100 %	100 %	100 %	100 %	100 %

PUL = palmar ulnolunate; SL = scapholunate; UC = ulnar collateral

this previous study, ligament injuries were evaluated on magnetic resonance imaging and most of them were sprains [3] rather than tears resulting in fiber disruption, which was our US criterion for diagnosis.

Some limitations of our study need to be addressed. First, our study population was relatively small and included only patients with tears of the scapholunate, palmar ulnolunate, and ulnar collateral ligaments. This, however, reflects our study population's characteristics, as all patients were referred to rule out injuries to the proximal interosseous ligaments or the triangular fibrocartilage complex, which also consists of the palmar ulnolunate and ulnar collateral ligaments [25]. Second, MRA was considered as the reference standard, and surgical inspection was not performed. Third, ligament thickness was evaluated on US and compared to MRA, although a certain degree of variability exists when performing these measurements using different imaging modalities [26, 27, 28, 29]. Fourth, all examinations were performed by one of two musculoskeletal radiologists without evaluating interob-



▶ **Fig. 5** False-positive case of palmar ulnolunate ligament tear in an 18-year-old male. **a** On US, hypoechoic ligament appearance (calipers) was misinterpreted as a tear. **b** On MRA, the palmar ulnolunate ligament was intact in the expected location (arrows).

server agreement. However, both radiologists were experienced in musculoskeletal US, and good interobserver agreement has already been shown when evaluating wrist ligaments on US [30]. Fifth, although a standardized protocol was used [19], learning curves of US assessment of wrist ligaments remain unknown and deserve investigation in less experienced operators.

In conclusion, US is a noninvasive, cost-effective, and largely available imaging method that enables evaluation of the intrinsic and extrinsic wrist ligaments. Tears of the scapholunate, ulnar collateral, and palmar ulnolunate ligaments can be detected using US with similar diagnostic performance compared to MRA, which is expensive and less easily available. Future larger studies are warranted to investigate US performance in the assessment of other ligamentous injuries and involve operators with different levels of expertise and experience.

Acknowledgement

S. Gitto was supported by Fondazione Umberto Veronesi (Post-doctoral Fellowship 2022)

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Berger RA. The ligaments of the wrist. A current overview of anatomy with considerations of their potential functions. Hand Clin 1997; 13: 63–82. doi:10.1016/S0749-0712(21)00081-0

[2] Taleisnik J. The ligaments of the wrist. J Hand Surg Am 1976; 1: 110–118. doi:10.1016/S0363-5023(76)80004-4

[3] Taneja AK, Bredella MA, Chang CY et al. Extrinsic wrist ligaments: prevalence of injury by magnetic resonance imaging and association with intrinsic ligament tears. J Comput Assist Tomogr 2013; 37: 783–789. doi:10.1097/RCT.0b013e318298aa2a

[4] Gilula LA, Weeks PM. Post-traumatic ligamentous instabilities of the wrist. Radiology 1978; 129: 641–651. doi:10.1148/129.3.641

[5] Bateni CP, Bartolotta RJ, Richardson ML et al. Imaging Key Wrist Ligaments: What the Surgeon Needs the Radiologist to Know. AJR Am J Roentgenol 2013; 200: 1089–1095. doi:10.2214/AJR.12.9738

[6] Theumann NH, Pfirrmann CWA, Antonio GE et al. Extrinsic Carpal Ligaments: Normal MR Arthrographic Appearance in Cadavers. Radiology 2003; 226: 171–179. doi:10.1148/radiol.2261011715

[7] Shahabpour M, Abid W, Van Overstraeten L et al. Extrinsic and Intrinsic Ligaments of the Wrist. Semin Musculoskelet Radiol 2021; 25: 311–328. doi:10.1055/s-0041-1731653

[8] Boutry N, Lapegue F, Masi L et al. Ultrasonographic evaluation of normal extrinsic and intrinsic carpal ligaments: preliminary experience. Skeletal Radiol 2005; 34: 513–521. doi:10.1007/s00256-005-0929-4

[9] Griffith JF, Nin Chan DP, Ho PC et al. Sonography of the normal scapholunate ligament and scapholunate joint space. J Clin Ultrasound 2001; 29: 223–229. doi:10.1002/jcu.1024

[10] Orlandi D, Fabbro E, Ferrero G et al. High-resolution ultrasound of the extrinsic carpal ligaments. J Ultrasound 2012; 15: 267–272. doi:10.1016/j.jus.2012.09.004

[11] Taljanovic M, Malan J, Sheppard J. Normal Anatomy of the Extrinsic Capsular Wrist Ligaments by 3-T MRI and High-Resolution Ultrasonography. Semin Musculoskelet Radiol 2012; 16: 104–114. doi:10.1055/s-0032-1311762

[12] Renoux J, Zeitoun-Eiss D, Brasseur JL. Ultrasonographic Study of Wrist Ligaments: Review and New Perspectives. Semin Musculoskelet Radiol 2009; 13: 055–065. doi:10.1055/s-0029-1202245

[13] Wang JC, Wu WT, Chang KV et al. Sonoanatomy and Stepwise/Systematic Ultrasound Examination of the Extrinsic/Intrinsic Wrist Ligaments. Diagnostics (Basel) 2021; 11: 1834. doi:10.3390/diagnostics11101834

[14] Gitto S, Draghi AG, Draghi F. Sonography of Non-neoplastic Disorders of the Hand and Wrist Tendons. J Ultrasound Med 2018; 37: 51–68. doi:10.1002/jum.14313

[15] Wu WT, Chang KV, Mezian K et al. Ulnar Wrist Pain Revisited: Ultrasound Diagnosis and Guided Injection for Triangular Fibrocartilage Complex Injuries. J Clin Med 2019; 8: 1540. doi:10.3390/jcm8101540

[16] Jacobson JA, Oh E, Propeck T et al. Sonography of the Scapholunate Ligament in Four Cadaveric Wrists: Correlation with MR Arthrography and Anatomy. AJR Am J Roentgenol 2002; 179: 523–527. doi:10.2214/ajr.179.2.1790523

[17] Sconfienza LM, Silvestri E, Cimmino MA. High-resolution ultrasound evaluation of extrinsic wrist ligaments in patients affected by rheumatoid arthritis. Eur Radiol 2012; 22: 1586–1591. doi:10.1007/s00330-012-2402-9

[18] Taljanovic MS, Goldberg MR, Sheppard JE et al. US of the Intrinsic and Extrinsic Wrist Ligaments and Triangular Fibrocartilage Complex – Normal Anatomy and Imaging Technique. Radiographics 2011; 31: 79–80. doi:10.1148/rg.e44

[19] Gitto S, Messina C, Mauri G et al. Dynamic high-resolution ultrasound of intrinsic and extrinsic ligaments of the wrist: How to make it simple. Eur J Radiol 2017; 87: 20–35. doi:10.1016/j.ejrad.2016.12.002

[20] Gitto S, Draghi F. Normal Sonographic Anatomy of the Wrist With Emphasis on Assessment of Tendons, Nerves, and Ligaments. J Ultrasound Med 2016; 35: 1081–1094. doi:10.7863/ultra.15.06105

[21] Draghi F, Gitto S, Bianchi S. Injuries to the Collateral Ligaments of the Metacarpophalangeal and Interphalangeal Joints: Sonographic Appearance. J Ultrasound Med 2018; 37: 2117–2133. doi:10.1002/jum.14575

[22] Messina C, Banfi G, Aliprandi A et al. Ultrasound guidance to perform intra-articular injection of gadolinium-based contrast material for magnetic resonance arthrography as an alternative to fluoroscopy: the time is now. Eur Radiol 2016; 26: 1221–1225. doi:10.1007/s00330-015-3945-3

[23] Finlay K, Lee R, Friedman L. Ultrasound of intrinsic wrist ligament and triangular fibrocartilage injuries. Skeletal Radiol 2004; 33: 85–90. doi:10.1007/s00256-003-0698-x

[24] Taljanovic MS, Sheppard JE, Jones MD et al. Sonography and Sonoarthrography of the Scapholunate and Lunotriquetral Ligaments and Triangular Fibrocartilage Disk. J Ultrasound Med 2008; 27: 179–191. doi:10.7863/jum.2008.27.2.179

[25] Nöbauer-Huhmann IM, Pretterklieber M, Erhart J et al. Anatomy and Variants of the Triangular Fibrocartilage Complex and Its MR Appearance at 3 and 7T. Semin Musculoskelet Radiol 2012; 16: 093–0103. doi:10.1055/s-0032-1311761

[26] Abrar DB, Schleich C, Nebelung S et al. High-resolution MRI of flexor tendon pulleys using a 16-channel hand coil: disease detection and differentiation of psoriatic and rheumatoid arthritis. Arthritis Res Ther 2020; 22: 40. doi:10.1186/s13075-020-2135-0

[27] Rosskopf AB, Martinoli C, Sconfienza LM et al. Sonography of tendon pathology in the hand and wrist. J Ultrason 2021; 21: 306–317. doi:10.15557/JoU.2021.0052

[28] Rosskopf AB, Taljanovic MS, Sconfienza LM et al. Pulley, Flexor, and Extensor Tendon Injuries of the Hand. Semin Musculoskelet Radiol 2021; 25: 203–215. doi:10.1055/s-0041-1727196

[29] Tinazzi I, McGonagle D, Aydin SZ et al. 'Deep Koebner' phenomenon of the flexor tendon-associated accessory pulleys as a novel factor in tenosynovitis and dactylitis in psoriatic arthritis. Ann Rheum Dis 2018; 77: 922–955. doi:10.1136/annrheumdis-2017-212681

[30] Lacelli F, Muda A, Sconfienza LM et al. High-resolution ultrasound anatomy of extrinsic carpal ligaments. Radiol Med 2008; 113: 504–16. doi:10.1007/s11547-008-0269-2