JOURNAL OF PLASTIC SURGERY AND HAND SURGERY
2022, VOL. 56, NO. 3, 151–159
https://doi.org/10.1080/2000656X.2021.1953038

RESEARCH ARTICLE

Lunate morphology: association with the severity of scapholunate ligament injuries and carpal instability patterns

Katarzyna Rachunek[a], Fabian Springer[b], Maja Barczak[a], Theodora Wahler[c], Adrien Daigeler[a] and Fabian Medved[a]

[a]Department of Hand, Plastic, Reconstructive and Burn Surgery, BG Trauma Center, Eberhard Karls University Tuebingen, Tuebingen, Germany; [b]Department of Diagnostic and Interventional Radiology, University Hospital, Eberhard Karls University Tuebingen, Tuebingen, Germany; [c]Department of Hand, Plastic and Aesthetic Surgery, Medius Clinic Nuertingen, Nuertingen, Germany

ABSTRACT

Type II lunate has been associated with a lower incidence of dorsal intercalated segment instability (DISI) in the case of scapholunate dissociation. We aimed to evaluate the frequency of different lunate types and their influence on the prevalence and severity of scapholunate ligament (SLIL) injuries and the development of DISI. The surgical records of 414 arthroscopies were reviewed retrospectively. Lunate types were diagnosed based on radiograms and MRI examinations. The Type II lunate had a facet between hamate and lunate; in the Type I lunate, this facet is lacking. We additionally included the assessment of the capitate–triquetrum distance (CTD), which defines Type I, Intermediate, and Type II lunates. We adopted the DISI when the scapholunate angle was more than 80° and/or the radiolunate angle less than $-15°$. Fisher's exact test was applied to compare the distribution frequency of SLIL lesions and DISI deformity of patients with different lunate types. To quantify the inter- and the intra-rater reliability of lunate type assessment Cohen's kappa was calculated and, for CTD measurements, a Bland–Altman plot was created. Up to 77.1% patients had Type II lunates. Regarding MRI and CTD classification in patients with Type I lunates, Grade 4 SLIL injuries were more common than in those with Intermediate and Type II ($p < 0.05$). In the case of Grade 4 SLIL lesions, DISI was more common in patients with Type I lunates ($p < 0.05$). There were, however, only 25 patients with Type I lunates, and Grade 4 SLIL lesions according to MRI, and 6 according to CTD measurement.

ARTICLE HISTORY
Received 23 October 2020
Revised 11 May 2021
Accepted 1 July 2021

KEYWORDS
Dorsal intercalated segment instability; lunate morphology; lunatohamate articulation; scapholunate dissociation

Introduction

Many authors have evaluated osseous morphology of the human wrist, especially the lunate morphology, and its influence on the development of carpal disorders. According to Viegas et al., the lunate is classified into two types [1–3]. The Type I lunate has a single midcarpal articulation with the capitate, whereas the Type II lunate has two midcarpal articular facets, one for the articulation with capitate and an additional one for the lunatohamate articulation. The prevalence of Type II lunates varies widely and ranges between 27% and 73%, depending on the classification methods used and the investigated population [1–9]. Both the lunate types represent normal anatomy, which can, however, influence the development of many wrist disorders.

The Type II lunate is associated with cartilage erosion at the proximal pole of the hamate and midcarpal arthritis [1–5]. On the other hand, the Type II lunate seems to have some protective effect on the development and progress of the Kienböck's disease [10,11]. The lunate's importance to the wrist's function is shown by manifestations of carpal instability due to scapholunate dissociation or scaphoid non-unions. In this case, the lunate's position within the wrist can change because of the lack of stable ligamentous connections between the lunate and the scaphoid or due to a lack of stability of the proximal scaphoid's pole, which enables the lunate to extend *via* the taut lunotriquetral ligament. As a consequence, dorsal intercalated segment instability (DISI) develops. The extension of the lunate within the proximal carpal row is associated with a tendency of the scaphoid to flex [12]. This can markedly change the anatomical relations of the wrist and, consequently, lead to osteoarthritis and a reduction in wrist function.

The development of wrist osteoarthritis due to an insufficient scapholunate ligament (SLIL), first described by Watson and Ballet (1984) and named SLAC-Wrist (scapholunate advanced collapse), is the most common form of posttraumatic wrist degeneration [13]. The first and crucial condition for the progression of any articular degeneration in this sequence is a sign of SLIL ligament incompetence. The second is the development of carpal misalignment, which depends on the interaction between bony and ligamentous structures as well as on the adequacy of the secondary wrist stabilizers [14,15]. Previous studies had revealed that the incidence of DISI was much lower in case of scaphoid non-unions [16] and scapholunate dissociation (SLD) [17] in patients with Type II lunates. Nevertheless, the influence of the lunate type on the incidence and severity of SLIL lesions has not been widely investigated.

The aim of our study was to analyze whether lunate morphology influences the prevalence and severity of SLIL disruptions and the development of carpal misalignment. The results should help extend the knowledge of the complex anatomical interactions of the wrist.

CONTACT Katarzyna Rachunek katarzyna.rachunek91@gmail.com, krachunek@bgu-tuebingen.de Department of Plastic, Reconstructive, Hand and Burn Surgery, BG Trauma Center, Eberhard Karls University Tuebingen, Schnarrenbergstr. 95, Tuebingen 72076, Germany

Materials and methods

Patients

All patients with persistent wrist pain and suspected SLIL injury, who underwent a wrist arthroscopy between January 2011 and December 2017 were included in the study. Patients under 18 years of age and cases of scaphoid fractures or nonunions as well as perilunate and radiocarpal luxation injuries were excluded from the study. Patients after wrist osteosynthesis, partial fusions, and with a history of inflammatory arthritis were also not included. Initially, 585 patients met the inclusion criteria; however, 171 of them had to be excluded due to incomplete records. An Institutional Review Board's approval (No. 513/2018BO2) of the Eberhard-Karl University in Tuebingen was granted for the study.

Arthroscopy

Arthroscopies were performed with a 2.7-mm diameter arthroscope with 30° lens angles under traction of 4.5 kg. We used standardized 3/4 and 6R portals for radio- and ulnocarpal arthroscopy and MCR/MCU portals for midcarpal diagnostic. The four-stage Geissler classification was used for the arthroscopic assessment of SLIL (Table 1) [18,19]. The arthroscopies were performed by three experienced board-certified hand surgeons of our department.

Table 1. Geissler arthroscopic classification of carpal instability in case of scapholunate ligament injuries.

Grade of Geissler classification	Description
1	Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. No incongruency of carpal alignment in the midcarpal space
2	Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. Incongruency/step-off as seen from midcarpal space. A slight gap (less than width of a probe) between carpals may be present
3	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. The probe may be passed through the gap between carpals
4	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. Gross instability with manipulation is noted. A 2.7-mm arthroscope may be passed through the gap between carpals

Radiological diagnostic

In all the 414 patients, who underwent arthroscopy, we additionally analyzed the corresponding 414 conventional anteroposterior and lateral X-ray views of the affected hand. Further, the available 201 anteroposterior and lateral views of the corresponding healthy hand were examined. The X-ray series were assessed by two reviewers who were blinded to the arthroscopy results. The first reviewer was a surgical resident in the third year of a residency program; the second was a senior consultant of the Department of Hand Surgery. The technical aspects of the radiological measurements were discussed with a senior physician of the Department of Radiology.

The radiological determination of lunate morphology was first evaluated by simply assessing the presence of a lunatohamate joint on anteroposterior X-ray views. The Type II lunate was diagnosed when it had a visible facet for the hamate, while the Type I lunate was diagnosed when this facet was clearly lacking (Figure 1). In addition, we included the classification of the lunate types, as proposed by Galley et al. [20]. This classification, based on the assessment of the shortest distance between capitate and triquetrum – the capitate–triquetrum distance (CTD) – which defines the three lunate subtypes: Type I lunates with the CTD $\leq$ 2 mm; Type II lunates with the CTD $\geq$ 4 mm; and an intermediate type with the values in between (Figure 2). The CTD measurements between two manually selected points were obtained with the help of a distance measuring tool of the IMPAX System.

Moreover, in 301 out of 414 patients, a magnetic resonance imaging (MRI) of the affected wrist was performed prior to the arthroscopy. In this group, we also determined the lunate type, based on the magnetic resonance imaging (fat-suppressed T2 and PD-weighted images) by simply assessing the presence and shape of the lunatohamate joint on the coronal slices (Figure 3) [21]. We, additionally, measured the maximal width of the lunatohamte joint on the coronal MRI slices.

On lateral X-ray views of the wrist, the scapholunate (SL) and radiolunate (RL) angles were measured based on the method proposed by Larsen [22]. The axes of carpal bones were determined as follows: for radius, as a line through the center of the medulla at 2 cm and 5 cm proximal to the radiocarpal joint; for lunate, as the line perpendicular to the tangent of the two distal poles; for scaphoid, as the tangent of the palmar proximal and distal convexities; and for capitates, as the tangent of the dorsal margin of

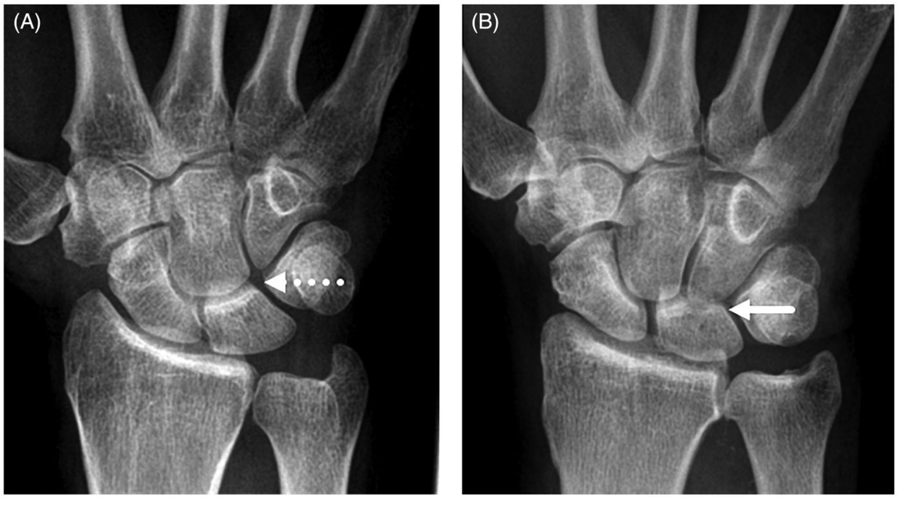

Figure 1. Anteroposterior X-ray views of the injured wrists with minor SLIL injuries (A: Grade 1, B: Grade 2 according to the arthroscopic Geissler classification), showing different lunate morphologies: (A) Type I lunate marked with a white dashed line with an arrowhead; (B) Type II lunate marked with a white arrow.

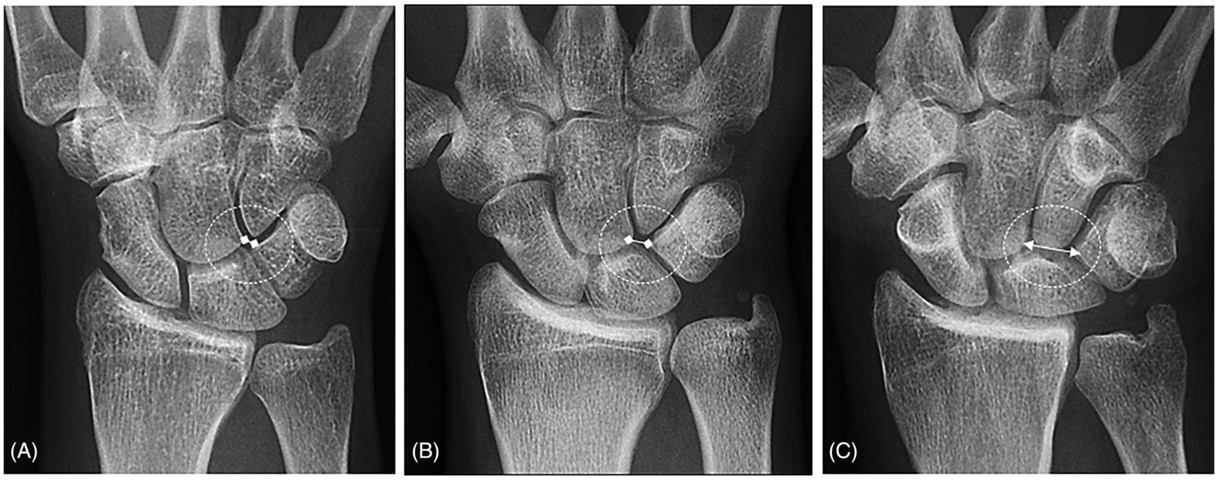

Figure 2. The anteroposterior X-ray views of the wrist demonstrating the technique of the measurement of the shortest distance between capitate and triquetrum (CTD) and the subtypes of lunate based on Galley's Classification. The CTD measurement was marked with a white line on each figure. Type I lunate with CTD <2 mm (A); Intermediate lunate type with CTD measuring 3.3 mm (B); Type II lunate with CTD measuring 9.6 mm (C).

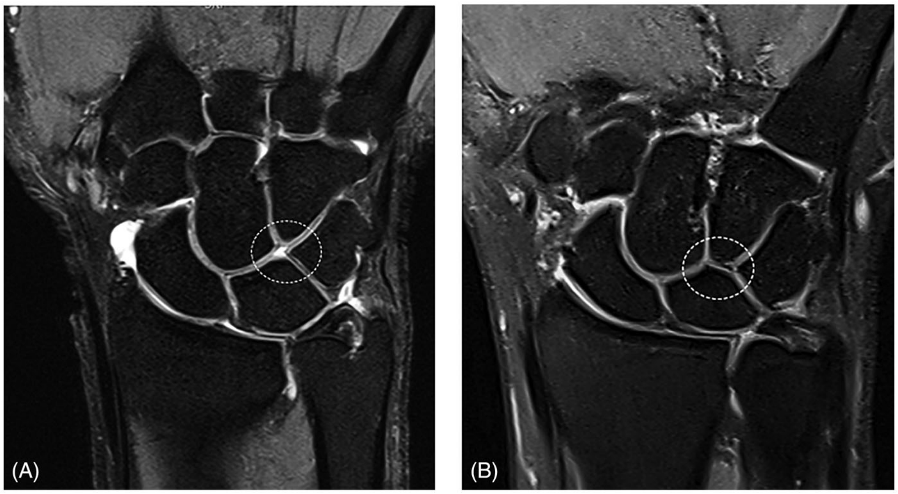

Figure 3. MRI scans (proton density fat suppressed weighted sequences) of the wrist showing different lunate morphologies: (A) Type I lunate marked with a white dashed circle; (B) Type II lunate marked analogously with a white dashed circle.

the diaphysis of the third metacarpal bone. The exact carpal angles determination was performed with the use of an angle measurement tool between two lines (carpal axes) in the IMPAX System. To describe the dorsal intercalated segment instability, we applied the terminology as defined by the International Wrist Investigators' Workshop (IWIW) in 2002. In case of carpal instability dissociative (CID) DISI, the combined dorsal tilting of the lunate and ventral tilting of the scaphoid result in a scapholunate angle of 80° was consistent with DISI configurations. With some limitations, we supposed a DISI configuration, when the SL angle measured more than 80° and/or the RL angle less than −15°. To differentiate between a typical DISI with a pathological SL-angle and an isolated rotatory subluxation of the scaphoid, lateral views in flexion/extension and ulnar deviation are needed to identify the abnormal motion of the lunate [23]. In our daily routine, these views are normally not performed and, hence, it could not be included in our retrospective study.

To assess the inter-reviewer reliability in the assessment of lunate morphology, 200 randomly chosen plain X-ray views and 200 MRIs, each, have been analyzed parallelly to the initial analysis by the second reviewer. To assess the intra-reviewer reliability in the radiological assessment of lunate types, 112–148 days after the initial analysis, both the reviewers repeated their radiological analysis on the 200 plain X-ray views and MRIs, which were first randomly chosen for the analysis of inter-reviewer reliability.

Statistical analysis

To compare the distribution of the metric variables of independent groups, the Shapiro–Wilk test was performed primarily to verify if the determined data in both groups were normally distributed. In the absence of a normal distribution, the Mann–Whitney *U* test was used to estimate the correlation between the width of the lunatohamate joint and carpal angles, and SLIL lesions, according to Geissler classification. Fisher's exact test was applied to compare the distribution frequency of the categorical variables such as DISI deformity or grades of SLIL lesions of independent groups of patients with different lunate types (including comparison between two and three groups). To quantify the inter-reviewer reliability of X-ray views and MRIs in the assessment of lunate types, Cohen's kappa was calculated (including a 95% confidence interval). A Bland-Altman plot was created to assess the inter-rater agreement of CTD measurements.

Statistical assessment of an intra-rater reliability was performed analogically to the inter-reviewer variability. All tests were calculated for two sides, and a statistical difference between the two groups was defined with a significance level of $p < 0.05$.

Results

In summary, we retrospectively analyzed the surgical records consisting of preoperative X-ray series and arthroscopies of 414 patients, of whom 302 were men and 112 women aged between 18 and 81 years (average 48 years, SD 12.65). The most common wrist pathologies diagnosed in the studied population are presented in Table 2. Of the 414 patients, 119 (28.7%) could not recall an index injury of the wrist. Two hundred and ninety-five of them identified a potential wrist trauma from 1 day to maximal 11 years prior to arthroscopy.

Table 2. The most common pathologies diagnosed in the performed arthroscopies of the wrist of 414 patients. The table include additionally the diagnosis of radius fractures, which were made with the radiological diagnostic.

Wrist pathologies diagnosed in the studied population (414 patients)	
SLIL injury	
Grade of Geissler Classification	Number of cases
1 Grade	12
2 Grade	24
3 Grade	29
4 Grade	111
TFCC injury	
Grade of Palmer Classification	
1A	43
1B	23
1C	4
1D	25
2A	28
2B	9
2C	27
2D	2
2E	2
1A, 1B	2
1B, 1D	5
1B, 2D	1
1A, 1D	1
1B, 1C	1
Radius fractures	
Extraarticular	8
Intraarticular	13
LTIL injury	
Grade of Geissler Classification	
1 Grade	3
2 Grade	14
3 Grade	3
4 Grade	9
Radiocarpal arthrosis	
Maximal Grade of Outerbridge Classification in the radiocarpal articulation	
0	171
1	33
2	39
3	80
4	91

The results of the radiological assessment of lunate types are shown in Table 3. The mean CTD reached 4.47 mm (SD: 1.75 mm) for reviewer 1 and 4.46 mm (SD: 1.78 mm) for reviewer 2, respectively. In 7 patients, the assessment of lunate morphology on the plain X-ray views and the CTD measurement in 12 of the 414 patients were not possible because of an inadequate picture resolution. As the MRI scans of the wrist of these patients were available, we decided not to exclude them from the study.

We saw a substantial inter-reviewer agreement in the assessment of lunate types based on X-ray views ($\kappa = 0.70$ [95% CI, 0.644; 0.762]) and, further, an excellent inter-observer reliability ($\kappa = 0.827$ [95% CI, 0.754; 0.900]) in the case of MRIs. Based on the Bland–Altman plot regarding CTD measurements, the limits of 95% confidence interval reached 0.785 mm and 0.798 mm in the case of inter-rater reliability and further 0.124 mm and 0.132 mm for the intra-rater variability for reviewer 1 and 0.041 mm and 0.044 mm for reviewer 2, respectively (Figures 4–6).

We further observed an excellent intra-rater agreement in the assessment of lunate morphology based on X-ray views (for reviewer 1: $\kappa = 0.846$, 95% CI [0.789; 0.903], for reviewer 2: $\kappa = 0.917$, 95% CI [0.874; 0.959]) and also an excellent intra-rater reliability in case of MRI (for reviewer 1: $\kappa = 0.888$, 95% CI [0.826; 0.950], for reviewer 2: 0.917, 95% CI [0.964; 0.970]).

In the arthroscopy, 176 SLIL tear cases (42.5%) were identified. Of these, the most common was Grade 4 (111 patients), according to Geissler's classification. In detail, Grade 1 injury occurred in 11 patients, Grade 2 in 24 patients, and Grade 3 in 29 patients. In one case of SLIL disruption, the Geissler grade was not directly mentioned by a surgeon. The description of the SLIL with a small hemorrhage without incongruence, step-off or gaps allowed us, however, to classify this case as Grade 1 SLIL injury.

Regarding patients with Type I lunates according to Galley's classification, 46.2% (6) revealed arthroscopically Grade 4 SLIL lesions. For patients with intermediate lunates, it was 27.6% (47), while it was 25.5% (55) in patients with Type II lunates (Table 4). Assessing MRI examinations, 36.2% (25) of patients with Type I lunates and 21% (48) of patients with Type II lunates revealed a complete Grade 4 SLIL rupture (Table 5). Further, we observed that SLIL ruptures were generally not more common in patients with particular types of lunate. Nevertheless, the distribution of Grade 4 SLIL disruptions varied, depending on the lunate morphology. In patients with Galley Type I lunates and Type I lunate in MRI, Grade 4 SLIL injuries were more common than in patients

Table 3. Results of the radiological assessment of lunate types according to three methods of classification: assessment of the presence of the lunatohamate articulation on plain X-ray views and in wrist MRIs, and measuring the CTD on plain X-ray views.

Radiological Classification of lunate morphology	Number of patients	%*
Plain X-ray views (assessment of the presence of the lunatohamate articulation)		
Data not obtained	7	
Type I	132	32.4
Type II	275	67.6
Galley's classification of capitate-triquetrum distance (CTD) on plain X-ray views		
Data not obtained	12	
$\leq$2 mm	13	3.2
2.2–3.9 mm	171	42.5
$\geq$4 mm	218	54.2
Wrist MRI (assessment of the presence of the lunatohamate articulation)		
Data not obtained	113	
Type I	69	22.9
Type II	232	77.1

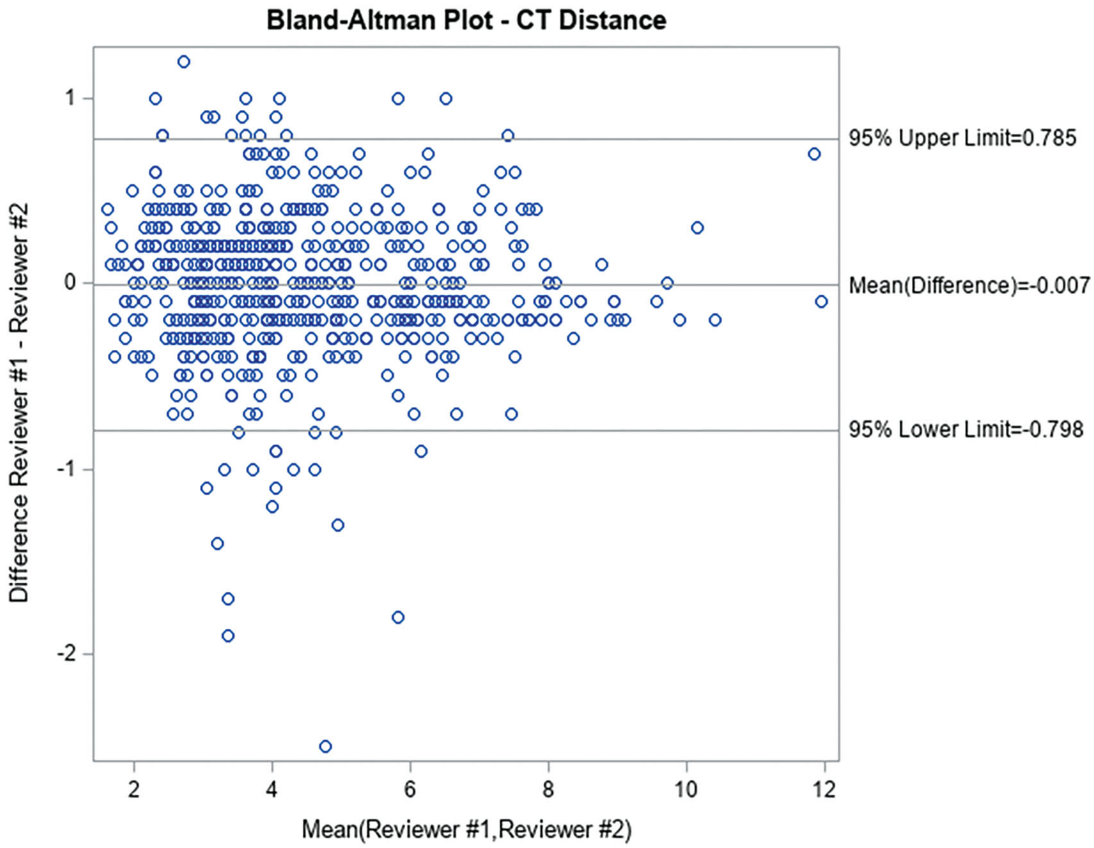

Figure 4. Bland–Altman plot regarding CTD measurements of two independent reviewers with mean difference of measurements (mm) and upper as well as lower limit of 95% CI (mm).

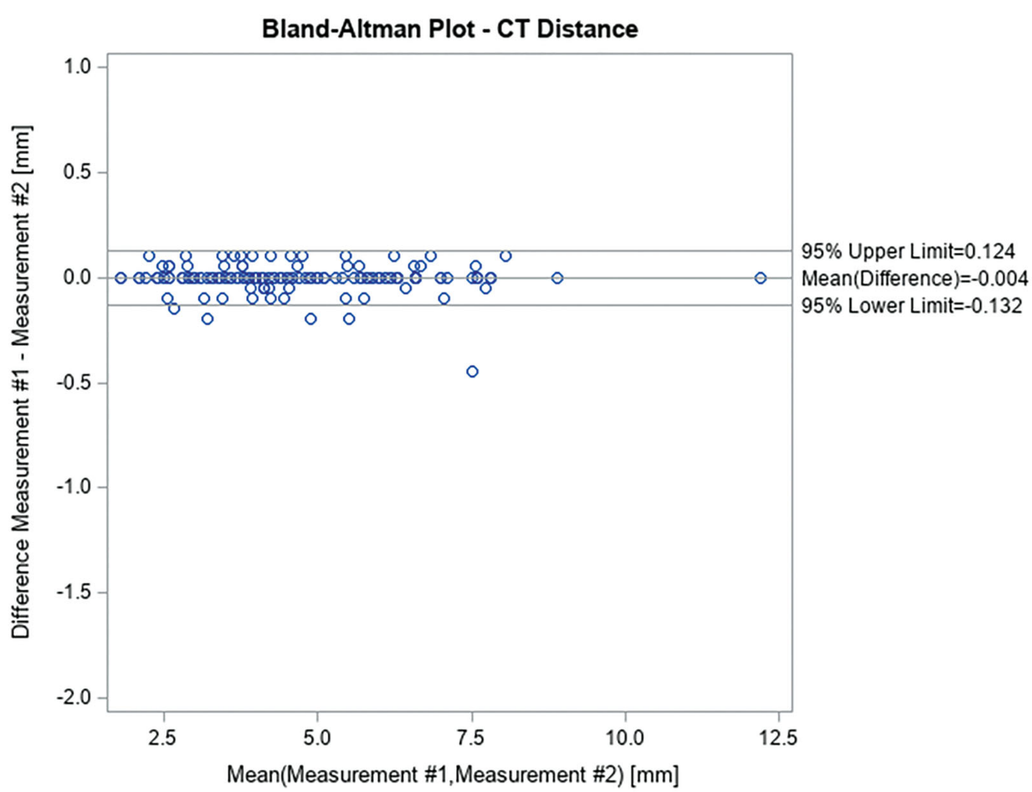

Figure 5. Bland–Altman plot regarding CTD measurements of the first reviewer – resident in plastic and hand surgery with mean difference of measurements (mm) and upper as well as lower limits of 95%-confidence interval (mm).

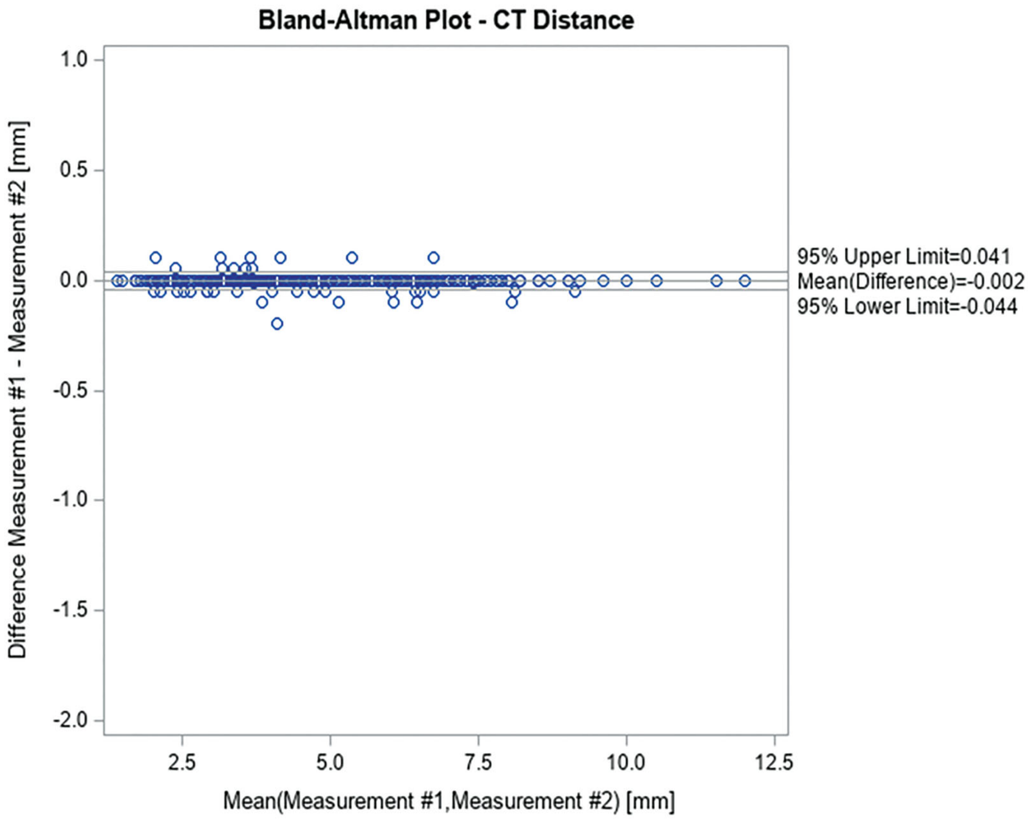

Figure 6. Bland–Altman plots regarding CTD measurements of the second reviewer – senior consultant in the plastic and hand surgery with mean difference of measurements (mm) and upper as well as lower limits of 95% CI (mm).

Table 4. Frequency and severity of SLIL lesions, assessed arthroscopically with grades of Geissler classification in three groups of patients with different lunate types, based on Galley's classification of capitate–triquetrum distance (CTD) assessed on the anteroposterior X-ray views.

Grade of Geissler Classification	Type I $n=13$		Intermediate $n=171$		Type II $n=218$		
	N	%*	*N*	%*	*N*	%*	*p*-value**
0	5	38.5	97	57.1	124	57.4	0.017
1			10	5.9	2	0.9	
2			10	5.9	14	6.5	
3	2	15.4	6	3.5	21	9.7	
4	6	46.2	47	27.6	55	25.5	

*The percentages relate to the proportion of the category of the row variable within the lunate types (column sum per variable = 100%).
**Fisher's exact test.

Table 5. Frequency and severity of SLIL lesions, assessed arthroscopically with grades of Geissler classification in two groups of patients with different lunate types, based on the assessment of the presence or absence of the lunatohamate articulation in MRI.

Grade of Geissler Classification	Type I $n=69$		Type II $n=232$		
	N	%*	*N*	%*	*p*-value**
0	37	53.6	140	61.1	0.04
1	2	2.9	7	3.1	
2	2	2.9	11	4.8	
3	3	4.3	23	10.0	
4	25	36.2	48	21.0	

*The percentages relate to the proportion of the category of the row variable within the lunate types (column sum per variable = 100%).
**Fisher's exact test.

with intermediate and Type II lunates ($p=0.017$ and $p=0.04$, respectively). Although a strong and statistical relevant correlation was observed, the analysis was performed on a limited number of cases with lunate type I and Grade 4 SLIL lesions (25 with MRI and 6 with CTD measurement).

The analysis of the correlation between a lunate morphology and DISI was performed in a subgroup of patients with Grade 4 SLIL lesions. In patients with Grade 4 SLIL lesions, we could not establish a correlation between a lunate morphology and pathological radiolunate ($<-15°$) and scapholunate ($>60°$) angles. However, an SL angle greater than 80 degrees and consistent with DISI was found in 44.2% (19) patients with Type I lunates based on plain X-ray examinations and only in 19.7% (13) of patients with Type II lunates ($p=0.009$) (Table 6). According to Galley's classification, 83.3% (5) patients with Type I lunates, 36.2% (17) patients with intermediate type lunates, and only 18.5% (10) of patients with Type II lunates showed an SL angle of more than 80° ($p=0.002$) (Table 7). By assessing the lunate morphology in the MRI, we obtained nearly similar values as those of the Galley's classification: a DISI was found in 76% (19) of patients with Type I lunate and only in 19.1% (9) of patients with lunate Type II ($p=0.001$) (Table 6).

The mean width of the lunatohamte joint assessed in MRI was 2.41 mm, min 0.8 mm, and max 7.9 mm, SD 1.23 mm. The width of lunatohamate joint in case of Type II lunates did not correlate with the carpal angles or the severity of SLIL lesions ($p>0.05$).

Discussion

The first classification of lunate types was first introduced by Viegas et al. based on a direct dissection of cadaver wrists [1–3]. Lunates with a separate medial facet on its distal surface for the hamate were described as their most common morphology,

Table 6. Frequency of SL-angle >80° in case of Grade 4 SLIL injury depending on lunate morphology, classified as lunate II in case of a presence of the lunatohamate articulation or as lunate I when this articulation is lacking on anteroposterior X-ray views and further based on the assessment of wrist MRI.

	Lunate morphology (based on assessment of the lunatohamate articulation on X-ray views)				
	Type I $n=43$		Type II $n=67$		
SL-Angle	*N*	%*	*N*	%*	*p*-value**
≤80°	24	55.8	53	80.3	0.009
>80°	19	44.2	13	19.7	
	Lunate morphology (MRI)				
	Type I $n=25$		Type II $n=48$		
SL-angle	*N*	%*	*N*	%*	*p*-value**
≤80°	6	24.0	38	80.9	0.001
>80°	19	76.0	9	19.1	

*The percentages relate to the proportion of the category of the row variable within the lunate types (column sum per variable = 100%).
**Fisher's exact test.

Table 7. Frequency of SL-angle >80° in case of Grade 4 SLIL injury in three groups of patients with different lunate types, based on Galley's classification of capitate–triquetrum distance (CTD) assessed on the anteroposterior X-ray views.

	Type I $n=6$		Intermediate $n=47$		Type II $n=55$		
SL-angle	*N*	%**	*N*	%*	*N*	%*	*p*-value**
≤80°	1	16.7	30	63.8	44	81.5	0.002
>80°	5	83.3	17	36.2	10	18.5	

*The percentages relate to the proportion of the category of the row variable within the lunate types (column sum per variable = 100%).
**Fisher's exact test.

identified in 73% of wrists and classified as Type II lunate. Lunates without lunatohamate articulation have been classified as Type I. Viegas et al. stated that the lunate morphology in cadaver wrists could have been correctly identified by radiograph, although the arthrosis of the lunatohamate joint was first evident through direct dissection [1]. Sagerman et al. observed the accuracy of predicting lunate morphology based on X-ray film to be between 64% and 72% [24]. Nakamura et al. showed that the CTD measurement on plain X-ray views correlated with width of the lunatohamate joint [25]. Galley et al. proposed, depending on the CTD measurements, an additional differentiation of an intermediate lunate type, which was further applied in the studies of carpal kinematics depending on the lunate morphology [20,25,26]. McLean et al. compared the results of multimodal radiological diagnosis to the dissection and showed that MRI provided the best method of differentiating between lunate types since it was possible to identify the small cartilaginous ulnar facets [21]. McLean et al. discussed that the lunate morphology should be seen as a spectrum with Type I at one end and Type II at the other with an intermediate type (lunates with small cartilaginous facet) lying in between [21] There is, however, much inconsistency in the literature as some authors included this intermediate type [6,8] in Type I and some in Type II group [1–5,16,24]. We believe that the various classifications of lunate morphology complement one another. As an assessment of the presence of the lunatohamate joint on anteroposterior X-ray views differentiates between lunate types based on a bony anatomy, the assessment with MRI enables classification of lunates based on the presence of cartilaginous facets. The last classification with CTD measurement helps to place our results in the context of studies on the wrist kinematics and differentiates between three groups: undoubtedly Types I and II – with a pronounced facet for the hamate -, and a big group of intermediate type lunates which cannot be undoubtedly classified as either Type I or II. In this group of patients with intermediate lunates in our study (171), 128 also received MRI which showed in 54 patients (42%) lunate I and in 74 (58%) cases lunate II morphology (with a small facet for the hamate).

Regarding X-ray, MRI, and CTD examinations for lunate morphology in our study, most of the analyzed patients had Type II lunate. The prevalence of the Type II lunate assessed in MRI was in our group up to 77% and on plain X-rays 67.6%. This seems to be in accordance with other anatomical, arthroscopic, and MRI examinations that reported a prevalence of Type II lunate between 46.4% and 73% [1–7,21,24,27]. Considering the CTD, we found clearly lesser Type I lunates (18% versus 3.2%) compared to the original study by Galley et al. [20]. This could be due to the reason that patients with SLIL lesions may develop an ulnar shift of lunate and triquetrum in relation to scaphoid – this could cause a relevant elongation of the CTD and could possibly lead to a wrong classification as Type II lunates. Another explanation for our different results is that Galley et al. examined only healthy individuals. As opposed to these explanations, we calculated a substantial inter-reviewer and an excellent intra-reviewer agreement in the assessment of lunate morphology based on CTD measurements, therefore, did not reject this classification.

Analyzing Grade 4 SLIL lesions according to Geissler's classification, we revealed in MRI analyses that patients with Type I lunates had significantly more Grade 4 SLIL lesions (25 (36.2%) patients with Type I lunates versus 48 (21%) patients with lunate type II). The MRI findings were in line with our performed CTD examinations. Here, we found similar results, in which Grade 4 SLIL lesions were more common in patients with Type I lunates (in 6 (46.2%) patients with Type I versus 47 (27.6%) with intermediate and 55 (25.5%) with Type II lunate). We could not find in the literature any data on the severity of SLIL lesions with respect to the type of lunate. It is certain, however, that the kinematics of the wrist varies, depending on the lunate morphology. Since the typical cause of an SLIL rupture is a fall on the extended wrist – frequently associated with high-energy trauma – the differences in the kinematics of the wrist should be considered under these conditions. Bain et al. [28] described the following differences of carpal kinematics in plane motion with wrist flexion (15°) and extension (15°). Regardless of the type of lunate, the dominant joint in the radial and ulnar column is the radiocarpal articulation. In the central column, however, the kinematics depends strongly on the morphology of the lunate; in wrists with Type I lunate, the dominant joint in the central column is the midcarpal articulation, whereas the radiolunate joint is the dominant articulation in patients with the Type II lunate [28]. Bain et al. [28] observed further, that in patients with Type I lunates during extension, only the scaphotrapeziotrapezoidal joint remains restricted, while the whole midcarpal articulation in patients with Type II lunate is restricted. In the studies by Nakamura et al. [26] and Galley et al. [20], the effect of lunate morphology on lunate and scaphoid kinematics in radial and ulnar deviation has also been described.

Moreover, in an arthroscopic analysis of patients with lunatohamate osteoarthritis, Harley at al. revealed a correlation between Type II lunates and lunotriquetral ligament (LTIL) injury [29]. Abe et al. analyzed the differences in the four-corner-kinematics of Type I and Type II wrists; they stated that an increased lunotriquetral shearing motion in wrists with Type II lunates during radial-ulnar deviation may cause LTIL tears [30]. Perhaps all these differences in the carpal kinematics may also influence the mechanism of the SLIL rupture and its severity could also depend on the type of lunate.

The important influence of lunate type on carpal misalignment was first observed by Haase et al. [16,31] in a group of patients with scaphoid non-unions and by Rhee et al. [17] in a group of patients with complete SLIL lesions. According to these authors, DISI occurs less frequently in patients with Type II lunate. In these studies, however, another definition of DISI as an RL angle of more than 15° was applied in contrast to our analysis. The incidence of DISI was also generally higher in our study, which could lead to some differences between the results. We are aware of the multiple definitions of DISI and the need to describe the carpal misalignment based on the measurements of many carpal angles for each patient. In the special case of CID–DISI due to SLD, the instability of the wrist results from the scaphoid's tendency to flex and further the lunate's tendency to extend [12]. The pathological SL angle can also differentiate CID–DISI from carpal instability no dissociative (CIND)–DISI. In CIND–DISI, there is a dysfunction of ligaments at midcarpal and radiocarpal levels – this causes the instability of the whole proximal row as a unit [23,32,33]. In CIND–DISI, there is, by definition, no significant scapholunate or lunotriquetral ligament abnormality and the SL angle remains normal, whereas RL and CL angles are pathological. Therefore, we believe, that the SL-angle >80° is consistent with DISI configuration in the special case of SLD [23].

Regardless of the method or radiological technique of diagnosing lunate morphology in our analyzed group, patients with Type I lunates (43 cases based on X-ray views assessment, 25 based on MRI, 6 cases according to CTD measurement, out of the study population of 414) more often showed a DISI configuration in case of complete Grade 4 SLIL lesions than patients with Type II and intermediate lunates. One explanation for this is that the additional midcarpal articulation of the lunate with the hamate can mechanically limit the lunate's tendency to extend in case of complete SLIL rupture. The described common osteoarthritis of the lunatohamate joint [1–5,29] must result from the relevant mechanical load of this articulation. The lunatohamate impaction was also demonstrated in kinematic studies during extensive ulnar deviation [26,30]. Further, Nakamura et al. [26] revealed that extension of Type II lunate follows later during an ulnar deviation than in Type I lunates. In our analysis, the size of the lunatohamate joint in case of Type II lunates seemed not to have an influence on the carpal angles and severity of SLIL lesions. It is possible that already small midcarpal articulations between lunates and hamates can play a role in carpal kinematics.

Lunate morphology may be associated with the severity of SLIL lesions and affect the progress of a carpal misalignment in complete SLIL ruptures. To better understand the role of a Type II lunate in the stabilization of the wrist, further kinematical studies should be performed.

The limitations of the study were its retrospective nature and a small number of Type I lunates when it came to measuring CTD. Moreover, the arthroscopies were performed on symptomatic patients and, therefore, the results may not be applicable to asymptomatic individuals with SLIL injury. The operative records did not involve the description of lunate morphology and, hence, it had to be evaluated radiologically. The other limitation of radiological diagnostics was the limited inter-rater reliability in assessing lunate morphology with CTD measurements, probably due to the different experience levels of the two reviewers with a satisfying intra-rater agreement for both of them.

Disclosure statement

The authors have no conflicts of interest to declare.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ORCID

Katarzyna Rachunek http://orcid.org/0000-0002-6751-0561

References

[1] Viegas SF, Wagner K, Patterson R, et al. Medial (hamate) facet of the lunate. J Hand Surg Am. 1990;15(4):564–571.
[2] Viegas SF, Patterson RM, Hokanson JA, et al. Wrist anatomy: incidence, distribution, and correlation of anatomic variations, tears, and arthrosis. J Hand Surg Am. 1993;18(3):463–475.
[3] Viegas SF. The lunatohamate articulation of the midcarpal joint. Arthroscopy. 1990;6(1):5–10.
[4] Burgess RC. Anatomic variations of the midcarpal joint. J Hand Surg Am. 1990;15(1):129–131.
[5] Nakamura K, Patterson RM, Moritomo H, et al. Type I versus type II lunates: ligament anatomy and presence of arthrosis. J Hand Surg Am. 2001;26(3):428–436.
[6] Malik A, Schweitzer ME, Culp R, et al. MR imaging of the type II lunate bone: frequency, extent, and associated findings. AJR Am J Roentgenol. 1999;173(2):335–338.
[7] Dautel G, Merle M. Chondral lesions of the midcarpal joint. Arthroscopy: J Arthrosc Relat Surg. 1997;13(1):97–102.
[8] Dharap A, Al-Hashimi H, Kassab S, et al. The hamate facet of the lunate: a radiographic study in an Arab population from Bahrain. Surg Radiol Anat. 2006;28(2):185–188.
[9] Elsaftawy A, Jabłecki J, Gworys B, et al. Radiological and anatomical study to investigate possibility of relationship between scaphoid fracture and lunate morphology. Ortop Traumatol Rehabil. 2013;15(4):305–314.
[10] Rhee PC, Jones DB, Moran SL, et al. The effect of lunate morphology in Kienböck disease. J Hand Surg Am. 2015;40(4):738–744.
[11] Tatebe M, Shinohara T, Okui N, et al. Arthroscopic lunate morphology and wrist disorders. Surg Radiol Anat. 2013;35(1):79–83.
[12] Short WH, Werner FW, Green JK, et al. Biomechanical evaluation of the ligamentous stabilizers of the scaphoid and lunate: Part III. J Hand Surg Am. 2007;32(3):297–297. e218.
[13] Watson HK, Ballet FL. The SLAC wrist: scapholunate advanced collapse pattern of degenerative arthritis. J Hand Surg. 1984;9(3):358–365.
[14] Salva-Coll G, Garcia-Elias M, Hagert E. Scapholunate instability: proprioception and neuromuscular control. J Wrist Surg. 2013;2(2):136–140.
[15] Salva-Coll G, Garcia-Elias M, Leon-Lopez M, et al. Effects of forearm muscles on carpal stability. J Hand Surg Eur Vol. 2011;36(7):553–559.
[16] Haase SC, Berger RA, Shin AY. Association between lunate morphology and carpal collapse patterns in scaphoid nonunions. J Hand Surg Am. 2007;32(7):1009–1012.

[17] Rhee PC, Moran SL, Shin AY. Association between lunate morphology and carpal collapse in cases of scapholunate dissociation. J Hand Surg Am. 2009;34(9):1633–1639.
[18] Geissler WB, Freeland AE, Savoie FH, et al. Intracarpal soft-tissue lesions associated with an intra-articular fracture of the distal end of the radius. JBJS. 1996;78(3):357–365.
[19] Lindau T, Arner M, Hagberg L. Intraarticular lesions in distal fractures of the radius in young adults: a descriptive arthroscopic study in 50 patients. J Hand Surg. 1997;22(5):638–643.
[20] Galley I, Bain GI, McLean JM. Influence of lunate type on scaphoid kinematics. J Hand Surg. 2007;32(6):842–847.
[21] McLean JM, Bain GI, Watts AC, et al. Imaging recognition of morphological variants at the midcarpal joint. J Hand Surg Am. 2009;34(6):1044–1055.
[22] Larsen CF, Mathiesen FK, Lindequist S. Measurements of carpal bone angles on lateral wrist radiographs. J Hand Surg Am. 1991;16(5):888–893.
[23] Gilula LA, Mann FA, Dobyns JH, et al. Wrist terminology as defined by the International Wrist Investigators' Workshop (IWIW). JBJS. 2002;84(suppl_1):S1–S66.
[24] Sagerman SD, Hauck RM, Palmer AK. Lunate morphology: can it be predicted with routine x-ray films. J Hand Surg Am. 1995;20(1):38–41.
[25] Nakamura K, Beppu M, Matsushita K, et al. Biomechanical analysis of the stress force on midcarpal joint in Kienböck's disease. Hand Surg. 1997;02(02):101–115.
[26] Nakamura K, Beppu M, Patterson RM, et al. Motion analysis in two dimensions of radial-ulnar deviation of type I versus type II lunates. J Hand Surg Am. 2000;25(5):877–888.
[27] Pfirrmann C, Theumann N, Chung C, et al. The hamatolunate facet: characterization and association with cartilage lesions-magnetic resonance arthrography and anatomic correlation in cadaveric wrists. Skeletal Radiol. 2002;31(8):451–456.
[28] Bain GI, Clitherow HD, Millar S, et al. The effect of lunate morphology on the 3-dimensional kinematics of the carpus. J Hand Surg Am. 2015;40(1):81–89. e81.
[29] Harley BJ, Werner FW, Boles SD, et al. Arthroscopic resection of arthrosis of the proximal hamate: a clinical and biomechanical study. J Hand Surg Am. 2004;29(4):661–667.
[30] Abe S, Moritomo H, Oka K, et al. Three-dimensional kinematics of the lunate, hamate, capitate and triquetrum with type 1 or 2 lunate morphology. J Hand Surg Eur Vol. 2018;43(4):380–386.
[31] Kim B-J, Kovacevic D, Lee Y-M, et al. The role of lunate morphology on scapholunate instability and fracture location in patients treated for scaphoid nonunion. Clin Orthop Surg. 2016;8(2):175–180.
[32] Wolfe SW, Garcia-Elias M, Kitay A. Carpal instability nondissociative. J Am Acad Orthopaedic Surgeons. 2012;20(9):575–585.
[33] Wright T, Dobyns J, Linscheid R, et al. Carpal instability non-dissociative. J Hand Surg: Br Eur Vol. 1994;19(6):763–773.