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Imaging assessment of dorsal scaphoid displacement in patients with scapholunate ligament tears: what is the best option for quantitative assessment?

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Abstract

Objective To compare four different methods for the quantitative assessment of dorsal scaphoid displacement in patients with scapholunate ligament tears.

Methods A total of 160 consecutive patients who underwent CT arthrography to evaluate a suspected scapholunate ligament tear were prospectively included in this study approved by the local ethics committee. MR images were available for 65 of these patients. Two readers independently evaluated the dorsal scaphoid displacement on conventional radiographs with the dorsal tangential line (DTL) method, the posterior radioscaphoid angle (PRSA) on both CT and MR, and the radioscaphoid congruency ratio on MR. These measurements were compared in groups of patients with and without scapholunate ligament tears.

Results The measurement interobserver agreement was considered excellent for the DTL and the PRSA on CT (ICC = 0.93 and 0.88, respectively), good for the PRSA (ICC = 0.65) on MR, and moderate for the RSCR (ICC = 0.49). There was a significant increase in the values of DTL and PRSA on CT between patients with normal and ruptured SLIL ($p <$ 0.0001). The same tendency was seen on MR-based methods, but these differences were only significant for one reader. The only method that allowed the differentiation between patients with normal and partially ruptured SLIL was the PRSA on CT. PRSA on CT yielded the best diagnostic performance for SLIL rupture (a sensitivity and a specificity of 70–82% and 70–72%).

Conclusion DTL on standard radiographs and the PRSA on CT are the most consistent imaging indicators of SDD with an excellent interobserver reproducibility.

Key Points

- *Dorsal scaphoid displacement is an important prognostic factor in patients with scapholunate instability.*
- *Quantitative assessment of dorsal scaphoid displacement can be performed on conventional radiographs and CT with an excellent reproducibility.*
- *The posterior radioscaphoid angle on CT yielded the best diagnostic performance for the identification of scapholunate ligament tears and the only method allowing differentiation between patients with normal and partially torn ligaments.*

Keywords Wrist injury · Joint instability · Interosseous ligament · Osteoarthritis · Multimodal imaging

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Abbreviations

AUC	Area under the curve
DTL	Dorsal tangential line
FOV	Field-of-view
ICC	Intraclass correlation coefficients
PACS	Picture archiving and communication system
PRSA	Posterior radioscaphoid angle
ROC	Receiver operator characteristics
RSCR	Radioscaphoid congruency rate
SDD	Scaphoid dorsal displacement

SLAC Scapholunate advanced collapse
SLI Scapholunate instability
SLIL Scapholunate interosseous ligament

Introduction

Damage to the scapholunate interosseous ligament (SLIL) is the main factor in the genesis of scapholunate instability. Scapholunate instability (SLI) may be challenging to diagnose. The scaphoid dorsal displacement (SDD) is an important diagnostic factor, and its assessment is not clearly codified to date [1, 2]. Also, SDD is currently considered a negative prognostic factor in patients with scapholunate instability and may imply a more invasive surgical treatment [3–5]. Additionally, previous studies indicated the degree of SDD is correlated to the severity of scapholunate instability and the presence of osteoarthritis due to increases of the compressive and shear stress on the lateral and dorsal aspect of the scaphoid fossa of the radius [6, 7]. Thus, a reliable quantitative imaging method for the evaluation of the SDD appears to be paramount.

There is no consensus in the literature on the most consistent imaging indicator to assess the SDD. Chan et al studied 20 patients using standard radiographs and concluded that the dorsal tangential line (DTL) method is the most practical and had an excellent reliability [8]. However, radiographs are susceptible to patient positioning issues and may have a low sensitivity to identify early carpal instability. Thus, Teixeira et al proposed measuring the posterior radioscaphoid angle (PRSA), defined as the angle between the scaphoid fossa surface plane and the most posterior point of the scaphoid, on CT images [7, 9]. The PRSA has been reported to be reproducible and correlated with scapholunate instability severity [6, 7]. Finally, Meister et al evaluated 36 patients and indicated that the radioscaphoid congruency rate (RSCR), defined as the ratio of SDD with respect to the radial articular surface on sagittal MR images, was positively associated with SLIL tears. Moreover, these authors suggested that MR imaging measurements were more reliable than those performed on conventional radiographs (excellent versus fair reliability, respectively) [10].

Based on the SLIL status and the presence of radio- and/or midcarpal osteoarthritis on CT arthrography, this study aimed to compare four different methods for the quantitative assessment of the SDD (e.g., DTL on conventional radiographs, PRSA on both CT and MR, and the RSCR on MR). The values obtained with each method were correlated with SLIL tears and wrist chondropathy (scapholunate advanced collapse (SLAC)). This information may help optimize and standardize the imaging evaluation of the dorsal scaphoid subluxation.

Materials and methods

Study population

Between January 2015 and Mars 2020, 177 consecutively included patients older than 18 years who presented with post-traumatic wrist pain (spontaneous and/or induced by palpation) over the scapholunate joint space and who underwent wrist CT arthrography were prospectively included in this study. Our institutional review board approved the study (CPP: 140707, Clinical Trials Registry No. NCT02401568), and all patients provided written informed consent. Patients with a history of wrist fractures (11 patients), previous wrist surgery (four patients), and suboptimal opacification of the radiocarpal and midcarpal compartments on wrist arthrography (two patients) were excluded. Thus, the final study sample was composed of 160 patients.

Radiographic evaluation

Conventional radiographs were performed in all patients in a radiography/fluoroscopy room with a Sonialvision G4 (Shimadzu) or Visionary DRF (Fujifilm) using a tube with a small focal spot, 48 kVp, 6.3–10 mAs, and 20–64 ms of exposure time without an anti-diffusion grid. Posteroanterior, profile, and posteroanterior with clenched fist views were performed.

CT arthrography

The intra-articular injection was performed by a musculoskeletal radiologist under strict asepsis using fluoroscopic guidance. The midcarpal and, subsequently, the radiocarpal compartments were opacified using a 25-gauge needle and 3 ml of non-diluted arthrography-dedicated iodinated contrast (Iodixanol, VISIPAQUE 270 mg, GE Healthcare). Images were acquired with patients lying in ventral decubitus with the arm above the head with the wrist in neutral position. Images were acquired with the following parameters: field-of-view (FOV) 160 mm, 520 × 520 matrix, 100 kVp, 100 mA (50 mAs effective), slice thickness 0.5mm, and tube rotation time 0.5 s. Images were reconstructed with a bone kernel with 1.5-mm-thick slices and a 0.3-mm increment in the three orthogonal planes.

MR imaging

MR imaging was performed either with a 1.5-T or 3-T MR scanner (Signa HDX or Discovery MR750 W GE Healthcare) with a dedicated wrist coil and patients lying in ventral decubitus with the arm above the head and the wrist in neutral position. Examinations included at least a T1-weighted sequence in one orthogonal plane and T2-weighted fat-saturated sequences in the three orthogonal planes. MR imaging was available for 65 of the patients included and 61 studies were performed with the 3-T scanner while four were performed with the 1.5-T scanner. The acquisition parameters used are presented in Table 1.

CT and conventional radiographs were performed on the same day. MR imaging was performed within 3 weeks of the initial evaluation.

Image analysis

All images acquired were retrospectively evaluated on a picture archiving and communication system (PACS) workstation (Fujifilm Synapse v4.1.600, Fujifilm). The three components of SLIL (dorsal, ventral, and membranous) were analyzed on CT arthrography using two-dimensional multiplanar reformats by a musculoskeletal radiologist (P.A.G.T.) with 13 years of clinical experience in musculoskeletal radiology. A ligament tear was characterized by a clear loss in continuity of the dorsal and/or ventral portion of the SLIL. Based on the ligaments' appearance, two groups were created: no tear or isolated tear of the membranous portion only (control group) and tears of the dorsal and/or volar portions (study group). The SLIL tears were further divided into partial tears (partial or total loss of continuity in the dorsal or volar segment) and full tears (total loss of continuity in the dorsal and volar segments). SLIL thickening without loss of fiber integrity and foci of needle-head ligamentous contrast insinuation were considered non-ruptured. The presence of radiocarpal and midcarpal chondropathy was evaluated on CT arthrography images by the same reader. Chondropathy was considered present when areas of superficial irregularity, fissures, erosion, or subchondral bone exposure were identified.

Table 1 MR imaging acquisition protocol

Field strength	1.5T	3T
Pulse sequence	Fast-spin echo	Fast-spin echo
Weighting	T2	T2
Plane	Sagittal	Sagittal
TE (ms)	45	42
TR (ms)	2153	4937
NEX	2	3
Bandwidth (kHz)	41.67	22.73
ETL	12	12
FOV (mm)	100	100
Matrix	384 × 352	416 × 384
Slice thickness (mm)	2.5	2.0
Gap (mm)	0.3	0.2
Acceleration factor	none	2

TE echo time, *TR* repetition time, *NEX* number of excitations, *ETL* echo train length, *FOV* field-of-view

SDD measurements

The SDD was measured by two independent radiologists, each with 2 years of clinical experience, with the following methods (Fig. 1):

– The DTL on radiographs [8]

On profile radiographic views, a longitudinal line was drawn through the dorsal articular rim of the radial articular surface, parallel to the long axis of the radius. The distance of the most posterior portion of the scaphoid to this line in millimeters was calculated.

– The PRSA on CT and MR imaging [7]
  The PRSA (in degrees) was evaluated independently on both CT and T2-weighted fat-saturated MR images. First, sagittal images were browsed to identify the image depicting the most posterior point of the scaphoid. Then, a line passing through the volar and dorsal rims of the scaphoid fossa of the radius was drawn on this image. A second line was drawn, passing through the dorsal rim radial articular surface and the most posterior point of the scaphoid. The angle between these lines was measured. Osteophytes are not included in the measurements.
– The RSCR on MR imaging [10]

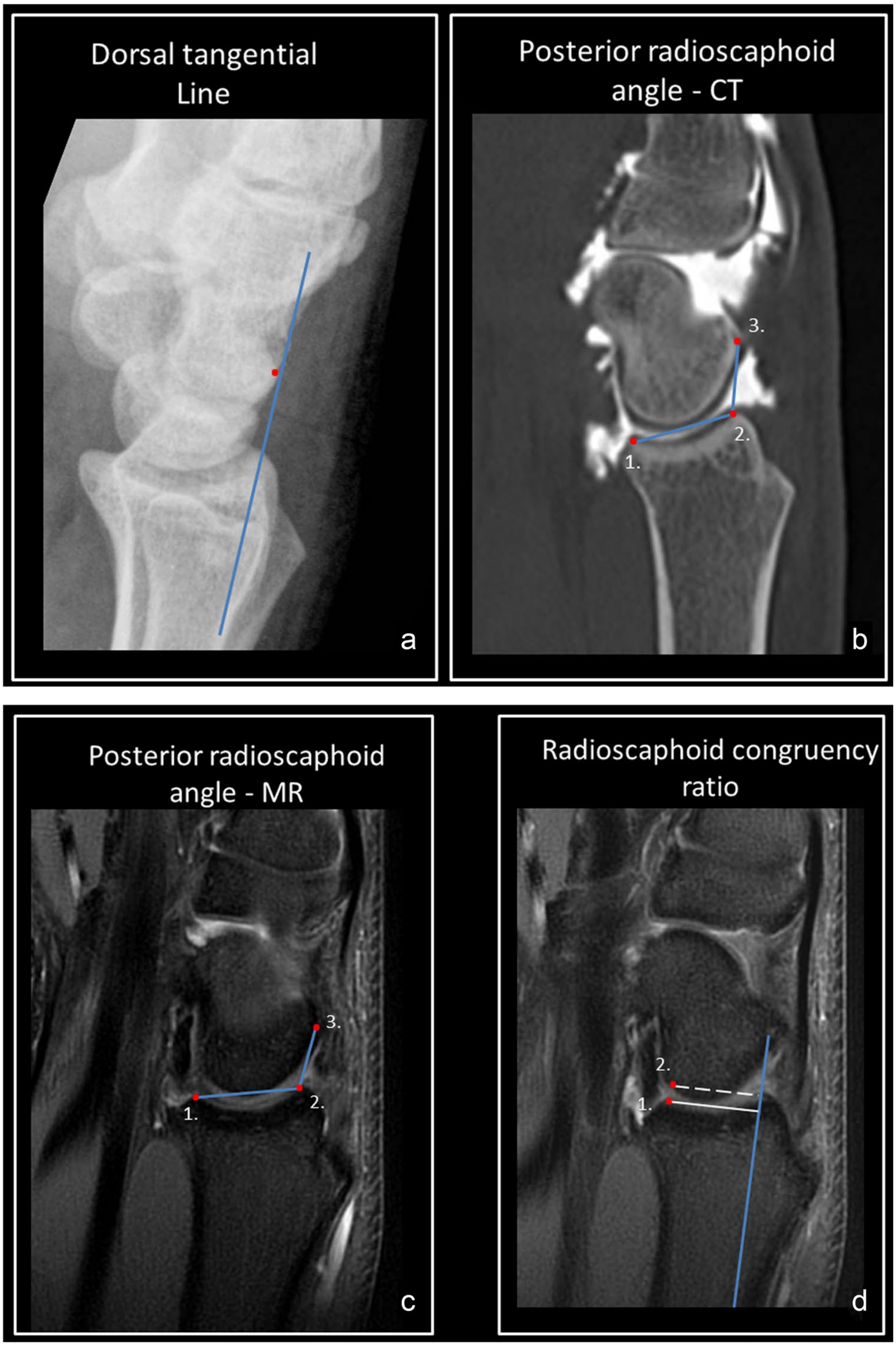
On sagittal T2-weighted fat-saturated MR images, the distance between the dorsal and volar rims of the articular surface of the radius was measured (distance 1). Then, the distance between the most volar point, the scaphoid articular surface, and the volar rim of the radial articular surface was measured (distance 2). The ratio between lines 1 and 2 was calculated (congruency rate %).

Thus, four different measurement data sets were available for analysis.

A training session with 10 cases not included in the study population was performed with the readers to ensure the measurements performed with the same technique.

Statistical analysis

Statistical analysis was performed using the social statistics software (Social Science Statistics. https://www.socscistatistics.com/tests/chisquare2/default2.aspx). The Shapiro-Wilk test was used to evaluate data normality. As all data sets evaluated except the PRSA measurements in MR images ($p > 0.4$) were considered non-normally distributed ($p < 0.0001$), quantitative data is presented as



median: interquartile range (minimal—maximal values). Intraclass correlation coefficients (ICC) were calculated to evaluate the interobserver agreement. ICC values of 0–0.20 were considered to represent slight; 0.21–0.4, fair; 0.41–0.60, moderate; 0.61–0.80, good; and 0.81–1, excellent agreement. The measurements in each data set were correlated with the SLIL status. The Mann-Whitney test was used to evaluate the differences in measurements between patients with and without SLIL ruptures. The ANOVA test was used to assess the measurement differences between patients with normal, partially, and fully torn SLIL ligaments. The threshold of statistical significance was set to $p < 0.05$. Receiver operator characteristics (ROC) analysis (pROC package, R software version 3.6.0) was performed to evaluate the diagnostic performance of each method of dorsal scaphoid subluxation assessment

◂**Fig. 1** Methods for the evaluation of the dorsal displacement of the scaphoid in a 22-year-old male with persistent wrist pain after trauma with normal scapholunate ligament and no chondropathy on arthro-CT (not shown). **a** Conventional radiograph of the wrist in profile depicting the application of dorsal tangential line method. The red marker shows the most posterior point of the scaphoid bone. A line parallel to the long axis of the radius passing through the dorsal rim of the radial articular surface is drawn (blue line). The distance between the red dots in the line represents the dorsal displacement of the scaphoid. **b**, **c** Sagittal CT arthrography and T2-weighted fat-saturated MR images showing the most posterior point of the scaphoid, demonstrating the application of posterior radioscaphoid angle method. A line passing through the volar (marker 1) and dorsal (marker 2) rims of the scaphoid fossa of the radius was drawn. A second line was drawn, passing through the dorsal rim radial articular surface (marker 2) and the most posterior point of the scaphoid. The angle between these lines represents the dorsal displacement of the scaphoid. **d** Sagittal T2-weighted MR image showing the most posterior point of the scaphoid, demonstrating the application of the radioscaphoid congruency ratio. A line parallel to the long axis of the radius passing through the dorsal rim of the radial articular surface is drawn (blue line). The distances between the volar rim of the radial articular surface (marker 1, white line) and the most volar congruency point between the radius and the scaphoid (maker 2, dashed line) are calculated. The ratio between these lines (white line/dashed line) represents the dorsal displacement of the scaphoid

for the differentiation between patients with and without SLIL tears and chondropathy.

Results

Among the 160 patients evaluated, there were 109 men and 51 women (M/F = 2.1/1). The median age was 43 (18–75) years. On the CT arthrogram, 100 SLIL were considered normal, 28 partially ruptured, and 32 fully ruptured. Wrist chondropathy was identified in 33 patients. In the group of patients for whom MR imaging was available, 45 SLIL were considered normal, 11 partially ruptured, and nine fully ruptured. In this group, nine patients presented chondropathy.

SDD assessment

Table 2 summarizes the data for the study sample. The measurement interobserver agreement was considered excellent for the DTL and the PRSA on CT (ICC = 0.93 and 0.88, respectively). The interobserver agreement was considered good for the PRSA on MR and moderate for the RSCR (ICC = 0.65 and 0.49, respectively).

Based on the SLIL status on CT arthrogram, for both readers, there was a significant increase in the values of DTL and PRSA on CT between patients with normal and ruptured (e.g., partial and full tears together) SLIL (p <0.0001). Although the same tendency was seen on MR-based methods (PRSA and RSCR), these differences were only significant for one of the readers (p = 0.1 and 0.017 with PRSA and 0.003 and 0.19 with RSCR for readers 1 and 2, respectively). When the DTL and PRSA on CT were evaluated on the same 65 patients for whom MR imaging was available, the differences between patients with normal and ruptured SLIL remained statistically significant for both readers (p < 0.0002) (Fig. 2).

A progressive increase in the median values was obtained with all four methods evaluated in patients with normal, partially ruptured, and fully ruptured SLIL. There was a statistically significant difference between patients with normal and fully ruptured SLIL in all evaluated methods (p values varying from 0.03 to < 0.0001) except the PRSA on MR for reader 1 (p > 0.06). Differences between patients with partially and fully ruptured SLIL were statistically significant with the values obtained with DTL and the PRSA on CT (p values varying from 0.03 to < 0.0001) as well as with the RSCR for reader 1 (p = 0.013). The only method that allowed the differentiation between patients with normal and partially ruptured SLIL was the PRSA on CT for both readers (p < 0.002) (Fig. 3).

Based on the articular surfaces' status on CT arthrogram, both the DTL and the CT PRSA methods showed a significant increase in measurements between patients with and without wrist chondropathy (p <0.0001). These differences were not statistically significant with MR-based measurements; however, the number of patients with chondropathy was small in this group (p >0.1).

Diagnostic performance for SLIL tears and wrist chondropathy

The performance of the four methods evaluated for the diagnosis of SLIL tears and wrist chondropathy is presented in Table 3. For the diagnosis of SLIL tears, the best performance was obtained with the PRSA on CT method with a ROC area under the curve (AUC) of 0.77–0.79 compared to 0.69–0.71, 0.61–0.71, and 0.52–0.66 for the DTL, PRSA on MR, and RSCR methods, respectively, for both readers. The PRSA method on CT yielded a sensitivity and a specificity of 70–82% and 70–72% for identifying SLIL tears (threshold 104.5°). When the diagnostic performance for the differentiation between normal and partially torn SLIL was considered in the 65 patient subgroup with all four imaging methods available, the PRSA on CT method yielded the best diagnostic performance with an ROC AUC of 0.75–0.81 compared to the other three methods for which these figures varied from 0.46 to 0.75. In this subgroup, the PRSA method on CT yielded a sensitivity and a specificity of 64–82% and 71–76% for identifying partial SLIL tears (threshold 104.5°).

Regarding the diagnosis of wrist chondropathy, both the DTL and PRSA on CT methods yielded a similar performance with ROC AUC of 0.77–0.79 and 0.79–0.81,

Table 2 Measurement results with the four methods of posterior scaphoid subluxation quantification in the subgroups studied

		DTL		PRSA CT		PRSA MR		RSCR	
	Metric	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2	Reader 1	Reader 2
Normal SLIL	Median	0.97	1.02	101	101	106	105	6.6	14
	IQR	1.32	1.34	8	9	9	9	8.3	8
	Min	−1.58	−2.06	87	88	88	88	1.2	3
	Max	5.72	5.8	122	127	117	120	29	38
Partial rupture	Median	1.28	1.29	106	107	105	107	11.4	15
	IQR	1.24	1.18	11	12	15.5	13.5	6.8	8.5
	Min	−1.1	−1.2	93	95	87	98	2.1	4
	Max	4.29	4.08	124	131	119	122	24.9	39
Complete rupture	Median	2.62	2.79	121	123.5	114	115	23	24
	IQR	1.44	1.63	13.75	12	18.5	14.5	32.3	36
	Min	−0.5	−2.21	92	90	93	98	1.5	3
	Max	11.6	10.86	137	139	133	126	40.7	47
Partial and complete tears combined	Median	1.96	2	112	116	108.5	112.5	12.2	16.5
	IQR	1.76	1.83	18	20	15.3	12.3	15.8	20
	Min	−1.1	−2.21	92	90	87	98	1.5	3
	Max	11.6	10.86	137	139	133	126	40.7	47
Chondropathy	Median	2.39	2.68	121	122	108	113	11.1	16
	IQR	1.94	2.45	17.5	23	14	13	15.7	21
	Min	−0.5	−0.54	92	90	97	98	2.1	3
	Max	11.6	10.86	137	139	133	126	38.4	47

IQR interquartile range, *SLIL* scapholunate interosseous ligament

respectively. The performance was worse with MR-based methods with ROC AUC varying from 0.53 to 0.65.

Discussion

The current study showed that DTL on radiographs and PRSA on CT are the most consistent indicators for evaluating the SDD in patients with SLIL tears on CT arthrography. Both imaging indicators yielded an excellent interobserver reproducibility (ICC > 0.88) and showed a significant increase in measurement in patients with a SLIL tear compared to normal ligament status. However, the PRSA on CT allowed the differentiation between patients with normal and partially ruptured SLIL ($p < 0.002$), while the DTL did not ($p > 0.3$). Additionally, the diagnostic performance for SLIL tears was better with the PRSA on CT compared to DTL, and the threshold 104.5° yielded a sensitivity and a specificity of 70–82% and 70–74%, respectively. The diagnostic performance of PRSA on CT was similar to that of prior reports, and the advantage of the PRSA on CT compared to DTL might be related to the fact that CT measurements are less susceptible to technical factors (e.g., patient positioning and superimposition) [11]. Finally, both of these methods showed similar performance for the diagnosis of wrist osteoarthritis. To the best of our knowledge, the DTL performance for identifying SLIL tears or osteoarthritis had not yet been evaluated.

The interobserver reproducibility of MR-based methods (ICC < 0.65) was worse than that of DTL and PRSA on CT. We hypothesize that the thicker slices influenced the choice of the sagittal MR image depicting the most posterior portion of the scaphoid by the readers on MR images compared to CT (2–2.5 mm versus 0.5 mm, respectively). Indeed the thicker slices on 2D sagittal spin echo images might have led to a less accurate depiction of the dorsal scaphoid bone surface and a wider variation in measurements among the readers (e.g., different slice selection). These results differ from the study of Meister et al, who reported a better reproducibility of the RSCR compared to that of DTL in a population of 33 patients [10]. These authors, however, did not describe the MR protocol used and evaluated a smaller patient population. Moreover, all patients evaluated by these authors had a surgically confirmed SLIL tear, which implies more severe lesions than in the population we studied, including patients with less severe lesions not necessarily requiring surgical treatment. The latter might also explain the fact that the performance of MR-based methods (ROC AUC varying from 0.52 to 0.71) was not only lower than that presented by Meister et al for the RSCR but also lower than that of the DTL and the PRSA on CT [10]. In light of these results,

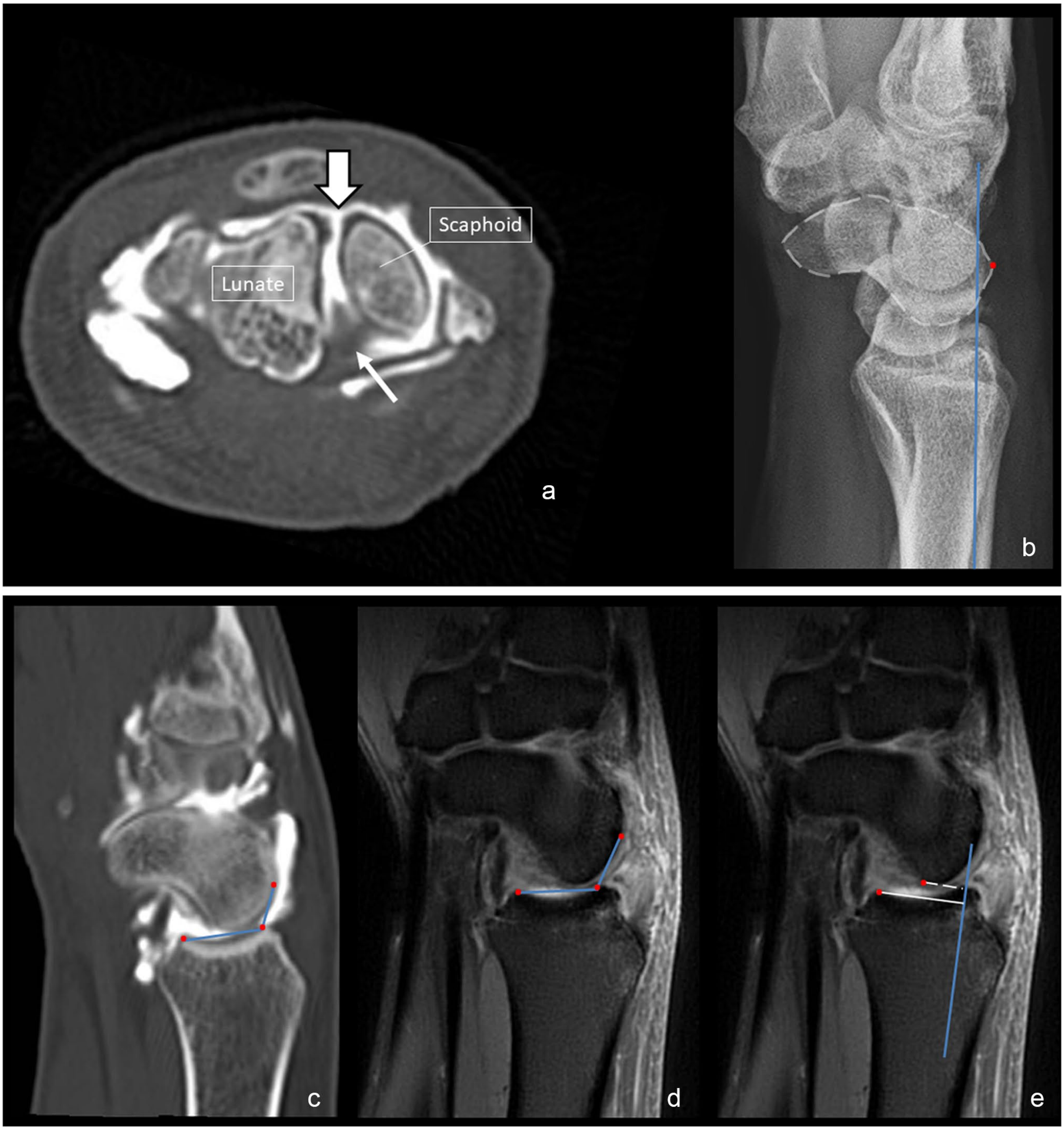


Fig. 2 A 44-year-old female with post-traumatic dorsal wrist pain. **a** Axial CT arthrography image depicting a full tear of the dorsal portion of the scapholunate ligament (fat arrow) and an irregular partially torn aspect of the ventral portion (arrow). **b–e** The dorsal tangential line (**b**), posterior radioscaphoid angle on CT (**c**), posterior radioscaphoid angle on MR (**d**), and the radioscaphoid congruency ratio methods (**e**) demonstrating an increased dorsal displacement of the scaphoid. Among the readers, the measured values obtained with these methods varied from 3.3 to 3.6 mm, 118 to 120°, 115 to 120°, and 40 to 45%, respectively

although the evaluation of SDD cannot be recommended using conventional 2D MR images, the use of 3D isometric MR sequences may help overcome these difficulties and requires further evaluation [12, 13].

With all the methods evaluated and in accordance with prior reports, the SDD increased with SLIL tear severity [6]. Moreover, the presence of wrist osteoarthritis was also associated with increases in SDD values. These differences

Fig. 3 A 54-year-old patient with a history of wrist trauma and recurrent wrist pain. **a**, **b** Axial and coronal CT arthrography images depicting a partial tear of the dorsal portion of the scaphoid (fat arrow). **c**, **d** The dorsal tangential line (**c**) was considered to be normal by both readers (−0.5 and −1.1 mm), while the posterior radioscaphoid angle on CT (**d**) was considered to be abnormal for both readers (105° and 112°)

were particularly well identified with the PRSA on CT method that showed statistically different measurements for both readers in all subgroups evaluated ($p < 0.002$). These data underscore and confirm the prognostic role of dorsal scaphoid subluxation in patients with scapholunate instability [6, 11]. Thus, evaluating the SDD on conventional radiographs (DTL) and CT (PRSA) can be recommended for patients with a suspected scapholunate instability as these methods are frequently used for the initial evaluation of wrist injury. Abnormal measurements should lead to a full wrist image workup with MRI and potentially CT or MR arthrography and may have surgical implications. For instance, the PRSA on CT may allow the identification of partial SLIL tears, which are frequently associated with dorsal capsular scapholunate septum injury and may be treated by minimally invasive partial ligament reconstruction during wrist arthroscopy. On the other hand, patients with higher degrees of SDD may require a more invasive surgical procedure such as an SL ligamentoplasty [4, 11, 14].

Various limitations of this study should be acknowledged. First, MR imaging was not available for the whole population, which might have led to an underestimation of the performance of the MR-based methods. However, the analysis of DTL and PRSA on CT in the subgroup of patients (65) in which all four methods were available yielded similar results. Second, the SLIL ruptures and SLI were not confirmed by arthroscopy, while for many surgical teams, wrist arthroscopy is considered the gold standard to directly explore the SLIL ligament and testing the SL joint space congruency. However, CT arthrography has a high performance (95% sensitivity and 86% specificity) with an almost perfect interobserver agreement (kappa = 0.96) to diagnose scapholunate ligament tears [15, 16]. The use of CT arthrography as gold standard may have influenced the diagnostic performance assessment of SDD measurements. Only standard 2D MR images were available for analysis and MR studies were performed at both 1.5- and 3-T MR scanners. An adapted MR protocol with isometric voxels

Table 3 Diagnostic performance and thresholds of the evaluated methods for the identification of SLIL tears and wrist chondropathy

		DTL	PRSA CT	DTL (all method subgroup)	PRSA CT (all method subgroup)	PRSA MR	RSCR
Reader 1							
SLIL*	AUC	0.71 (0.63–0.79)	0.79 (0.71–0.86)	0.82 (0.7–0.93)	0.82 (0.69–0.96)	0.61 (0.46–0.76)	0.66 (0.51–0.80)
	Threshold	1.24 mm	104.5°	1.24 mm	104.5°	112.5°	9.5%
	Sensitivity	62%	82%	75%	80%	40%	56%
	Specificity	76%	72%	80%	75%	80%	70%
Partial SLIL tears	AUC	0.65 (0.53–0.77)	0.72 (0.6–0.84)	0.75 (0.6–0.76)	0.81 (0.64–0.99)	0.46 (0.23–0.46)	0.71 (0.53–0.88)
	Threshold	1.24 mm	104.5°	1.24 mm	104.5°	107.5°	9.9%
	Sensitivity	57%	67%	73%	82%	64%	64%
	Specificity	73%	74%	80%	76%	38%	71%
Full SLIL tears	AUC	0.86 (0.77–0.95)	0.91 (0.84–0.99)	0.89 (0.78–1)	0.84 (0.63–1)	0.73 (0.51–0.95)	0.76 (0.54–0.98)
	Threshold	1.28 mm	109.5°	1.28 mm	109°	113.5	11%
	Sensitivity	73%	81%	78%	78%	56%	67%
	Specificity	81%	94%	80%	96%	91%	73%
Chondropathy	AUC	0.79 (0.69–0.89)	0.81 (0.71–0.91)	0.78 (0.6–0.95)	0.77 (0.54–0.99)	0.53 (0.31–0.76)	0.65 (0.44–0.86)
	Threshold	1.96 mm	113.5°	1.94 mm	113.5°	114.5°	22%
	Sensitivity	64%	59%	56%	44%	82%	91%
	Specificity	89%	90%	91%	93%	33%	33%
Reader 2							
SLIL*	AUC	0.69 (0.61–0.77)	0.77 (0.70–0.84)	0.79 (0.67–0.91)	0.79 (0.66–0.92)	0.71 (0.57–0.84)	0.52 (0.36–0.68)
	Threshold	1.24 mm	104.5°	1.24 mm	104.5°	112.5°	9.5%
	Sensitivity	66%	70%	80%	70%	50%	73%
	Specificity	64%	70%	67%	71%	95%	20%
Partial SLIL tears	AUC	0.62 (0.5–0.74)	0.73 (0.62–0.83)	0.70 (0.54–0.87)	0.75 (0.58–0.92)	0.63 (0.43–0.83)	0.57 (0.37–0.77)
	Threshold	1.24 mm	104.5°	1.23 mm	104.5°	111.5	10%
	Sensitivity	54%	68%	72%	64%	45%	81%
	Specificity	64%	66%	66%	71%	87%	24%
Full SLIL tears	AUC	0.85 (0.76–0.95)	0.89 (0.81–0.97)	0.89 (0.78–1)	0.84 (0.65–1)	0.76 (0.55–0.96)	0.65 (0.37–0.92)
	Threshold	1.5 mm	109.5°	1.5 mm	106.5°	114.5°	15%
	Sensitivity	84%	78%	89%	78%	56%	67%
	Specificity	77%	86%	78%	82%	96%	62%
Chondropathy	AUC	0.77 (0.67–0.87)	0.79 (0.79–0.89)	0.73 (0.55–0.73)	0.68 (0.44–92)	0.64 (0.40–0.88)	0.61 (0.37–0.85)
	Threshold	1.96 mm	113.5°	1.88 mm	113.5°	114.5°	22%
	Sensitivity	61%	65%	55%	56%	44%	77%
	Specificity	83%	88%	75%	88%	86%	44%

*Complete and partial tears combined

SLIL scapholunate interosseous ligament, *DTL* dorsal tangential line, *PRSA* posterior radioscaphoid angle, *RSCR* radioscaphoid congruency ratio

In parenthesis = (95% confidence interval)

and thinner slice thicknesses might have positively impacted the evaluation of SDD on MR-based methods. Finally, the patient management impact of SDD measurement was not evaluated in this study.

In conclusion, for the quantitative assessment of the SDD, the DTL on standard radiographs and the PRSA on CT are the most consistent imaging indicators with an excellent interobserver reproducibility and abnormal values strongly associated with SLIL tears and chondral lesions on CT arthrography. The PRSA on CT was the only method allowing the differentiation between patients with normal and partially torn SLIL on CT arthrography. Both the evaluated MR-based methods presented fair to good interobserver reproducibility and a worse correlation with CT arthrography findings. Further studies using a more suitable acquisition protocol are required before these methods can be recommended to evaluate SDD.

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Declarations

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Two authors involved in the work (PAGT, AB) participate in a non-remunerated research agreement on CT imaging with Canon medical Systems.

Statistics and biometry One of the authors (Dr. Hossu, Gabriela PhD) has significant statistical expertise.

Informed consent Written informed consent was obtained from all subjects (patients) in this study.

Ethical approval Institutional Review Board approval was obtained.

Methodology
• prospective
• case-control study
• performed at one institution

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