The Effect of Axial Loading on Ulnar Variance

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Abstract

Background Forearm rotation results in change in ulnar variance. Axial loading of the wrist is required to maintain daily activities. Change in ulnar variance during axial loading has not been investigated previously.

Purpose To measure the change in ulnar variance on axially loaded wrists.

Patients and Methods We examined 21 asymptomatic individuals and 24 patients with unilateral ulnar-sided wrist pain. All patients underwent standard neutral posterolateral wrist radiographs without load and under axial loading on bilateral wrists. Axial loading was standardized at 18.1 kgf using an analog weight scale. A magnetic resonance (MR) arthrogram was obtained only in patients with ulnar-sided wrist pain. Beighton flexibility score was recorded on healthy volunteers. Change in ulnar variance between 0 and 18.1 kgf was compared for each wrist among all subjects. A correlation was sought between the change in ulnar variance, MR arthrogram findings, and physical examination.

Results In individuals without wrist pain, on average, 0.4 mm increase in ulnar variance was measured between 0 and 18.1 kgf. There was no difference between the dominant and nondominant side. No correlation was found with increasing age. In contrast, patients with ulnar-sided wrist pain displayed an average increase of 0.8 mm in ulnar variance. Compared with the contralateral wrist, more than 1 mm increase in ulnar variance was correlated with intra-articular pathologies including dorsoulnar ligament disruption, central triangular fibrocartilage complex (TFCC) perforation, and foveal detachment.

Conclusion Compared with contralateral side, more than 1 mm increase in ulnar variance is suggestive of longitudinal instability or TFCC pathology.

Level of Evidence Level II, diagnostic.

Keywords

- ▶ ulnocarpal abutment
- ▶ impingement
- ▶ ulnar variance
- ▶ TFCC
- ▶ axial loading

Ulnar variance (UV) is a radiographic measure, used in the evaluation of conditions including ulnocarpal abutment, Kienbock's disease, and distal radius fractures. It is considered neutral when the relative height difference between the radius and ulna is zero. The relationship between the ulna and radius is dynamic and changes with the forearm rotation. To measure UV, various methods have been described.^{1–4} Neutral rotation forearm radiographs were initially pro-

posed but later, supplemented with pronated grip views particularly in patients with neutral or negative UV where dynamic UV change may not be apparent in earlier stages of the ulnocarpal abutment.

Patients with ulnocarpal abutment often complain about ulnar-sided wrist pain (USWP), when they exert axial pressure to their wrists in activities such as pushups, or pushing a revolving door. There may be a relationship with axial loading

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and USWP in patients with ulnar impaction. There are a few patient-reported instruments that allow us to quantify these symptoms of discomfort in a predictive way to determine next stages of intervention or additional diagnostic tests needed. In this context, identifying cost-effective, practical strategies to capture ulnocarpal pathology and instability could provide a useful clinical tool for clinicians. In addition, this option could provide a more sensitive assessment of early ulnocarpal pathology over existing options.

Axial loading of the wrist appears to be a dynamic process leading to increase in UV depending on the load applied at the time of the activity. We tested the null hypothesis that there is no difference in UV with axial load in patients with USWP versus those without USWP. We achieved that by having healthy volunteers and patients apply axial pressure on a weight scale and measured their UV on plain posterolateral (PA) radiographs taken in neutral forearm rotation.

Patients and Methods

Institutional review board reviewed and approved this cross-sectional study. This was conducted prospectively on two groups of patients.

In group 1, we had 21 healthy volunteers who did not have USWP at the time of enrollment or a history of wrist injury. In group 2, we examined 24 individuals with USWP with axial loading, but no pain with distractive forces (carrying a suitcase with hook grip). Individuals in both groups had a routine encounter including history and physical examination, and radiographic stress views. Individuals with USWP also underwent a magnetic resonance (MR) arthrogram to further delineate the intra-articular pathology. In the volunteer group, we also measured Beighton flexibility index.⁵ All patients were older than 18 and younger than 65 years of age.

Patients who had previous distal radius fractures or had extra-articular source of pain (such as tenderness along with extensor carpi ulnaris tendon sheath or fifth metacarpal base) on their physical examination were excluded from the study.

Power analysis based on the primary outcome measure (ulnar variance) revealed that we needed a minimum of 20 patients in each group to detect a statistically significant difference of 0.05.

Axially Loaded Stress Views of the Wrist

We used a flat, height adjustable platform to place an analog weight scale. We then placed memory foam pads on a weight scale to apply pressure (► Fig. 1). Patients were asked to make a fist and push against the foam keeping shoulder in neutral position, upper arm in internal rotation, elbow, wrist, and forearm in neutral positions. First, PA radiographs were taken without loading followed by 18.1 kgf (40 lbs) axial loading of the wrist. Patients were able to visualize the amount of pressure applied and were asked to hold it at 18.1 kgf briefly when radiographs were taken. Attention was paid to align third metacarpal with the long axis of the forearm to avoid ulnar or radial deviation of the wrist. All patients were asked to grade their discomfort (mild, moderate, severe) at the time of the axial loading.

Fig. 1 Transverse guide beam should be centered at wrist, while the longitudinal one coincides with the third metacarpal and the forearm axis. Foam pad is used to provide a smooth surface and prevent radial/ulnar deviation of the wrist.

Magnetic Resonance Imaging of the Wrist

We obtained 3-tesla MR arthrogram in all patients with USWP. A board certified radiologist blinded to all other findings of the study evaluated images. Findings of the MR arthrogram were divided into two groups using the classification system reported previously.⁶

Two board certified, fellowship trained hand surgeons have measured UV using a method of perpendiculars on Picture Archiving and Communication System (PACS).² After identifying the longitudinal axis of the radius, a line is drawn through its distal ulnar aspect that is perpendicular to its longitudinal axis. Distance between this line and the distal cortical rim of the ulna is measured to determine UV. All images were magnified eight to ten times using the image software prior to measurements. Both reviewers were blinded to other variables at the time of measurement. Data included demographic variables, UV measurement on each side, UV difference between 0 and 18.1 kgf on the same side, and changes in UV difference between the two sides, MR arthrogram findings (in group 2 only) and Beighton score (in group 1 only).

Statistical Analysis

We used Welch's two-sample *t*-test and Fisher's exact test as appropriate to test the association between axially loaded stress views with MR arthrogram findings with respect to UV, as well as patient attributes including age, sex, hand dominance, and flexibility score groups. Multiple comparisons adjustments were made on *p* values via the Holm method.

Statistical significance was determined by adjusted p values less than 0.05.

Results

Among volunteers, 5 were males and 16 were females with an average age of 41.0 (standard deviation[SD]: 10.2). Among patients, 7 were males and 17 were females with an average age of 32.7 (SD: 12.9). Sex proportions did not differ significantly (tested with Fisher's exact test, $p = 0.73$) between the two groups. Although average age was significantly higher in volunteers group ($p = 0.02$), there was significant overlap between the two groups.

Within the control group, we specifically examined differences in grip strength by hand dominance, as USWP would be a confounding variable to exert maximum effort during stress testing (► **Table 1**). The average change in UV with grip on nondominant hand side was 1.45 (SD: 0.74) and on dominant side was 1.13 (SD: 0.57), which was not significantly different ($p = 0.07$). In addition, we did not observe differences in flexibility scores ($p = 0.44$), nor UV by laterality among the controls.

Changes of Differences in UV: Group 1 (Healthy Volunteers) versus Group 2 (Patients with USWP)

We placed changes in UV difference between the two sides in ► **Fig. 2** and noted that majority of patients and healthy volunteers have equal or less than 1 mm difference between the two sides. On average, there was no statistically significant difference between the two groups. However, we found a disproportionate number of individuals having more than 1 mm change in UV difference between the two sides (Case #25,26,29,31,35,37)(► **Fig. 3**).

We performed a Fisher's exact test to compare differences in UV between patients with USWP and controls, and observed that a difference in UV of 1 or more is significantly correlated with USWP ($p = 0.02$).

Magnetic Resonance Arthrograph Findings

This imaging study was only conducted on patients with USWP. Data exploration showed no relationship between changes in UV difference and the type of pathology diag-

nosed in MR arthrograms. This analysis was restricted by limited sample size. In individuals with greater than 1 mm change in UV difference (6 patients), one patient had central perforation of the triangular fibrocartilage complex (TFCC), two of them had foveal detachment of the TFCC, and three had disruption of the dorsal ligaments of the distal radio-ulnar joint (DRUJ). Among patients with less than 1 mm change in UV difference, only five of them showed central TFCC perforation. None of them showed foveal detachment or DRUJ ligament disruption.

Moderate-to-Severe Pain on Axial Loading

Seven patients in group 2 had reported moderate-to-severe discomfort at the time of axial loading. Those patients include all six patients who had differences greater than 1mm. Limiting the analysis to patients, fitting a linear regression model, and predicting changes in UV differences predicted that those reporting moderate-to-severe discomfort have a 1.39 higher response on average ($p < 0.001$) when controlling for age and gender ($R^2 = 0.72$).

Discussion

Findings of this study is further evidence that ulnocarpal abutment is a dynamic process, often manifests itself when forearm is axially loaded. Patients with this condition often complained about activity-related pain upon loading during pushing off a chair or pushing a revolving door. Ulnocarpal abutment is related to excessive load bearing across the ulnar carpus, TFCC, and ulnar head.³ UV directly influences load transmission across the wrist. Impaction is more commonly seen in ulnar-positive wrist.⁷ Excessive compressive force, however, may result in symptoms in ulna-neutral and -negative wrists.⁴ Various imaging modalities as well as exam maneuvers have been proposed for the diagnosis.^{1,2,8-10} Neutral rotation forearm radiographs and pronated clenched fist views are the most practical ones that can be obtained in an office setting. In advanced stages of the disease, radiographic views and MR imaging show changes in proximal ulnar corner of the lunate along with a counter lesion on the radial aspect of the ulnar head. In earlier stages of the disease, particularly in patients with negative UV,

Table 1 Values represent means and standard deviation

	Group 1: Volunteers (n = 21)				Group 2: Patients (n = 24)			
	Dominant		Nondominant		Injured		Uninjured	
	No load	Axial loading	No load	Axial loading	No load	Axial loading	No load	Axial loading
UV	−1.03 (1.75)	0.10 (1.75)	−1.00 (1.25)	0.45 (1.49)	0.66 (1.86)	1.99 (1.81)	0.30 (1.72)	1.85 (1.71)
UV difference	1.13 (0.57)		1.45 (0.74)		1.33 (0.86)		1.55 (1.05)	
Change in UV difference	0.45 (0.33)				0.80 (0.88)			

Abbreviation: UV, ulnar variance.

Note: "Change in UV Difference" is the absolute difference. STROBE guidelines for cross-sectional studies were followed and checked throughout this text.

Fig. 2 Graph shows the entire study population. Change in UV difference was calculated using the following formula: $[(\text{injured side UV at } 18.1 \text{ kgf} - \text{injured side UV at } 0 \text{ kgf}) - (\text{uninjured side UV at } 18.1 \text{ kgf} - \text{uninjured side UV at } 0 \text{ kgf})]$. UV, ulnar variance.

ulnocarpal abutment may not be visible on plain radiographs. Our proposed radiographic view in this study is helpful to diagnose the condition at an earlier stage particularly in patients with neutral or negative UV. The method is practical requiring minimal training for the technician and easy to measure, particularly in the era of electronic imaging and well-developed software.

In individuals without USWP, the average UV difference between 0 and 18.1 kgf of axial loading was 1.13 mm. This does not appear to be affected by hand dominance, age, or Beighton flexibility score. In the control group, males have greater UV difference than females when controlled for age. In comparing the two sides on the same individual, change in UV difference is no more than 1 mm on an average. In individuals, who had greater than 1 mm change in difference between the two sides, there is substantial pathology as shown on MR arthrograms. While MR arthrogram findings are not specific to this group, association with pain is highly suggestive of TFCC pathology as all patients in this group reported moderate-to-severe degrees of pain during the axial loading while others did not. These findings suggest that presence of moderate-to-severe pain during axial loading is more sensitive than MR arthrogram findings when change in UV difference between the two sides is more than 1 mm. In other words, MR arthrogram may provide evidence for the damaged structure, but it is not as helpful as localized pain in diagnosing the condition.

The change under axial load is likely related to several factors including ligamentous laxity, injury, degenerative changes of the DRUJ, and TFCC, and possible laxity of the interosseous membrane. In our study, MR arthrogram findings in patients with greater than 1 mm change in UV difference included rupture of the dorsal radioulnar liga-

ments, foveal detachment, as well as central perforation of the TFCC. It appears that an injury to each of these components could lead to a form of longitudinal instability and result in contact between the ulna and the carpus. Previous authors have investigated the relationship between DRUJ stability and relative contributions of each anatomic structure. Most of these studies have focused on stability in the anteroposterior plane.^{11–13} Only a few looked into the relationship between the TFCC injury and UV. Shen et al sequentially cut deep and superficial fibers of the TFCC while applying longitudinal traction at the proximal radius.¹⁴ They found significant change in UV when superficial and deep layers were both severed. These findings are parallel to what we have observed at the clinical setting.

In this study, we reported *statistically* significant results along with nonsignificant ones. Statistical significance, however, does not always represent *clinical* relevance. The case presented in ▶Fig. 4 is an example of this paradox. The patient's change in UV difference was only 0.1 mm and did not appear to be an outlier (much less than 1 mm). However, she could only push 9 kgf due to severe pain. At 9 kgf axial loading, her ulna-lunate distance was substantially less than the opposite site, clinically suggesting ulnocarpal abutment. This patient subsequently underwent ulnar shortening osteotomy. She is now 18 months after the surgery with full range of motion and no residual wrist pain. During our evaluations, we did not obtain pronated clenched views on all patients. Therefore, no conclusions can be drawn regarding the most preferred method of radiographic evaluation for ulnocarpal abutment. However, axial loading appears to make UV more obvious as seen in ▶Fig. 3. We asked our patients to apply 18.1 kgf based on a pilot study on patients reporting inability to maintain load above that level due to

Fig. 3 A 30-year-old, right-hand dominant male patient presented with a 6-month history of left ulnar-sided wrist pain following a fall on outstretched hand. (A) Pronated clenched fist views did not show substantial difference between the two sides. (B) We then obtained an unloaded and axially loaded wrist radiographs on both sides. Ulnar variance (UV) measurements are indicated on radiographs. Change in UV difference between injured and uninjured side is $2.3 - 0.2 = 2.1$ mm. His magnetic resonance arthrogram showed radial-sided detachment of the triangular fibrocartilage complex.

severe pain. It is possible to see a greater change in UV with higher axial loads as long as pain is tolerated or controlled with local anesthetic injection.

Limitations of the current study include a larger sample size required to improve diagnostic accuracy of 1 mm value on plain radiographs. Greater than 1 mm change in UV difference is not an absolute threshold unless associated with pain. The way we graded pain (mild, moderate, or severe) was based on patient's experience and was subjective. MR arthrogram is also not a gold standard in the

diagnosis of ulnar-sided wrist pathology and similar pathologies may be seen in patients with less than 1 mm change. To study the cause of UV change under load, we designed and executed a cadaver study recreating axial loading of the wrist at the laboratory setting, which we aimed to report separately. Finally, all patients selected as part of the study had USWP with compressive axial force and no pain with distraction. These inclusion criteria may have resulted in selection bias. Therefore, results of this study may not be generalizable to all patients with USWP.

Fig. 4 A 40-year-old, right-hand dominant female patient presented with insidious onset, right ulnar-sided wrist pain. Figures show her ulnar variance (UV) at no load and axial loading posteroanterior views. UV measurements are indicated on radiographs. Patient was unable to push to 18.1 kgf due to severe pain on right side. Her UV showed 1.1 mm increase on right side and 1 mm on left. While change in UV difference (0.1 mm) was less than 1.5 mm, the space between the ulnar head and the lunate was substantially less on symptomatic right side than her left. Her magnetic resonance arthrogram showed central perforation of the triangular fibrocartilage complex on right wrist.

In conclusion, axial loading of the wrist increases UV. The proposed radiographic method is practical to apply, easy to measure, and can be particularly useful in patients with negative or neutral UV. Physicians should be concerned about the presence of significant wrist pathology, if there is more than 1 mm change between the two sides in UV difference (from 0 to 18.1 kgf) or severe pain experienced during axial loading. Further studies are required to reveal the causal relationship between our findings and wrist pathology.

Note

Institutional review board approved this study.

Funding

None.

Conflict of Interest

None.

References

- Palmer AK, Glisson RR, Werner FW. Ulnar variance determination. *J Hand Surg Am* 1982;7(04):376–379
- Steyers CM, Blair WF. Measuring ulnar variance: a comparison of techniques. *J Hand Surg Am* 1989;14(04):607–612
- Friedman SL, Palmer AK. The ulnar impaction syndrome. *Hand Clin* 1991;7(02):295–310
- Tomaino MM. Ulnar impaction syndrome in the ulnar negative and neutral wrist. Diagnosis and pathoanatomy. *J Hand Surg [Br]* 1998;23(06):754–757
- Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. *Ann Rheum Dis* 1973;32(05):413–418
- Palmer AK. Triangular fibrocartilage complex lesions: a classification. *J Hand Surg Am* 1989;14(04):594–606
- af Ekenstam FW, Palmer AK, Glisson RR. The load on the radius and ulna in different positions of the wrist and forearm. A cadaver study. *Acta Orthop Scand* 1984;55(03):363–365
- Imaeda T, Nakamura R, Shionoya K, Makino N. Ulnar impaction syndrome: MR imaging findings. *Radiology* 1996;201(02):495–500
- Nakamura R, Horii E, Imaeda T, Nakao E, Kato H, Watanabe K. The ulnocarpal stress test in the diagnosis of ulnar-sided wrist pain. *J Hand Surg [Br]* 1997;22(06):719–723
- Friedman SL, Palmer AK, Short WH, Levinsohn EM, Halperin LS. The change in ulnar variance with grip. *J Hand Surg Am* 1993;18(04):713–716
- Stuart PR, Berger RA, Linscheid RL, An KN. The dorsopalmar stability of the distal radioulnar joint. *J Hand Surg Am* 2000;25(04):689–699
- Haugstvedt JR, Berger RA, Nakamura T, Neale P, Berglund L, An KN. Relative contributions of the ulnar attachments of the triangular fibrocartilage complex to the dynamic stability of the distal radioulnar joint. *J Hand Surg Am* 2006;31(03):445–451
- Moriya T, Aoki M, Iba K, Ozasa Y, Wada T, Yamashita T. Effect of triangular ligament tears on distal radioulnar joint instability and evaluation of three clinical tests: a biomechanical study. *J Hand Surg Eur Vol* 2009;34(02):219–223
- Shen J, Papadonikolakis A, Garrett JP, Davis SM, Ruch DS. Ulnar-positive variance as a predictor of distal radioulnar joint ligament disruption. *J Hand Surg Am* 2005;30(06):1172–1177