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Morphology at the Distal Radioulnar Joint: Identifying the Prevalence of Reverse Obliquity

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Abstract

Background Recent advances in the understanding of ulnar-sided wrist pathologies such as ulnar abutment syndrome (UAS) have brought increased attention to the anatomy of the distal radioulnar joint (DRUJ). Previous work established three anatomical variants of the sigmoid notch (parallel, oblique, and reverse oblique). The reverse oblique DRUJ poses theoretical risk of increased contact forces following ulnar shortening osteotomy, a common method of treating UAS.

Purpose As prevalence of reverse oblique morphology has been under-reported, this study aims to better define the prevalence of reverse oblique morphology in the adult population.

Methods Institutional Review Board-approved review of 1,000 radiographs over a 2-year period was performed. Demographic data and radiographic measurements were recorded (ulnar variance, notch inclination, and presence of arthritis). Correlation tests, a test of proportions, a *t*-test, and linear and logic regression tests were used to examine associations between ulnar variance, sigmoid inclination, sex, age, and presence of arthritis.

Results One thousand radiographs were analyzed revealing prevalence rates of: parallel—68%, oblique—26%, and reverse oblique—6%. Females were significantly more likely to have reverse inclination. No significant correlation was noted for morphology by age. Ulna positive variance was negatively correlated with reverse inclination. DRUJ arthritis was noted in 14% of patients. Higher sigmoid inclination was associated with higher odds of presence of arthritis, adjusting for sex and age. Higher incidence of arthritis was noted among patients with the oblique (20.8%) or reverse oblique (24.6%) compared with parallel (10.5%) morphology.

Conclusion This series of 1,000 radiographs demonstrates a 6% overall prevalence of reverse obliquity. This large dataset allows for better quantification of the prevalence of DRUJ morphologies and determination of correlations that have clinical implications for patients with ulnar-sided wrist pathology.

Level of Evidence This is a Level IV study.

Keywords
- distal ulna
- morphology
- sigmoid inclination
- ulnar variance
- ulnar abutment syndrome
- ulnar shortening osteotomy

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Ulnar abutment syndrome (UAS) may be a chronic and disabling condition. This occurs when normal load bearing through the ulna increases, typically from positive ulnar variance.[1,2] UAS results in increased forces through the lunate-distal ulna articulation that may cause tearing and degeneration of the triangular fibrocartilage complex (TFCC) as well as cartilage degeneration of the lunate and/or distal ulna. A common surgical option for UAS is an ulnar shortening osteotomy (USO). By shortening the ulna, the load borne through the ulnocarpal joint decreases, thus relieving pressure from the pathologic joint.[3,4] Indications for USO have expanded from UAS to include chronic TFCC injuries, with USO gaining in popularity.[5,6]

Shortening the ulna changes the biomechanics of the distal radioulnar joint (DRUJ). Of particular concern is the morphology of the DRUJ and the effect a USO may have on the DRUJ. Previous work by Tolat et al[7,8] defined three distinct morphologies of the DRUJ, particularly in reference to the shape of the sigmoid notch of the radius (►**Fig. 1**). Tolat type I is parallel, type II is oblique (articular surface facing proximal, running from radial proximally to ulnar distally), and type III is reverse oblique or reverse inclination (articular surface facing distal with the sigmoid notch running from ulnar proximally to radial distally).

Tolat type III morphology comes under scrutiny when USO is utilized to treat ulnar-sided pathology. When the distal radial articular surface of the sigmoid notch faces distally, shortening of the ulna may theoretically lead to increased load concentration across the joint, predisposing patients to arthritic changes (►**Fig. 2**). Several authors have argued that USO in patients with reverse inclination is difficult without disturbing the joint and may lead to worsening pathology.[8–14] A 4-year follow-up study of patients undergoing USO by Baek et al found that 6 of 36 wrists had radiographic signs of DRUJ arthritis at follow-up, with five of these six having a Tolat type III morphology.[12]

The incidence of the Tolat type III morphology varies amongst previous reports, ranging from 0 to 19%.[8,10,15–17] Limited studies exist, with only five articles published to date reporting the prevalence of type III morphology. Furthermore, the number of patients analyzed in these studies have been limited ($n = 13–248$). We sought to evaluate the prevalence of the Tolat types with radiographic analyses in the largest cohort of patients to date and conduct exploratory analyses to examine the associations of age, gender, sigmoid inclination, and arthritis with sigmoid inclination.

Materials and Methods

Reporting for this study follows STROBE guidelines. Institutional Review Board approval was obtained.[18] A cohort was selected by retrieving all patients undergoing a wrist radiograph (CPT code 73110) for any reason during a 2-year period (July 2016–July 2018) at a single level I tertiary referral center. Although this study was retrospective in nature, posteroanterior wrist radiographs were taken with the patient seated, the shoulder abducted to 90', the elbow flexed to 90', and the ipsilateral hand placed on the receiver. Wrist radiographs were evaluated and demographic data including age and sex were recorded. Patients younger than 18 were excluded. We excluded those with radiographic pathology or trauma affecting the DRUJ (i.e., distal radius or ulna fractures or developmental variants such as Madelung's deformity). Patients with advanced erosive arthritis with unmeasurable

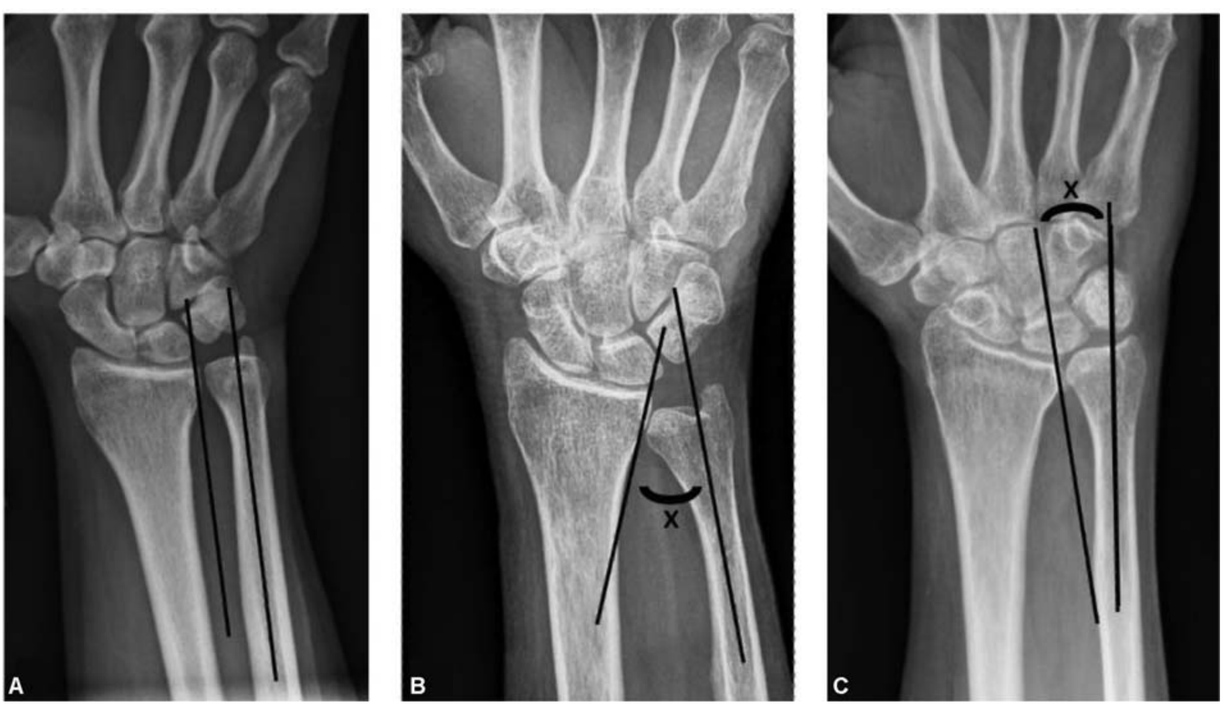

Fig. 1 Distal ulna morphology Tolat types. The angle between the ulna and the sigmoid notch is measured. Tolat type I is parallel (**A**), type II is oblique (**B**), and type III is reverse oblique (**C**).

Fig. 2 Type III reverse oblique morphology treated with ulnar shortening osteotomy. Preoperative images (A) and postoperative images (B). Note that postoperatively the proximal sigmoid notch contacts the distal ulnar head.

angles were excluded. Radiographs with insufficient length of the ulna to calculate the inclination angle were also excluded. A total of 1,393 radiographs were reviewed to obtain 1,000 radiographs meeting inclusion (►**Fig. 3**).

Radiographic analysis was performed by two fellowship trained hand surgeons (blinded) and three orthopaedic surgery residents (blinded). The 1,000 radiographs were distributed amongst the five raters. Absolute values of ulnar variance were measured and recorded according to work by Coleman et al.[19] Ulnar variance measurements were then classified as neutral ($\pm$1 mm), positive ($> +1$ mm), or negative (< -1 mm).[20]

Sigmoid inclination angles were measured according to the technique described and used in previous work.[15–17,21] Angles were measured electronically using standard imaging software (McKesson Radiology 12.2, McKesson Corporation, Irving, Texas). The angle of sigmoid inclination was measured based on the ulnar border of the radius (sigmoid notch), as described by Ross et al,[17] and demonstrated in ►**Fig. 4**. As described by Heiss-Dunlop et al, angles were given positive values for DRUJs with inclinations facing proximally and negative values for those facing distally, e.g., a *reverse* inclination will have a *negative* value.[15]

The inclination values were then used to classify the radiographs by Tolat DRUJ type: type I—parallel, type II—oblique (articular surface facing proximal), and type III—reverse inclination (articular surface facing distal). We defined a type I DRUJ as $\pm$ 10 degrees based on work showing this to be a reliable value based on computed tomography and radiographic analysis with good intra- and interobserver reliability.[15]

The DRUJ was evaluated for evidence of arthritis. Arthritis was defined as joint space narrowing, osteophyte formation, subchondral sclerosis, or cystic changes. If arthritis was present, it was graded according to the criteria defined by Knirk and Jupiter.[22] The joint was graded as mild if there was slight narrowing of the joint space, moderate if there was marked narrowing of the joint space and formation of osteophytes, and severe if there was complete loss of joint space, formation of osteophytes, and subchondral cysts.

Data were analyzed using R and Rstudio.[23,24] Means and standard deviations were calculated for age, sigmoid inclination, and ulnar variance. Frequencies and percentages were

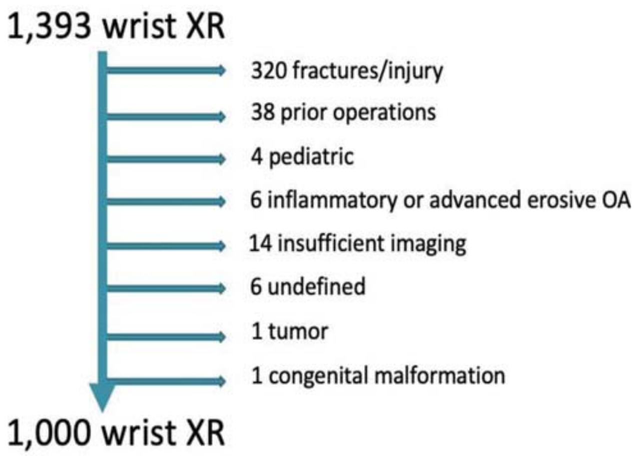

Fig. 3 Over 1,300 radiographs were reviewed, and after exclusion criteria were met, 1,000 total radiographs underwent analysis.

calculated for sex, Tolat type, ulnar variance (positive, neutral, negative), and DRUJ arthritis. Correlation tests were used to examine the associations between ulnar variance (continuous measure), age, and sigmoid inclination. A test of proportions was used to examine sex differences in reverse inclination. A *t*-test was used to examine age differences in reverse inclination. A linear regression model adjusting for sex and age examined the association between sigmoid inclination and ulnar variance. Incidence of DRUJ arthritis by inclination type was examined with a test of proportions. A logistic regression model adjusting for sex and age examined the association between sigmoid inclination and presence of arthritis. A *p*-value of less than 0.05 was considered statistically significant. There were no missing data.

Results

The mean sigmoid inclination relative to the ulnar shaft was 4.37 degrees (standard deviation [SD] = 9.38; range −25.60 to +39.00 degrees). Tolat type III morphology was recorded with a prevalence rate of 6.1% (►**Table 1**). Ulnar variance was on average 0.58 (SD = 1.97, range −9.3 to +15). Prevalence rates of ulnar positive, ulnar neutral, and ulnar negative radiographs are listed in ►**Table 1**.

Fig. 4 Measurement of sigmoid notch inclination. The ulnar inclination angle (×) is measured between the ulnar border of the radius, i.e., sigmoid notch, and the ulnar diaphysis. (**A**) demonstrates Tolat type II morphology (oblique with articular surface facing proximal) and (**B**) demonstrates Tolat type III morphology (reverse oblique with articular surface facing distally).

Table 1 Prevalence of Tolat type, DRUJ arthritis, and ulnar variance

		DRUJ arthritis
Tolat type		
Type I—parallel	675 (67.5%)	10.2%
Type II—oblique	264 (26.4%)	20.4%
Type III—reverse oblique	61 (6.1%)	24.6%
Ulnar variance		
Positive	530 (53%)	
Neutral	190 (19%)	
Negative	280 (28%)	

Abbreviation: DRUJ, distal radioulnar joint.

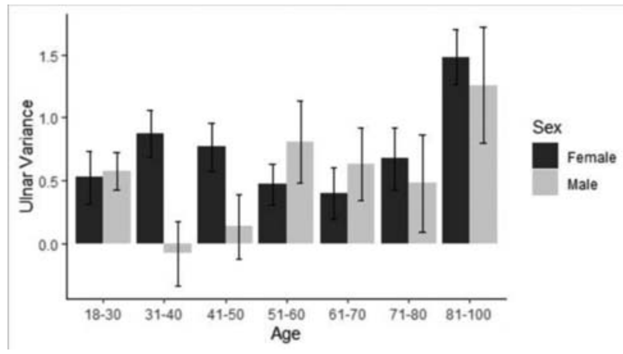

Fig. 5 Distribution of ulnar variance by age and sex. Positive ulna variance was positively correlated with older age.

Positive ulna variance was positively correlated with older age ($r = 0.07$, 95% confidence interval [CI] = 0.01 to.13, $p = 0.03$) (►**Fig. 5**) and negatively correlated with sigmoid inclination ($r = -0.54$, 95% CI = −0.58 to −0.49, $p < 0.001$) (►**Fig. 6**). Females were significantly more likely to have reverse inclination (Type III) than males (8.0 vs. 3.8%, $p = 0.009$, 95% CI = 1.2–4.2) (►**Fig. 7**). No difference was noted by age for prevalence of reverse inclination ($t = -1.6$, $p = 0.12$, 95% CI = −10.0 to 1.2). A linear regression model indicated that sigmoid inclination was negatively associated with ulnar variance, unadjusted ($b = -0.11$, $p < 0.001$, 95% CI = −0.12 to −0.10) and adjusted for sex and age ($b = -0.12$, $p < 0.001$, 95% CI = −0.13 to −0.10).

Presence of DRUJ arthritis (mild, moderate, or severe) was noted in 14.1% of the patients. A higher prevalence of arthritis was noted in those with a type III inclination (24.6%) or type II inclination (20.8%) compared with patients with type I inclination (10.5%, $p < 0.001$) (►**Fig. 8**). There was no difference in likelihood of moderate or severe arthritis by Tolat group. Higher sigmoid inclination was associated with higher odds of the presence of arthritis, unadjusted (odds ratio [OR] = 1.03, 95% CI = 1.01–1.05, $p = 0.003$) and adjusted for sex and age (odds ratio = 1.04, 95% CI = 1.02–1.06, $p < 0.001$).

Discussion

Previous authors have reported on the prevalence of reverse inclination with rates ranging from 0 to 19%.[8,10,15–17] The sample sizes in these studies have been limited, however, with total patient numbers ranging from 13 to 248, restricting the ability to estimate true prevalence. Our series of 1,000 radiographs demonstrate a prevalence of reverse inclination of 6.1%.

Several findings were noted in our series regarding sigmoid inclination. After adjusting for age and sex, sigmoid inclination

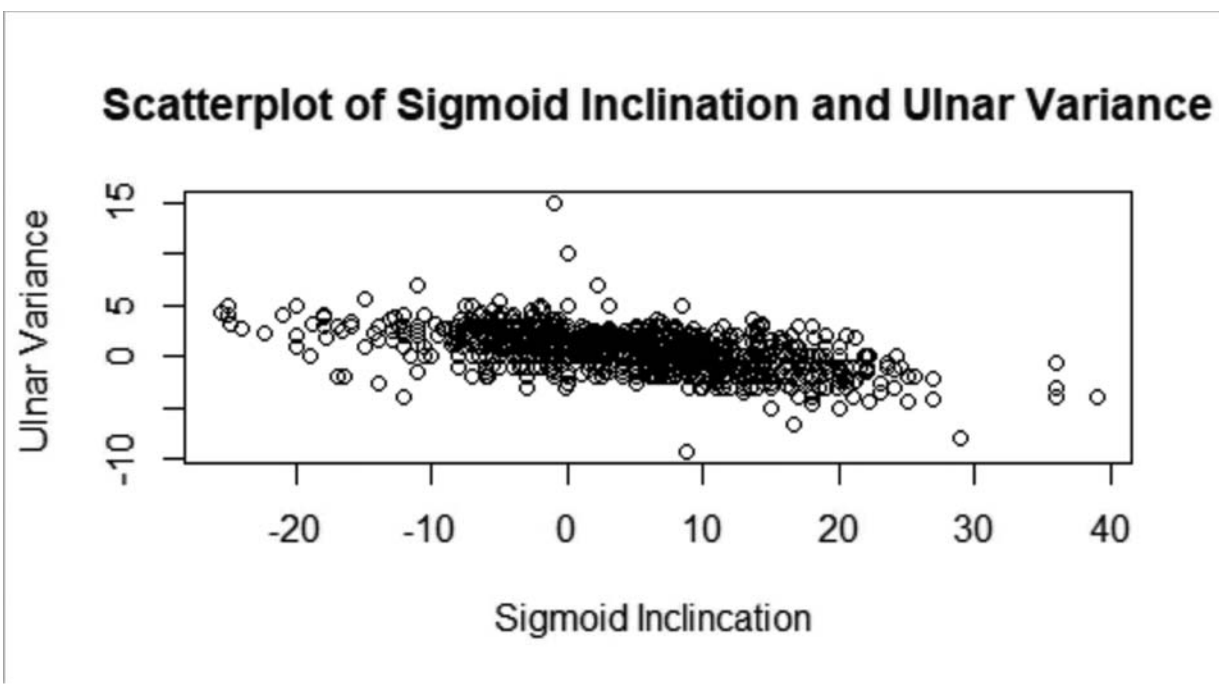

Fig. 6 Scatterplot of ulnar variance and sigmoid inclination. Positive ulna variance is negatively correlated with sigmoid inclination.

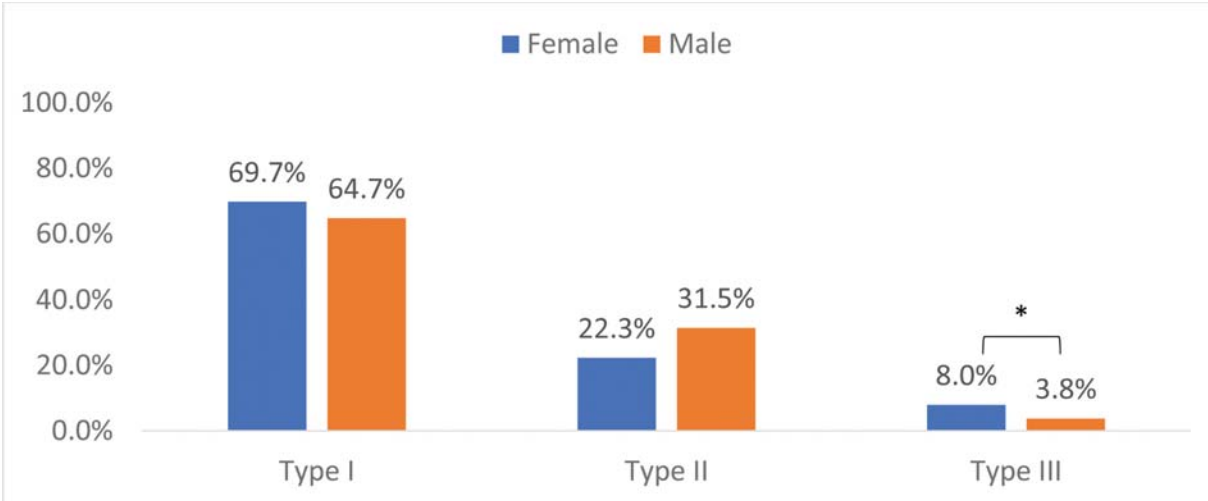

Fig. 7 Distribution of Tolat type by sex. Females were significantly more likely to have reverse inclination (type III) than males.

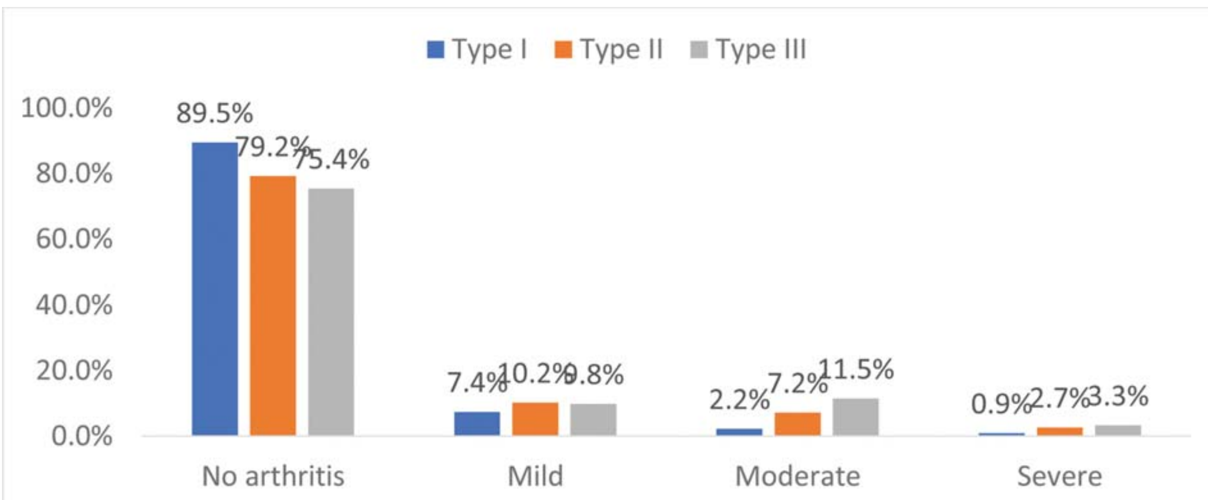

Fig. 8 Distribution of Tolat type by presence and stage of arthritis. A higher prevalence of arthritis was noted in those with a type III morphology or type II morphology compared with patients with type I morphology. There was no difference in likelihood of moderate or severe arthritis by Tolat group.

was negatively associated with ulnar variance, corroborating the findings of other anatomical studies[7,9,11,14] Garcia-Elias et al correlated ulnar variance with measures of joint laxity and found that ulnar positive, reverse inclination morphology was more likely to be present in relatively stiff wrists.[11] The question remains, however, as to how these anatomical findings and joint laxity are related. It remains to be seen if one predisposes to the other or if a natural progression exists. Given that ulnar variance is associated with ulnar impaction syndrome and is commonly treated with USO, this underscores the need to understand whether the reverse inclination morphology has an impact on the DRUJ following USO as hypothesized by various authors.[8–14] Additionally, females were more likely to have reverse inclination morphology, highlighting the impact that USO may have on female patients.

Additionally, our cohort demonstrates that there is no difference in sigmoid inclination by age. This could represent a static rather than progressive nature of the morphologic patterns. Prospective, longitudinal studies are needed to better understand the association of age and sigmoid inclination.

This series demonstrates that patients with parallel morphology were less likely to have DRUJ arthritis when compared with those with oblique or reverse oblique morphology (with those patients with reverse oblique morphology having the highest rates of arthritis). Prior work demonstrates that patients with reverse oblique morphology were less likely to have arthritis than patients with parallel or oblique morphology.[16] These differences raise question regarding the mechanism behind development of arthritis at this joint. Interestingly, the current investigation notes higher rates of arthritis despite having a younger demographic (patients greater than 18 years of age in the current study and patients greater than age 50 in the study by Hollevoet et al) It is possible that parallel morphology may have a lower rate of arthritis (reflected in this series) due to more uniform wear of the joint. Alternatively, it may be that oblique and reverse oblique morphology is a spectrum of joint degeneration. Our finding that there is no difference in inclination by age argues against this latter theory. In light of these findings and their contrast to prior investigation, the impact of DRUJ morphology and age on the development of DRUJ arthritis deserves more study.

Our analysis also demonstrated that positive ulnar variance was correlated with older age, in accordance with many previous studies.[25–29] However, some authors have found contradictory results noting no correlation between age and ulnar variance, including a longitudinal study by Chen and Wang.[30,31] The literature notes a likely difference by race, with Caucasians tending to a negative variance of -0.84 to -0.9 mm[32,33] and Asians having positive variance $+0.20$ to $+0.86$ mm.[25,30,34] Our study was performed in a suburban Northern California area with a population estimate of 64% white and 27% Asian[35]; however, we did not identify patient race in our cohort.

We recognize the limitations inherent to retrospective cohort analyses. Our study lacks individual level demographics (e.g., race) and clinical data (e.g., range of motion) that may help strengthen our analyses. This study did not evaluate proximal forearm, wrist, or elbow radiographic anatomy, nor were we able to control pronosupination of the forearm—limiting our analyses. Heiss-Dunlop et al previously demonstrated high inter- and intra-rater reliabilities for sigmoid inclination (intraclass coefficient [ICC]: 0.95 and ICC: 0.90, respectively)[15] and Laino et al and Steyers and Blair demonstrated high inter- and intra-rater reliabilities for ulnar variance (ICC: 0.87–0.98 and ICC: 0.97, respectively).[36,37] We did not perform reliability testing as part of our study. Of note, our results may be limited by our choice of imaging modality. Recent work by Ross et al, evaluating radiographic and magnetic resonance imaging (MRI) of the DRUJ morphology, not only calls into question the existence of reverse obliquity as they found no reverse oblique variants on MRI of 100 wrists but recommends the use of MRI to validate wrists of patients with radiographs consistent with reverse obliquity.[17] Our sample may be subject to selection bias. We attempted to control this by analyzing a large set of patients undergoing wrist radiographs over a 2-year period likely for some clinical pathology; however, we did not have any healthy controls for comparison. Additionally, we did not conduct any *a priori* power analyses as our primary question was related to prevalence, which limits the conclusions that can be drawn regarding our secondary outcome questions. The exclusion of patients with any wrist trauma, developmental variants, or advanced destructive changes helped to decrease the number of pathologies and may increase the chance of a random sample. Additionally, patients younger than 18 years of age were excluded, limiting the application of this analysis to the adult population.

These limitations notwithstanding, this radiographic series is noteworthy in the sense that it is the largest series to date specifically reviewing DRUJ morphology. This large dataset allows for better quantification of the prevalence of DRUJ morphologies and determination of correlations that have clinical implications on patients with ulnar-sided wrist pathology.

Ethical Approval

The authors have complied the ethical standards as detailed in "Instructions to the Author" set forth by *Journal of Wrist Surgery*.

Conflict of Interest

B.S. reports other from StabilizOrtho, outside the submitted work. Remaining authors do not have any conflict of interest.

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