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MUSCULOSKELETAL

Accuracy of simple plain radiographic signs and measures to diagnose acute scapholunate ligament injuries of the wrist

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Abstract

Objective To determine the accuracy of common radiological indices for diagnosing ruptures of the scapholunate (SL) ligament, the most relevant soft tissue injury of the wrist.

Methods This was a prospective diagnostic accuracy study with independent verification of index test findings by a reference standard (wrist arthroscopy). Bilateral digital radiographs in posteroanterior (pa), lateral and Stecher's projection were evaluated by two independent expert readers. Diagnostic accuracy of radiological signs was expressed as sensitivity, specificity, positive (PPV) and negative (NPV) predictive values with 95 % confidence intervals (CI).

Results The prevalence of significant acute SL tears (grade≥III according to Geissler's classification) was 27/72 (38 %, 95 % CI 26–50 %). The SL distance on Stecher's projection proved the most accurate index to rule the presence of an SL rupture in and out. SL distance on plain pa radiographs, Stecher's projection and the radiolunate angle contributed independently to the final diagnostic model. These three simple indices explained 97 % of the diagnostic variance.

Conclusions In the era of computed tomography and magnetic resonance imaging, plain radiographs remain a highly sensitive and specific primary tool to triage patients with a suspected SL tear to further diagnostic work-up and surgical care.

Key Points

- *Scapholunate ligament (SL) lesions are the most relevant soft tissue wrist injuries.*
- *Missed and untreated SL ruptures can cause painful and disabling post-traumatic wrist osteoarthritis.*
- *Reliable threshold values of radiographic indices should prompt further imaging or surgical care.*
- *Plain radiographs deliver conclusive clinical information if certain hand positions are used.*

Keywords Scapholunate ligament tear · Lesion · Wrist · Plain radiographs · Stecher's projection · Radiolunate angle

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Abbreviations

ACCORDS	ACcuracy of COmmon Radiological tests for Diagnosing SL ligament ruptures
AUC/ROC	area under the receiving operating characteristics curve
CI	confidence interval
NPV	negative predicted value
pa	posteroanterior
PACS	Picture Archiving and Communication System
PPV	positive predicted value

RL	radiolunate
SD	standard deviation
SL	scapholunate
STARD	Standards for Reporting of Diagnostic Accuracy

Introduction

Traumatic tears of the scapholunate (SL) ligament are the most common ligament injuries of the carpus. They typically result from forced hypertension or fractures of the wrist and, if missed and untreated, expose patients to a high risk of post-traumatic osteoarthritis of the radio-carpal joint. The reported prevalence of SL ligament tears among studies which used wrist arthroscopy as a diagnostic reference standard after trauma ranges from 9 to 32 % [1, 2].

Clinical red flag signs suggesting a torn SL ligament are persistent tenderness and pain of the dorsal aspect of the SL joint when extending the hand. Plain radiographs remain a ubiquitously available and cost-effective clinical standard for the initial diagnostic work-up of wrist injuries, and an abundance of measures and indirect signs have been proposed which may signal deterioration of carpal alignment caused by ligament ruptures. The best known indices are a widened SL joint space and abnormalities of the carpal angles [3–5]. Other radiologic features like disruption of carpal arc alignment, a foreshortened scaphoid, loss of SL articular parallelism or asymmetric widening and a dorsally or subdisplaced scaphoid onto the dorsal rim of the radius in lateral projection have also been associated with this condition and may indicate ligament disruption [6–9]. Contralateral radiographs are suggested as a simple reference method for intraindividual comparison of common indices of wrist physiology and pathology [10–12]. Stress tests should be considered as a useful adjunct to conventional radiographs when screening for SL tears. On the basis of dissection of 16 fresh human cadaver wrists, Özcelik et al. found that the radioscaphocapitate ligament plays an integral role in carpal stability [13, 14].

Available studies, however, have limited validity because of a retrospective design, convenience sampling, unclear definition of individual signs and quantitative thresholds, and the lack of a consistent reference standard. We previously showed that cineradiography and simple plain film findings like widening of the SL distance and pathological carpal angles offer reliable information for clinicians when planning the adequate management and counselling patients with pain after wrist trauma [3].

We set out to prospectively study the utility of common indices and angles measured by plain radiographs in

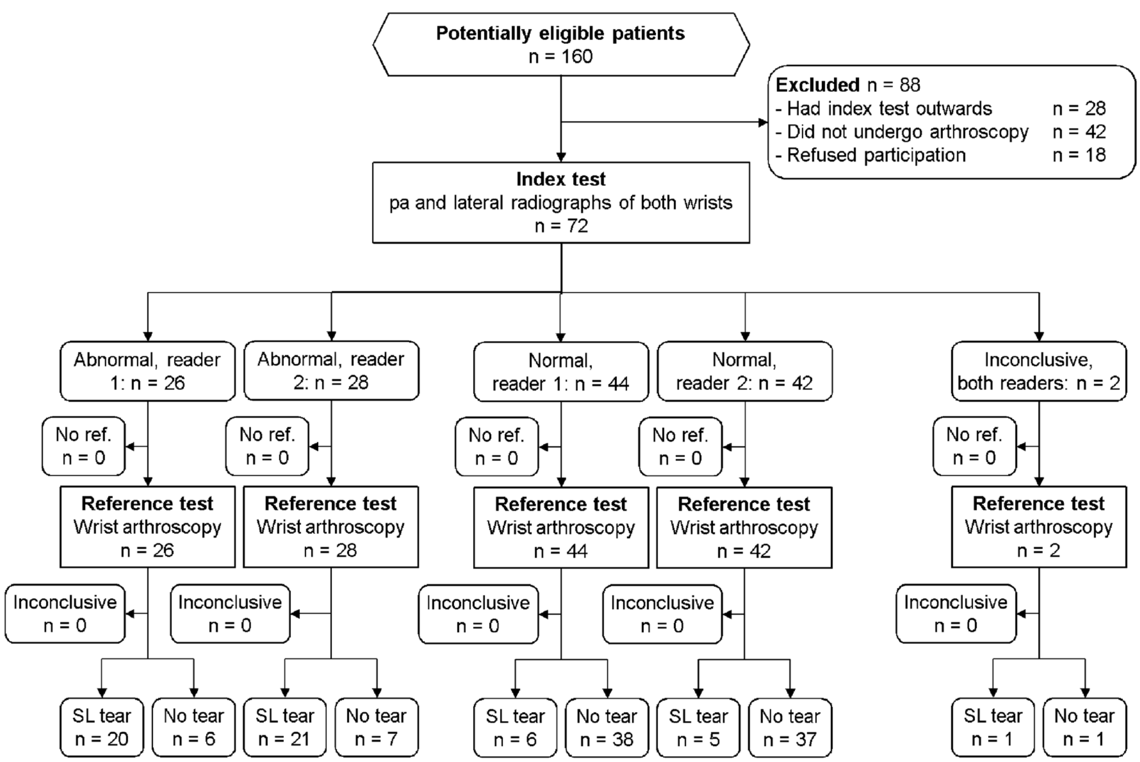

Fig. 1 Study profile and flow diagram according to the Standards of Reporting Diagnostic Accuracy (STARD). To comply with the dichotomous structure of STARD, positive index test results represent the cut-off values of the single best radiological index (i.e. the SL distance on Stecher views) with optimal balance of sensitivity and specificity. A positive reference test was defined as a Geissler grade III or IV SL tear proven by arthroscopy

diagnosing acute SL ligament tears, using wrist arthroscopy as an independent reference test. Our objective was to determine the accuracy of individual and distinct patterns of clinically established radiographic signs, and to evaluate whether they allow for ruling the diagnosis of an SL ligament rupture in or out.

Material and methods

Patients

The ACcuracy of COmmon Radiological tests for Diagnosing SL ligament ruptures (ACCORDS) was a prospective diagnostic accuracy study conducted at a metropolitan trauma and tertiary orthopaedic referral centre with a renowned hand surgery unit. The institutional review board approved the study (Charité University Medical Centre, Berlin, Germany, EA1/210/07), and all patients provided written informed consent. The study was registered with Current Controlled Trials (ISRCT N57744239).

Eligibility criteria

ACCORDS consecutively enrolled male and female patients older than 18 years who were scheduled for wrist arthroscopy because of continuing wrist pain for more than 3 weeks after an acute hyperextension injury, contusion, or extra-articular distal radial fracture.

We excluded patients with chronic wrist pain, rheumatoid arthritis or related diseases, previous injuries or surgeries of the same hand or wrist, as well as pregnant or breastfeeding women.

Data collection

Clinical evaluation included range of motion (ROM) and the provocative Watson scaphoid shift test [15] of the injured and the contralateral wrist. We recorded demographic and occupational information as well as injury details using electronic case-report forms.

To ensure representativeness of radiographs, we used a standardized protocol fixing the wrist in the following positions:

1. Posteroanterior (pa) view: radiographs were taken with the wrist placed in neutral position, 90° flexion of the elbow and 90° abduction of the shoulder.
2. Lateral view: the shoulder was held in adduction, the elbow in 90° flexion and the forearm in a neutral position.
3. Stecher's projection: the patient closed their fists in ulnar deviation, as described by Schmitt and Lanz [16].

Radiographs of the contralateral wrist were taken to assess alignment of the carpal bones on an individual basis. Radiographs were stored in a digital Picture Archiving and Communication System (PACS) for further processing and evaluation.

Table 1 Characteristics of patients at baseline

Characteristic	*n*=72
Mean age, years (SD)	41.4 (11.6)
Median age, years (range)	43 (18–68)
Gender	
Male	44 (61 %)
Female	28 (39 %)
Worker's compensation	45 (63 %)
Mean interval injury - examination, days (SD)	20.9 (17.6)
Median interval injury - examination, days (range)	18 (0–76)
MRI	
Chondral lesions	
Radial, scaphoid	11
Radial, lunatum	3
Triquetrum	1
Medcarp	1
Ulnar head	3
Plica	4
CT	
Chondral lesions	
Radial, scaphoid	10
Radial, lunatum	6
Scaphoid	12
Lunatum	6
Triquetrum	4
Ulnar head	2
Arthroscopy	
Chondral lesions	
Radial, scaphoid	18
Radial, lunatum	17
Scaphoid	12
Lunatum	20
Medcarp	3
Triquetrum	7
Ulnar head	0
Synovitis	
Radial	59
Ulnar	16
Haemorrhagic	28
Chronic	3

Table 2 Areas under receiver operating characteristics (AUC/ROC) of individual signs and measures

Diagnostic index	*n*	Correlation	Observer 1	Observer 2
SL distance, plain pa view	72	0.9490	89.6 (81.0–98.2)	89.8 (81.3–98.3)
SL angle	72	0.9523	80.8 (68.8–92.8)	84.5 (74.3–94.7)
RL angle	72	0.9296	82.0 (69.7–94.3)	79.6 (67.3–91.9)
Ring sign	72	0.7624*	78.9 (69.0–88.8)	73.0 (62.3–83.7)
SL distance, fist image	71	0.9767	88.9 (80.6–97.2)	87.2 (78.1–96.3)
SL distance, Stecher's projection	70	0.9776	92.7 (87.0–98.4)	90.6 (83.7–97.5)
Side difference in SL distance, plain pa view	58	0.9776	85.8 (70.0–101.6)	86.3 (70.7–101.9)
Side difference in SL distance, fist image	58	0.9597	88.6 (75.3–101.9)	88.4 (75.1–101.7)
Side difference in SL distance, Stecher's projection	56	0.9556	92.0 (84.5–99.5)	88.8 (79.2–98.4)

Values in parentheses are 95 % confidence intervals. Correlation between observers is expressed as r^2, derived from linear correlation analysis

*Kappa value for interobserver agreement beyond chance

Evaluation of the index test

Two observers, a hand surgery resident with 5 years and a board-certified radiologist with 10 years of experience in interpreting musculoskeletal imaging, independently evaluated all radiographs. Both readers were blinded to surgical reports, and were unaware of the individual patient's medical history.

As suggested by Schimmerl-Metz and Lee, the SL distance was measured in neutral pa view, and in the middle of the facet of the scaphoid and lunate (i.e. at the midpoint of the carpal

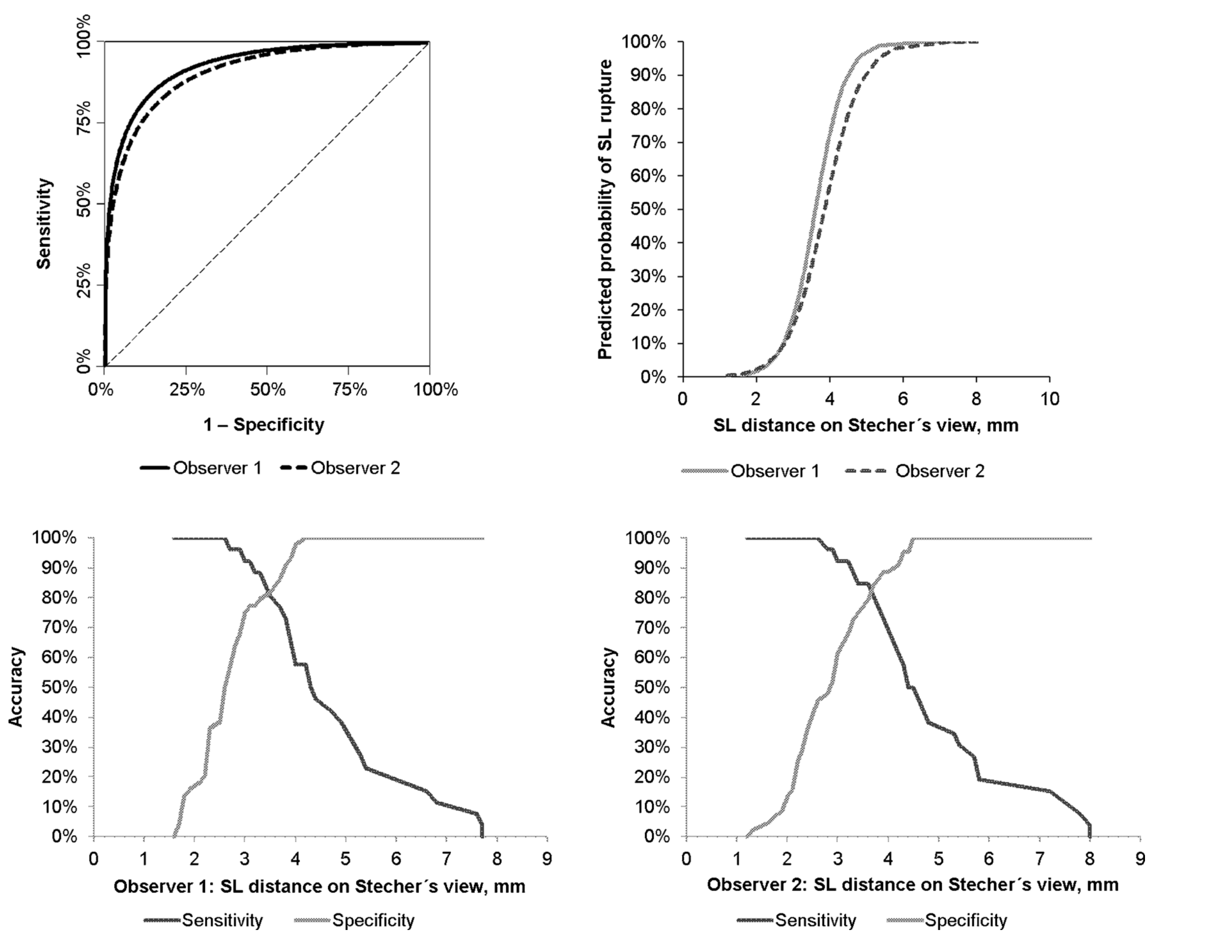

Fig. 2 Diagnostic accuracy of the SL distance measured on Stecher's views. *Top left panel* receiver operating characteristics for both readers, derived from binormal curve fitting. *Top right panel* predicted probability of an acute SL tear depending on the SL width traced from Stecher's radiographs. *Bottom left panel* Relationship between sensitivity and specificity, and optimal cut-off point, reader 1. *Bottom right panel* Relationship between sensitivity and specificity, and optimal cut-off point, reader 2

arcs) [17, 18]. Carpal angles were measured in true lateral view using the tangential method for the SL angle and axial method for RL angle as proposed by Larsen and colleagues [4, 19]. Furthermore the flexed position of the scaphoid was evaluated. As described by several authors, a scaphoid cortical ring sign is visible when the distal pole of the scaphoid is projected end-on and overlapping the waist of the scaphoid as a ring on pa view [6, 8].

Disruption of carpal arc alignment, loss of SL articular parallelism or asymmetric widening and a dorsally or subdisplaced scaphoid onto the dorsal rim of the radius in lateral projection were evaluated as well.

Diagnostic reference standard

Arthroscopy of the wrist was performed by two experienced, board-certified hand surgeons. Surgeons were aware of imaging results at the time of arthroscopy. Arthroscopy was performed under general or regional anaesthesia. Traction of 3 to 5 kg was applied, and standard 3-4, 4-5, 6R and midcarpal (MCR, MCU) portals were used. The radiocarpal and mediocarpal joints were examined using a 2.4-mm arthroscope with a 30° wide angle lens (Storz, Erlangen, Germany). The SL ligament was inspected and probed with a hook. Instability was classified according to Geissler [20]. As suggested by other authors, grade III and IV injuries were classified as pathologic findings requiring open ligament repair and Kirschner wire fixation [5, 21]. In case of grade II tears, the stability of the joint was tested intraoperatively and repaired if necessary. Grade I and II lesions without instability were treated by arthroscopic debridement. Additionally, the presence of synovitis, chondral lesions and tears of the lunotriquetral ligament or the triangular fibrocartilage complex was recorded.

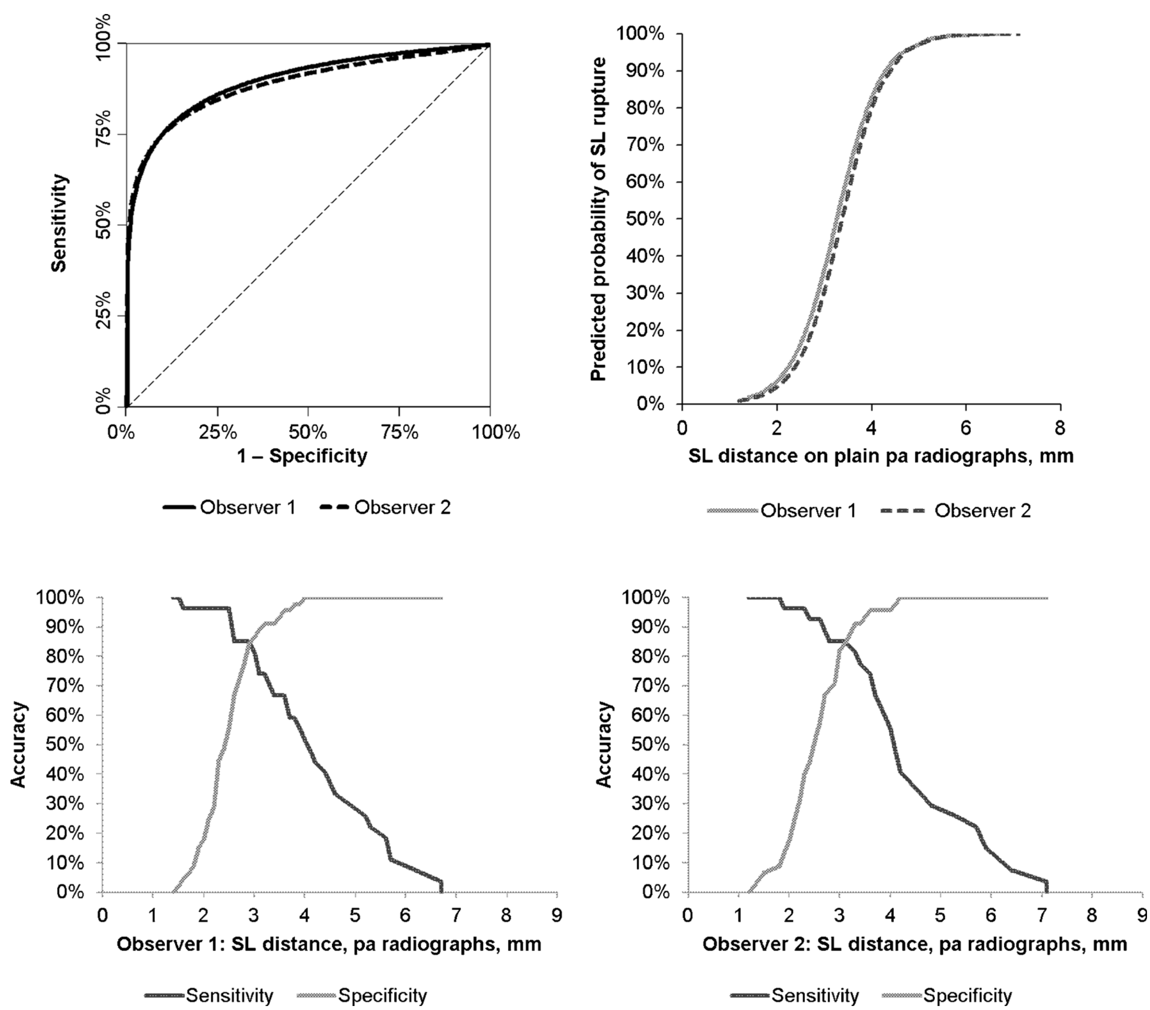

Fig. 3 Diagnostic accuracy of the SL distance measured on plain pa views. *Top left panel* receiver operating characteristics for both readers, derived from binormal curve fitting. *Top right panel* predicted probability of an acute SL tear depending on the SL width traced from plain pa radiographs. *Bottom left panel* relationship between sensitivity and specificity, and optimal cut-off point, reader 1. *Bottom right panel* relationship between sensitivity and specificity, and optimal cut-off point, reader 2

Statistical analyses

Reporting adhered to the Standards for Reporting of Diagnostic Accuracy (STARD) statement and recommendations [22]. Descriptive statistics include means, medians, proportions and ratios with their appropriate measures of distribution and error. Interobserver agreement for binary test findings was assessed by Cohen's kappa coefficient. A kappa greater than 0.6 indicates substantial agreement beyond chance. For continuous measures, correlation between readers was measured by the Pearson's correlation coefficient (r). Since there is no commonly accepted threshold which indicates perfect, moderate or poor correlation, reported r values should be interpreted in an exploratory fashion. We also did not attempt a consensus meeting in case of divergent measures but rather reported the results of both observers separately.

The diagnostic accuracy of binary radiological signs compared to reference test findings was expressed as sensitivity, specificity, positive (PPV) and negative (NPV) predicted values with 95 % confidence intervals (CI). Most variables of interest in this study comprised continuous measures for which we computed areas under the receiving operating characteristics curves (AUC/ROC). We also used sensitivity–specificity plots to derive optimal cut-offs for distances and angles.

Logistic regression analysis was employed to identify radiological signs which independently contribute to the probability of an acute scapholunate interosseous ligament (SLIL) rupture. Categorical signs and continuous measures with univariate p values less than 0.2 were entered into a multivariate model, and were excluded for p values greater than 0.1. Model fit was assessed by the Bayesian Information Criterion (BIC), the Hosmer–Lemeshow test and the AUC/ROC. The STATA 11.0 software package for Windows (Stata Corporation, Texas, USA) was employed for all statistical analyses.

Results

Between February 2008 and February 2011, 160 patients were screened for eligibility, and 72 were enrolled in the study. The patient flow according to STARD recommendations is illustrated in Fig. 1.

We included 44 men and 28 women with a mean age of 41.4 (SD 11.6) years. Forty-five patients had sustained a work-related injury. Demographic baseline variables are summarized in Table 1.

Wrist arthroscopy revealed 27 grade III or IV SL ligament lesions according to Geissler's classification,

Table 3 Best and worst case scenarios accounting for two inconclusive results on Stecher's projection

	Prevalence (%)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Reader 1					
Observation	37 (26–49.5)	76.9 (56.4–91)	86.4 (72.6–94.8)	76.9 (56.4–91)	86.4 (72.6–94.8)
Scenario 1: all inconclusive findings true positive	39 (28–51.1)	78.6 (59–91.7)	86.4 (72.6–94.8)	78.6 (59–91.7)	86.4 (72.6–94.8)
Scenario 2: all inconclusive findings false negative	39 (28–51.1)	71.4 (51.3–86.8)	86.4 (72.6–94.8)	76.9 (56.4–91)	82.6 (68.6–92.2)
Scenario 3: all inconclusive findings false positive	36 (25–48.3)	76.9 (56.4–91)	82.6 (68.6–92.2)	71.4 (51.3–86.8)	86.4 (72.6–94.8)
Scenario 2: all inconclusive findings true negative	36 (25–48.3)	76.9 (56.4–91)	87 (73.7–95.1)	76.9 (56.4–91)	87 (73.7–95.1)
Reader 2					
Observation	37 (26–49.5)	80.8 (60.6–93.4)	84.1 (69.9–93.4)	75 (55.1–89.3)	88.1 (74.4–96)
Scenario 1: all inconclusive findings true positive	39 (28–51.1)	82.1 (63.1–93.9)	84.1 (69.9–93.4)	76.7 (57.7–90.1)	88.1 (74.4–96)
Scenario 2: all inconclusive findings false negative	39 (28–51.1)	75 (55.1–89.3)	84.1 (69.9–93.4)	75 (55.1–89.3)	84.1 (69.9–93.4)
Scenario 3: all inconclusive findings false positive	36 (25–48.3)	80.8 (60.6–93.4)	80.4 (66.1–90.6)	70 (50.6–85.3)	88.1 (74.4–96)
Scenario 2: all inconclusive findings true negative	36 (25–48.3)	80.8 (60.6–93.4)	84.8 (71.1–93.7)	75 (55.1–89.3)	88.6 (75.4–96.2)

Values in parentheses are 95 % confidence intervals for an overall prevalence of 38 % (95 % CI 26–50 %). Linear correlations of continuous measures between both observers, as expressed by Pearson's *r*, reached or exceeded 0.95 except for the RL angle (Table 2). Both observers had only moderate agreement beyond chance in diagnosing a ring sign.

The SL distance measured on Stecher's projection proved the most accurate single predictor of SL tears. AUC/ROCs obtained by the first and second reader were 92.7 and 90.6 % (Fig. 2). However, both readers experienced difficulties in measuring SL space widening in two cases which were classified as inconclusive. Surgery revealed one grade I and IV lesion each. At a cut-off of 3.7 mm, the first reader achieved a sensitivity and specificity of 76.9 and 86.4 %, respectively. For the second reader, sensitivity and specificity at this threshold were 80.8 and 84.1 %. Sensitivities and specificities for varying SL distances are shown in Fig. 3. Worst and best case scenarios assuming that inconclusive results simply represented missed injuries or overestimated injury severity are shown in Table 3.

An SL distance exceeding 3.0 mm on plain pa radiographs was associated with a sensitivity of 81.5 and 85.2 %, and specificities of 86.7 and 82.2 %, respectively (Fig. 3). A SL angle of ≥66° was associated with sensitivities and specificities of 77.8 and 82.2 % reached by both readers (Fig. 4). An RL angle threshold of 11° allowed observer 1 to diagnose an SL tear with 81.5 % sensitivity and 82.2 % specificity. In contrast, observer 2 reached a sensitivity and specificity of only 74.1 and 71.1 % using this cut-off (Fig. 5). Table 2 shows AUC/ROCs of individual measures.

The best fitting multivariate model included the SL distances on plain pa view and Stecher's projection as well as the RL angle, and explained 97 % of the overall variance (Table 4). Related ROCs are illustrated in Fig. 6.

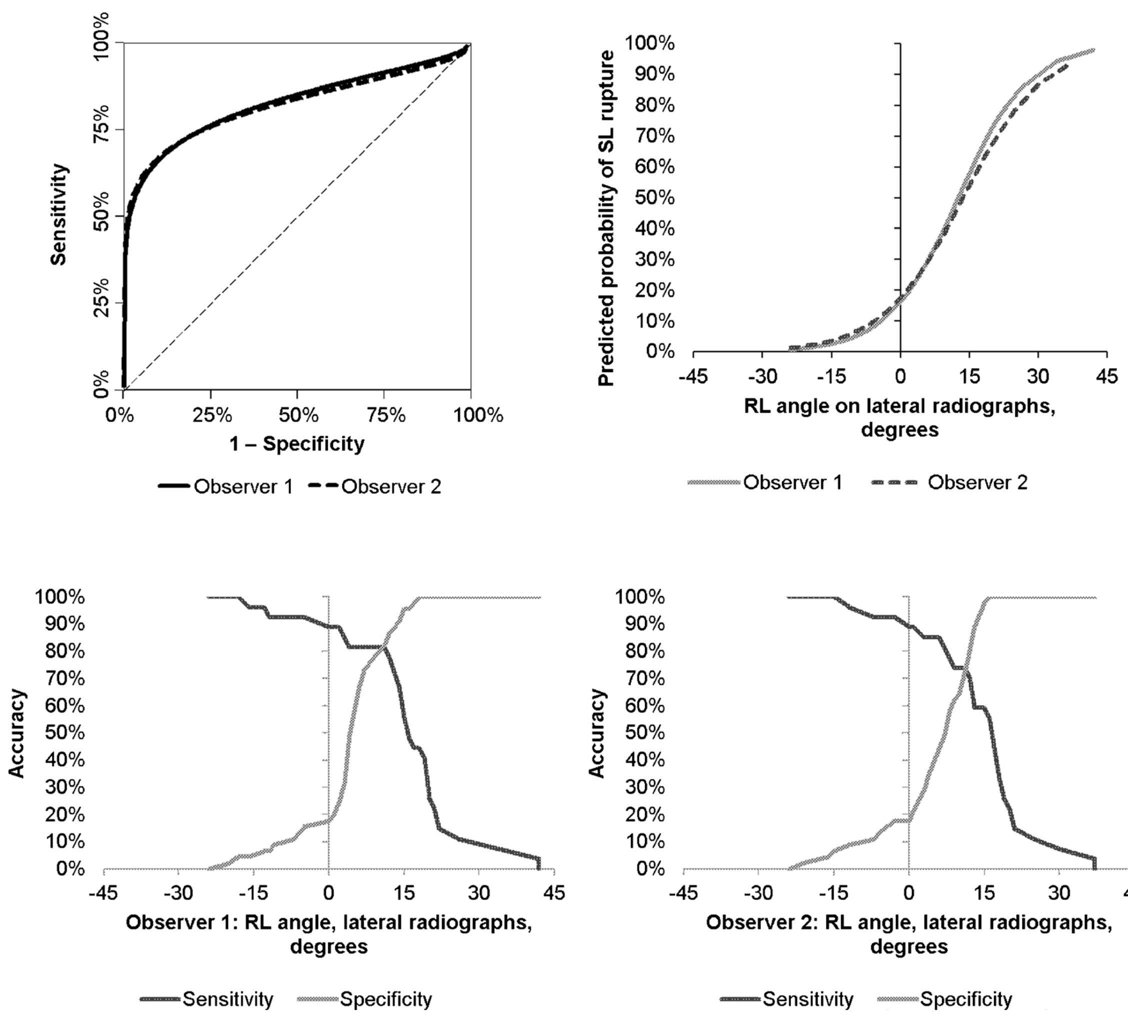

Fig. 4 Diagnostic accuracy of the RL angle measured on plain lateral views. *Top left panel* receiver operating characteristics for both readers, derived from binormal curve fitting. *Top right panel* predicted probability of an acute SL tear depending on the RL angle assessed on plain lateral radiographs. *Bottom left panel* relationship between sensitivity and specificity, and optimal cut-off point, reader 1. *Bottom right panel* relationship between sensitivity and specificity, and optimal cut-off point, reader 2

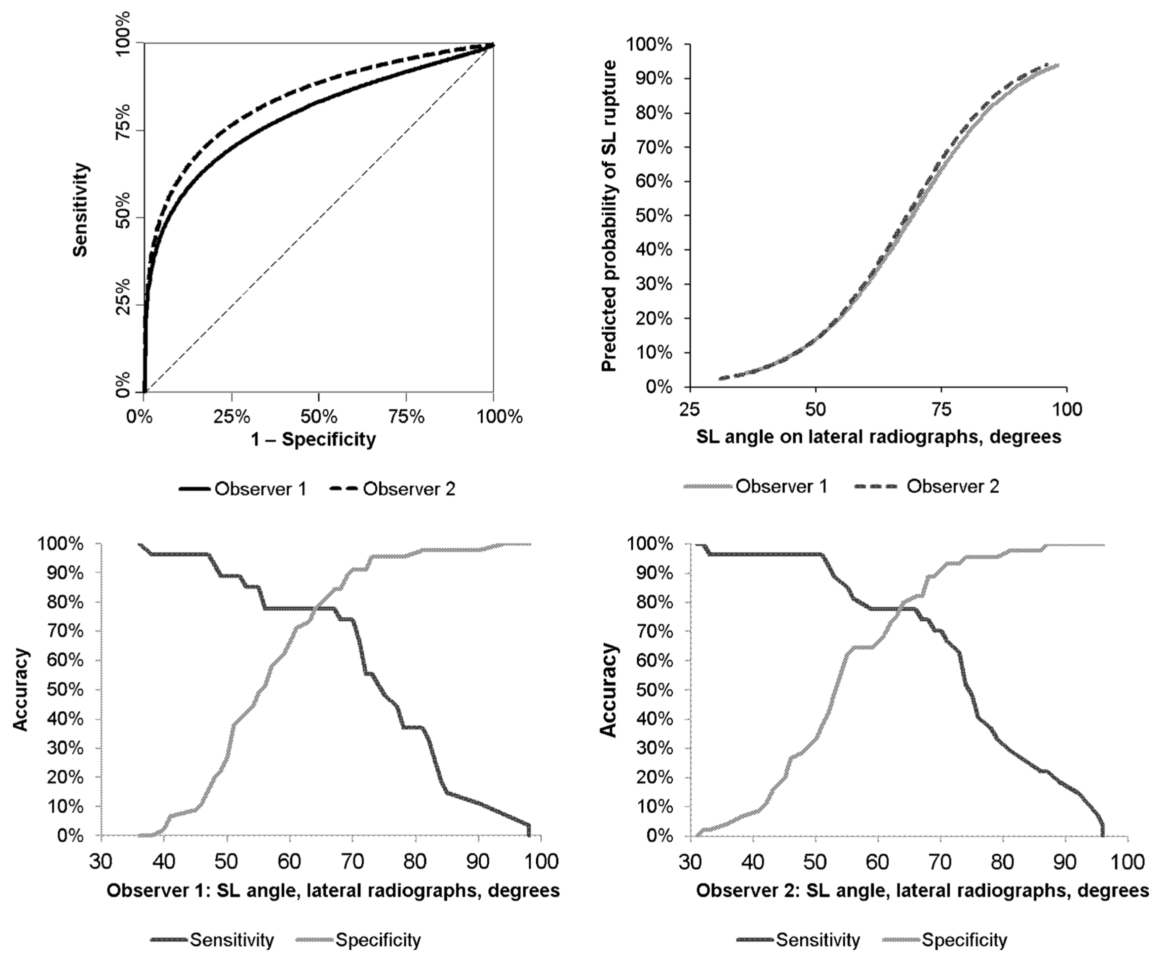

Fig. 5 Diagnostic accuracy of the SL angle measured on plain lateral views. *Top left panel* receiver operating characteristics for both readers, derived from binormal curve fitting. *Top right panel* predicted probability of an acute SL tear depending on the SL angle assessed on plain lateral radiographs. *Bottom left panel* relationship between sensitivity and specificity, and optimal cut-off point, reader 1. *Bottom right panel* relationship between sensitivity and specificity, and optimal cut-off point, reader 2

Discussion

Radiographs remain the most important instrument to screen for suspected SL ligament tears after wrist trauma. We previously identified the SL distance, SL angle and RL angle as the most reliable conventional indices pointing towards the presence of an acute SL ligament tear [3]. This prospective study confirmed the high accuracy of pathological SL distances and angles but also highlighted the unrivalled importance of the Stecher's projection. Altogether, simple x-ray imaging may deliver conclusive clinical information if certain hand positions are actively used and taken into consideration.

Limitations of this study

Several shortcomings of this study deserve discussion. First, this was a single-centre study with less than 100 patients and a rather brief period of 3 weeks of conservative treatment. This interval, however, resembled clinical practice at our institution and other referral centres for hand surgery in Germany.

While to the best of our knowledge ACCORDS is the currently largest prospective study investigating acute SL tears, the external validity of our findings may be limited. Interagreement beyond chance involved only two observers. This was a trade-off between recommendations provided by our statistician, the resources available and the time and effort spent for compiling and analysing a comprehensive data set. Second, only 45 % of all potentially eligible patients were enrolled, suggesting selection bias. This concern is hard to overcome but may still reflect clinical practice. Third, the way of performing Stecher's view in this study adhered to reference recommendations but was not standardized in terms of determining the degree of ulnar deviation. Finally, the outcome definition may remain a matter of debate. The competing classification of SL tears against

Table 4 Independent contributors to the final multivariable model

Diagnostic index	Reader 1							Reader 2						
	Odds ratio (95 % confidence interval)	P	Log likelihood	BIC	df	Pearson chi²	Goodness of fit P	Odds ratio (95 % confidence interval)	P	Log likelihood	BIC	df	Pearson chi²	Goodness of fit P
SL distance on Stecher's projection	10.4 (1.5–71.4)	0.017	−13.8	44.6	66	25.74	1.000	9.0 (1.7–49.1)	0.011	−16.0	49.0	65	43.75	0.9802
SL distance on pa radiographs	7.7 (1.7–34.8)	0.008						4.3 (1.5–12.2)	0.006					
RL angle	1.1 (1.0–1.3)	0.022						1.1 (1.0–1.3)	0.028					

BIC Bayesian information criterion, *df* degrees of freedom

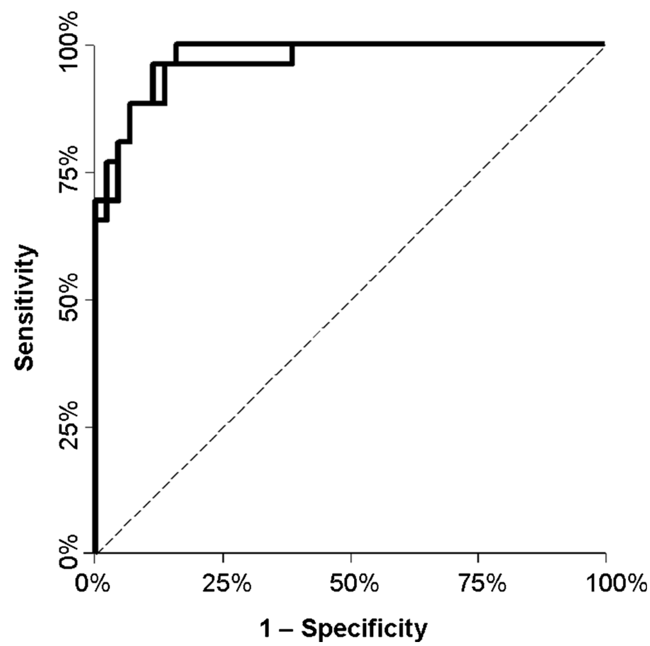

Fig. 6 Receiver operating characteristics of the best fitting multivariable model. Variables contributing this model are the SL distance measured on plain pa and Stecher's views, as well as the RL angle

the Geissler scheme is the Weinzweig system. We discussed both rules in advance and, because of its practicability and widespread use, decided in favour of the Geissler classification.

Comparison with other studies

Current thresholds for an acceptable SL distance range between 2 and 5 mm [23–25]. Variations are partially due to different measuring techniques [3, 18, 24], but the mid portion of the SL joint should be used as the preferred anatomical landmark [5, 17, 25, 26]. In this study, SL distances of 3.0 and 3.7 mm on pa and Stecher's projection were associated with the optimal balance between sensitivity and specificity, targeting SL lesions of grade III and higher according to the widely accepted Geissler staging system.

Yet, we urge to account for the distribution of values and their likelihood in determining SL ruptures rather than to insist on a single cut-off value when making clinical decisions. We also stress that the physiological variability of the SL joint distance is substantial [24].

Intraindividual comparison by contralateral imaging is regarded as being clinically important [8, 27–29] but did not contribute significant extra information in this study. While it may reveal anatomic outliers and variants or even bilateral SL pathologies [30–33] its routine use should be questioned with regard to the diagnosis of acute SL ligament injuries. Also, the scaphoid ring sign is not a specific finding pointing towards SL ligament tears [6, 24].

Conclusions

Plain radiographs can be recommended as a non-invasive, rapid, reproducible, widely available and inexpensive (thus probably cost-effective) technique to diagnose SL ligament injuries after wrist trauma. This, however, needs precise positioning of the forearm, wrist and hand, and practitioners of any background must insist on high-quality images. A Stecher's projection may be mandatory if the primary diagnostic question is ruling in or out an acute SL tear with all its potential therapeutic consequences. The SL distance and RL angle are likely to provide conclusive information for decision making, and additional diagnostics like computed tomography or magnetic resonance imaging may only be required in selected cases.

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