Inter- and Intrarater Reliability of Ulna Variance Versus Lunate Subsidence Measurements in Madelung Deformity

Sebastian Farr, MD, Donald S. Bae, MD

Purpose To assess inter- and intrarater reliability of both ulna variance and lunate subsidence measurement methods in a large consecutive series of children with Madelung deformity.

Methods Ulnar variance and lunate subsidence were measured on 41 standard anteroposterior wrist radiographs from 31 patients with Madelung deformity. The patients had a mean age of 13 years (range, 5–25) at the time of presentation. Two pediatric orthopedic hand/upper limb surgeons evaluated all radiographs twice in a 4-week interval using standard digital imaging software. Intraclass correlation coefficients (ICCs) were calculated for inter- and intrarater reliability, and results were reported using the Landis and Koch criteria.

Results The interrater ICC for the ulna variance measurements was substantial, and for the lunate subsidence almost perfect. The intrarater ICC for ulna variance was substantial for both raters. In contrast, the intrarater ICC for lunate subsidence was almost perfect for both raters.

Conclusions Measurement of lunate subsidence showed both superior interrater and intrarater reliability compared with the ulnar variance method. Whenever relative ulna length is assessed in children and adolescents with Madelung deformity, the lunate subsidence should be the preferred method to characterize deformity. *(J Hand Surg Am. 2015;40(1):62–66. Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Diagnostic IV.

Key words Lunate subsidence, Madelung deformity, reliability, ulnar variance.

Additional material is available online.

Madelung deformity is a growth disturbance of the distal radial physis eventually leading to a progressive deformity of the wrist during growth.[1] As a consequence the majority of patients develop relative ulna overgrowth and may subsequently develop ulnar-sided wrist pain. The prominent ulna, caused by the premature closure of the volar–ulnar radial physis, is therefore one of the pathognomonic clinical findings in moderate to severe cases.

Although ulnar variance can generally be measured using anteroposterior (AP) wrist radiographs for many pediatric and adult wrist pathologies, the utility of this measurement in Madelung deformity remains controversial.[2] There is a risk of measurement error when evaluating this deformity; the radial plateau and particularly the lunate fossa may be severely tilted and thus, the horizontal reference line, which defines the length of the radius, is difficult to identify. McCarroll et al proposed measurement of lunate subsidence as a better method for characterizing this pathological

From the Department of Pediatric Orthopaedics, Deformity Correction, and Adult Foot & Ankle Surgery, Orthopaedic Hospital Speising, Vienna, Austria; and the Department of Orthopedic Surgery, Boston Children's Hospital, Boston, MA.

Received for publication June 9, 2014; accepted in revised form August 23, 2014.

Investigation performed at the Department of Orthopedic Surgery, Boston Children's Hospital, Boston, MA.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

Corresponding author: Sebastian Farr, MD, Orthopaedic Surgeon, Orthopaedic Hospital Speising, Department of Pediatric Orthopaedics, Deformity Correction, and Adult Foot & Ankle Surgery, Speisinger Strasse 109, 1130 Vienna, Austria; e-mail: sebastian.farr@oss.at.

0363-5023/15/4001-0012$36.00/0
http://dx.doi.org/10.1016/j.jhsa.2014.08.037

FIGURE 1: Ulnar variance in this patient is +1 mm (arrow). Note, however, that the ulnar border of the distal radius physis is rather round and not a distinct edge.

FIGURE 2: The arrow indicates where the radial plateau is tilted downwards. This particular, often sclerotic-appearing, point was chosen as the reference point for placement of the horizontal measurement line.

deformity.[3] Nevertheless, many pediatric hand surgeons still prefer to measure ulnar variance when defining the deformity and/or deciding when an ulnar shortening osteotomy is indicated.

The lunate subsidence, in contrast, is relatively easy to measure because it compares ulna length to the (normal) anatomy of the proximal pole of the lunate, which migrates proximally with the entire carpus. Patients with Madelung deformity and normal controls showed a wide overlap of subsidence from lacking 5 mm to 3 mm.[4] A subsidence threshold of 4 mm has been found to be characteristic for this deformity.[5] The lunate subsidence method has shown to be reliable between observers.[3] The purpose of this study was to assess inter- and intrarater reliability of both ulnar variance and lunate subsidence measurement methods in a large consecutive series of children and adolescents with Madelung deformity.

METHODS

This retrospective study was approved by our institutional review board prior to the chart review. All patients with the diagnosis of Madelung deformity who underwent surgery between 1999 and 2013 were identified using an electronic medical record database. After exclusion of cases with insufficient or missing digital imaging, 31 patients (41 wrists) remained for evaluation and inclusion in this study. The included patients represented a wide range of radius deformity, ranging from mild to severe alteration of their wrist geometry. Two independent, fellowship-trained pediatric orthopedic hand surgeons performed a standardized assessment of ulnar variance and lunate subsidence according to previously established criteria.[3,6] First, both observers familiarized themselves independently with the methodology of the measurement methods. Then, a pilot series of measurements built consensus regarding measurement methodology before study radiographs were rated individually. All study measurements were performed using AP wrist radiographs, which were obtained in the same institution in a standardized manner prior to wrist surgery. Measurements were made on digital images using standard software (Synapse PACS, Fujifilm, Stamford, CT). Thereafter, measurements were repeated after a 4-week interval by both raters in order to assess intrarater reliability. For this reason, the raters were blinded to their first readings, and all radiographs were evaluated in random order for the second evaluation.

Ulnar variance was assessed using a modified method of perpendiculars (Fig. 1).[6] First, a line was placed along the longitudinal axis of the ulna. Then, a perpendicular line at the most distal aspect of the articular surface of the ulna, excluding the ulnar styloid, was drawn. We then measured the longitudinal distance from this perpendicular line to the most ulnar aspect the radial plateau. Given the fact that the ulnar border of the radius in Madelung deformity is often distorted and/or tilted, the observers agreed on the following radius reference point: the most ulnar sclerotic aspect of the radial plateau (lunate facet) beneath

FIGURE 3: Anteroposterior wrist radiograph shows the measurement technique of lunate subsidence. In this case, the subsidence is positive (5 mm; arrow), and thus a relative overlength of the ulna compared with the radius is evident.

FIGURE 4: This case illustrates the difficulty of placing the perpendicular ulnar reference line in a case with whole bone involvement and a hat-shaped ulnar styloid. The distal ulnar plateau is anticipated and projecting behind the triquetral bone (arrow).

the downward tilted lunate fossa (Fig. 2). Moreover, the observers had to agree on where to place the perpendicular ulnar line in cases with a hyperplastic, irregular distal ulna. In these cases, we decided not to place the line on the tip of the ulna styloid (as there is presumably no articular plateau present), but to place it proximal to the tip of the ulna styloid at the transition point to the articular surface of the distal ulna. A positive value denoted a longer ulna, and a negative value denoted an ulna shorter than the radius.

Lunate subsidence was defined as the distance between the abovementioned perpendicular line to the longitudinal ulna axis and the proximal pole (most proximal point) of the lunate (Fig. 3).[3] A positive value denoted a lunate that had migrated proximally to the ulna articular surface, and a negative value indicated a lunate, and thus a carpus, that was positioned distal to the ulna articular surface.

The electronic search retrieved 40 patients. After exclusion of insufficient cases, both observers evaluated 41 radiographs of 31 patients (29 female, 2 male). Overall, 20 left and 21 right wrist radiographs were assessed (Appendix A, available on the *Journal's* Web site at www.jhandsurg.org). The patients had a mean age of 13 years (range, 5−25) at the time of presentation.

Statistical analysis

We calculated intraclass correlation coefficients (ICCs) in order to measure interrater and intrarater reliability and to evaluate the agreement between observers and within the same observer at different time points.[7] The two-way mixed model (single measures) with absolute agreement was used, and confidence intervals (95% CI) are reported. The first x-ray readings of the two raters were used for calculation of the interrater reliability. To interpret overall agreement, we adhered to the criteria published by Landis and Koch, where 0 indicates no agreement, .01 to .20 slight, .21 to .40 fair, .41 to .60 moderate, .61 to .80 substantial, and .81 to 1.0 perfect agreement.[8]

RESULTS

The interrater ICC for ulnar variance measurements was .68 (95% CI, −0.03 to 0.89), whereas the interrater ICC for the lunate subsidence measurements was .83 (95% CI, 0.68−0.91). This indicated substantial agreement for ulnar variance, and almost perfect agreement for lunate subsidence measurement methods, respectively. The intrarater ICC for ulna variance was .80 (95% CI, 0.65−0.89) for rater 1 and

.80 (95% CI, 0.66−0.89) for rater 2. The intrarater ICC for lunate subsidence was .86 (95% CI, 0.75−0.92) for rater 1, and .85 (95% CI, 0.72−0.92) for rater 2, respectively. Hence, our statistical analysis revealed substantial agreement for ulnar variance, and almost perfect agreement for the lunate subsidence measurement method.

DISCUSSION

Since Hulten described "ulnar variance" in 1928, several studies have investigated different measurement techniques, as well as the effects of age, forearm position (rotation), or active grip on the ulnar variance.[9−16] Most of these studies measured normal cohorts or patients with conditions other than Madelung deformity.[17] Goldfarb et al, who assessed the reliability of ulnar variance in a large series of healthy children, found a high reliability of this technique among raters.[2] They observed a mean variance of lacking 0.7 mm for boys and lacking 0.4 mm for girls, showing no significant differences between the younger and older age groups.[2] Patients with Madelung deformity frequently undergo ulnar shortening osteotomies in order to enhance their wrist geometry and reduce ulnocarpal pain. Established methods designed to define ulnar length compared to radius length, such as the ulnar variance, are difficult to use in this entity. The medial border of the radial epiphysis is often distorted due to the volar−ulnar physeal growth arrest, which may impede a proper measurement using this technique. Another radiographic parameter—lunate subsidence—has in contrast been suggested specifically for Madelung cases. This parameter, which has previously been measured on hard copies, has so far shown to be reliable.[3] Hence, the purpose of this study was to assess and compare inter- and intrarater reliability of both ulnar variance and lunate subsidence measurement in patients with Madelung deformity.

Our results demonstrated that the lunate subsidence measurement was superior to the ulnar variance method, although the latter still exhibited substantial agreement between raters. Nevertheless, given the mean ICC and the lower boundary of the confidence interval, we propose using lunate subsidence measurements especially in moderate to severe cases to define the magnitude of bone length discrepancy between radius and ulna and/or indicate ulna surgery based on AP radiographs. Concerning the intrarater agreement, we observed relatively similar agreement between the raters for both methods, but the subsidence method was still slightly superior to the ulnar variance method. Although both methods were reproducible by both observers, appropriate radiographic landmarks were easier to identify when measuring lunate subsidence. As opposed to the medial border of the radius physes, the proximal pole of the lunate can be easily identified and used for the assessment of lunate subsidence. In cases with a "hat-shaped" ulnar styloid without an obvious distal ulnar articular surface, however, both methods were inadequate; this was particularly true in patients with whole bone involvement (Zebala type 2; Fig. 4).[18] In these cases we suggest drawing the horizontal, perpendicular line proximal to the tip of the ulnar styloid, where the distal joint line would be anticipated. Nevertheless, despite the fact that the ulnar variance method is widely used, even for this entity, we would encourage uniform use of the subsidence method in order to obtain comparable data in further studies and especially for surgical planning.

Besides clinical findings, surgery should be based on reliably established radiographic criteria of the deformity, which is particularly true for a three-dimensionally distorted wrist as found in Madelung deformity. The lunate subsidence method is not only the most reliable method published so far, but it is also relatively easy to establish. Subjectively, both observers in this study did not find this method to be more inconvenient or difficult than the ulnar variance method. We currently advise surgery primarily based on persistent wrist pain and radiographic deformity. Thus, proper AP radiographs are important for us to define the magnitude of radial growth disturbance and ulnar overgrowth. Although we do not have a distinct cutoff value to indicate ulnar shortening, we use our measurements for determining the amount of ulna resection whenever surgery is warranted.

Although this study included a relatively large number of patients with Madelung deformity whose radiographs were measured in a reproducible digital fashion, some limitations are noted. The vast majority of the radiographs were performed at a tertiary care pediatric hospital in a standardized technique. Given the fact that patients with Madelung deformity might lack forearm rotation, subtle variations in technique and projection errors cannot be completely ruled out. Nevertheless, we believe that these variations are negligible.

REFERENCES

1. Dubey A, Fajardo M, Green S, et al. Madelung's deformity: a review. *J Hand Surg Eur Vol*. 2010;35(3):174−181.
2. Goldfarb CA, Strauss NL, Wall LB, et al. Defining ulnar variance in the adolescent wrist: measurement technique and interobserver reliability. *J Hand Surg Am*. 2011;36(2):272−277.

3. McCarroll HR Jr, James MA, Newmeyer WL 3rd, et al. Madelung's deformity: quantitative assessment of x-ray deformity. *J Hand Surg Am*. 2005;30(6):1211−1220.
4. McCarroll HR, James MA, Newmeyer WL 3rd, et al. Madelung's deformity: quantitative radiographic comparison with normal wrists. *J Hand Surg Eur Vol*. 2008;33(5):632−635.
5. McCarroll HR Jr, James MA, Newmeyer WL 3rd, et al. Madelung's deformity: diagnostic thresholds of radiographic measurements. *J Hand Surg Am*. 2010;35(5):807−812.
6. Steyers CM, Blair WF. Measuring ulnar variance: a comparison of techniques. *J Hand Surg Am*. 1989;14(4):607−612.
7. Bedard M, Martin NJ, Krueger P, Brazil K. Assessing reproducibility of data obtained with instruments based on continuous measurements. *Exp Aging Res*. 2000;26(4):353−365.
8. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159−174.
9. Hulten O. Über anatomische Varianten der Hand Gelenkknochen. Ein Beitrag zur Kenntnis der Genese zweier verschiedener Mondbeinveränderungen. *Acta Radiol*. 1928;9:155−169.
10. Kristensen SS, Thomassen E, Christensen F. Ulnar variance determination. *J Hand Surg Br*. 1986;11(2):255−257.
11. Palmer AK, Glisson RR, Werner FW. Ulnar variance determination. *J Hand Surg Am*. 1982;7(4):376−379.
12. Sanderson PL, Cameron IC, Holt GR, et al. Ulnar variance and age. *J Hand Surg Br*. 1997;22(1):21−24.
13. Jung JM, Baek GH, Kim JH, et al. Changes in ulnar variance in relation to forearm rotation and grip. *J Bone Joint Surg Br*. 2001;83(7):1029−1033.
14. Yeh GL, Beredjiklian PK, Katz MA, et al. Effects of forearm rotation on the clinical evaluation of ulnar variance. *J Hand Surg Am*. 2001;26(6):1042−1046.
15. Kawanishi Y, Moritomo H, Omori S, et al. A comparison of 3-D computed tomography versus 2-D radiography measurements of ulnar variance and ulnolunate distance during forearm rotation. *J Hand Surg Eur Vol*. 2014;39(5):526−532.
16. Sönmez M, Turaçlar UT, Taş F, et al. Variation of the ulnar variance with powerful grip. *Surg Radiol Anat*. 2002;24(3-4):209−211.
17. Laino DK, Petchprapa CN, Lee SK. Ulnar variance: correlation of plain radiographs, computed tomography, and magnetic resonance imaging with anatomic dissection. *J Hand Surg Am*. 2012;37(1):90−97.
18. Zebala LP, Manske PR, Goldfarb CA. Madelung's deformity: a spectrum of presentation. *J Hand Surg Am*. 2007;32(9):1393−1401.

APPENDIX A. Demographic Data and Disease Characteristics

Patient	Sex	Age at Presentation (y)	Side	Bilateral	Zebala Type[18]
1	F	16	R	Yes	1
1	F	18	L	-	1
2	F	10	L	Yes	2
2	F	10	R	-	2
3	F	14	R	No	1
4	F	13	R	Yes	1
4	F	13	L	-	1
5	F	13	R	Yes	1
6	F	11	R	Yes	1
7	F	13	R	Yes	1
7	F	15	L	-	1
8	F	10	L	Yes	2
9	F	13	R	No	1
10	F	14	L	Yes	1
11	F	5	L	Yes	1
11	F	5	R	-	1
12	F	10	R	No	1
13	F	13	L	Yes	1
14	F	17	R	Yes	1
15	F	25	R	No	1
16	F	13	L	Yes	1
16	F	14	R	-	1
17	F	10	R	Yes	1
18	M	13	R	No	1
19	F	14	L	Yes	1
20	M	15	L	No	1
21	F	14	L	Yes	1
22	F	13	L	Yes	2
23	F	12	R	Yes	2
23	F	12	L	-	2
24	F	7	L	No	1
25	F	11	R	Yes	1
25	F	12	L	-	1
26	F	13	R	No	1
27	F	9	L	No	1
28	F	15	R	Yes	1
28	F	15	L	-	1
29	F	14	R	Yes	1
30	F	13	L	Yes	1
30	F	13	R	-	1
31	F	12	L	Yes	1

F, female; M, male, L, left; R, right.