The Role of Triangular Fibrocartilage Complex in Axial Stability of the Forearm

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Abstract

Background The triangular fibrocartilage complex (TFCC) provides stability to the wrist and disruption of this complex can result in axial instability which can lead to ulnocarpal abutment.

Purpose This article determines the individual contributions of the volar radioulnar ligament (VRUL), dorsal radioulnar ligament (DRUL), and foveal attachment of the TFCC to longitudinal stability of the forearm under axial load.

Materials and Methods Eighteen cadaveric specimens were randomly assigned into three groups representing the component of the TFCC to be initially transected: VRUL, DRUL, and foveal attachment. Prior to transection, posterioranterior radiographs of the wrist were obtained at 0, 44.5, and 90 N of axial load. Serial transection of the TFCC components were performed with radiographs obtained at each of the aforementioned loads. Ulnar variance was assessed with two-way repeated measures analysis of variance and paired *t*-tests.

Results Transection of the foveal attachment demonstrated a significant change in ulnar variance of 1.5 and 0.6 mm under 45 and 90 N of load, respectively. At 0 N of load, there was no significant change in ulnar variance between an intact wrist and a wrist with all three ligaments transected; however, a significant change in ulnar variance, 1.0 mm, was observed under 90 N of load.

Conclusion The foveal attachment of the TFCC provides the largest contribution to axial stability.

Clinical Relevance The TFCC provides axial stability to the wrist and disruption of the TFCC may result in change in ulnar variance observed on an axial loaded wrist radiograph.

Keywords

- axial instability
- triangular fibrocartilage complex
- TFCC
- ulnocarpal abutment
- dynamic X-ray

Ulnocarpal abutment is characterized by ulnar-sided wrist pain, localized swelling, and limited range of motion. It is a result of impaction of the ulnar head against the triangular fibrocartilage complex (TFCC) and ulnar carpus.¹ Over time it can lead to deterioration of the TFCC as well as pathologic changes in the dome of the ulnar head, the ulnar corner of the

lunate, the triquetrum, and the lunotriquetral interosseous ligament.² Ulnar impaction syndrome is associated with positive ulnar variance, but it can also occur in wrists with neutral or negative ulnar variance.^{3–6}

Palmer and Werner demonstrated that the ulnocarpal joint bears 18% of the load in an ulnar neutral wrist and

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that increasing the length of the ulna by 2.5 mm increased the ulnocarpal load to 42% of the total load.⁷ The TFCC plays a critical role in distal radioulnar joint (DRUJ) stability and is a complex fibrocartilage entity comprising of the triangular fibrocartilage proper, volar radioulnar ligament (VRUL), dorsal radioulnar ligament (DRUL), ulnar collateral ligament, and the subsheath of the extensor carpi ulnaris tendon.⁸ Damage to any combination of these structures may result in DRUJ instability and development of ulnar impaction syndrome.

The purpose of our study was to determine the individual contributions of the VRUL, DRUL, and foveal attachment of the TFCC to longitudinal stability of the forearm under axial loading.

Materials and Methods

Eighteen fresh frozen upper extremity cadaver specimens were procured for testing (< 50 years; average age, 42 years; 18 male). Prior to testing, each upper extremity specimen was potted with a polymethyl methacrylate resin mixture in a 10 × 10 cm mold to make a fist. The third metacarpal head was placed in the center of the mold with the shaft perpendicular to the base of the mold. The mixture was allowed to harden and the mold was removed from the specimen. Skin was circumferentially removed around the wrist joint to gain access to the wrist.

The custom loading apparatus consisted of two sliding plates connected to a base plate (► Fig. 1). The sliding plates were freely adjustable to accommodate varying specimen sizes. The two sliding plates were connected by a loading rotational screw which allowed for minor adjustments to axial load when the proximal plate was secure and a specimen was attached to the distal plate. The proximal portion of the specimen was secured to the distal sliding plate via a large compressive clamp. The base plate consisted of a rotational platform with a 10 × 10 cm loading dock to accommodate the distal portion of the specimen. A Vernier FP-BTA force plate (Vernier Software & Technology, Beaverton, OR) was placed under the sliding base plate and provided recordings for axial load. The force plate was calibrated to zero prior to loading of each specimen. Each specimen was secured to the loading device with the wrist in neutral position and elbow at 90°. The loading rotation screw was adjusted based on real-time force plate readings to ensure no tensile or compressive force was applied at baseline.

The 18 specimens were placed in 3 groups using a random number generator. Each of the three groups represented the first ligament to be transected: VRUL, DRUL, and foveal attachment. Radiographs were taken at 0, 44.5, and 90 N of axial load before and after each transection. The specimens were unloaded between loads to prevent plastic deformation of cadaveric soft tissues. All radiographs were taken using a C-arm (Fluoroscanner, Scottsdale, AZ) in the posterioranterior plane with the wrist in neutral position and elbow flexed to 90°. An 8.0-mm radiopaque sphere was placed in the same plane with the specimen for reference to account for any effects of magnification. Specimens were

Fig. 1 Specimen loaded in custom-built loading apparatus.

screened prior to testing and any specimen demonstrating more than 2 mm increase in ulnar variance under load was not included due to probable existing TFCC injury. A dorsal incision was made between the 4th and 5th extensor compartment to access the DRUL. A volar skin incision was made and the VRUL was accessed in the plane between the flexor digitorum superficialis/profundus and flexor carpi ulnaris. The ligament to be transected was cut along with the capsule under direct visualization and subsequently stressed to ensure complete disruption of all fibers. The foveal attachment was detached using a blade under fluoroscopic guidance through a small incision over the extensor carpi ulnaris tendon sheath.

Radiographs were presented to two blinded, board-certified hand surgeons. Ulnar variance was measured using project a line technique (► Fig. 2).⁹ All measurements were made on a computer using the ImageJ software (U.S. National Institute of Health, Bethesda, MD). The measurement tool was calibrated to the 8.0-mm radiopaque reference prior to each measurement.

Prior to the study, a pilot study on three specimens was conducted to estimate sample size for the study. Using each specimen's ulnar variance change under load between its intact state and with one of the structures cut, a standard deviation of 0.5 mm was observed among the three specimens for this change. Assuming similar variability in the final study, we determined that five specimens in each group

Fig. 2 Project a line technique with a line drawn from the ulnar side of the articular surface of the distal radius toward the ulna. Ulnar variance is measured as the distance between this line and the carpal surface of the ulna.

(*N* = 15 total) would be necessary to detect a *clinically relevant* ulnar variance change of 1.0 mm under load with 80% power and a significance level of *p* < 0.05. A specimen was added to each group to control for any type I error inflation that would result from the multiple factors in the final study design.

The variable of interest was the change in each specimen's ulnar variance from its baseline, intact, and unloaded ulnar variance. This change from baseline was first assessed using a repeated measures analysis of variance with load (0, 45, and 90 N) and number of structures cut (none, one, and three) as repeated factors. The two factors and their interactions were assessed at an $\alpha = 0.05$. To examine the differences in ulnar variance change from baseline after transection of each of the three structures of interest in the TFCC, paired *t*-tests against baseline values and 95% confidence intervals for the change from baseline were conducted using Tukey's method for multi-

ple comparisons for each load and transection condition, with 18 specimens in the intact and fully transected (three structures cut) groups, and 6 specimens in each of the single transection groups. All analysis was performed with R v3.2 (R Foundation for Statistical Computing, Vienna, Austria) and all figures were plotted using Prism 7 (GraphPad Software, Inc., La Jolla, CA).

Results

The interclass correlation coefficient between the two readers was 0.58, indicating fair agreement.¹⁰ The ulnar variance change from baseline (unloaded, all structures intact) summary statistics are presented below. The data collected can be seen in **Table 1**.

In an intact wrist, there was a statistically significant 0.6 mm change in ulnar variance at 90 N compared with no load (*p* < 0.01). Transection of the foveal attachment resulted in a statistically significant change in ulnar variance from baseline of 1.5 and 0.6 mm under 45 (*p* = 0.04) and 90 N (*p* < 0.01) of load, respectively. Transection of the DRUL demonstrated a 0.8 and 1.2 mm change in ulnar variance compared with baseline at 45 (*p* = 0.20) and 90 N (0.23), respectively. There was a 0.0 and 0.1 mm change in ulnar variance at 45 (*p* = 0.39) and 90 N (*p* = 0.83), respectively, with transection of the VRUL. At 0 N of load, there was no significant change in ulnar variance (*p* = 0.12) between an intact wrist compared with a wrist with all three ligaments transected. Under 45 N of load, the fully transected wrists demonstrated a change in ulnar variance of 0.9 mm (*p* = 0.05) and there was a statistically significant change of 1.0 mm (*p* = 0.03) under 90 N of load.

Discussion

Ulnocarpal abutment can cause debilitating ulnar-sided wrist pain from abutment of the ulnar head against the ulnar carpus. The TFCC confers axial stability to the wrist and disruption of

Table 1 Experimental data

No. of structures cut	Structure cut	UV change (mm) – mean ± SD and 95% CI			N
		0 N	45 N	90 N	
0	None	0.0 ^a	0.4 ± 1.0	0.6 ± 1.3	18
		(0.0, 0.0)	(–0.1, 0.9)	(0.1, 1.2)	
1	VRUL	–0.3 ± 0.7	0.0 ± 0.6	0.1 ± 1.2	6
		(–0.8, 0.3)	(–0.5, 0.5)	(–0.8, 1.1)	
	DRUL	0.5 ± 0.5	0.8 ± 1.4	1.2 ± 2.2	6
		(0.1, 0.9)	(–0.3, 1.9)	(–0.5, 3.0)	
	Fovea	0.1 ± 0.3	1.5 ± 1.3	0.6 ± 0.3	6
		(–0.1, 0.4)	(0.5, 2.5)	(0.4, 0.9)	
3	All	0.5 ± 1.3	0.9 ± 1.8	1.1 ± 1.9	18
		(–0.1, 1.1)	(0.1, 1.7)	(0.2, 1.9)	

Abbreviations: CI, confidence interval; DRUL, dorsal radioulnar ligament; SD, standard deviation; UV, ulnar variance; VRUL, volar radioulnar ligament.
^aAll combination of loads and transections were compared with the baseline wrist, intact with no load.

the complex can result in excess longitudinal translation of the ulnar head resulting in painful abutment. Our study evaluated the contribution of specific ligaments within the TFCC complex to forearm stability under axial load.

There are several limitations to this study. The study is an in vitro cadaver study and as a result may not accurately represent clinic measurements. An attempt was made to minimize creep by removing all load prior to application of a new load but some amount of plastic deformation inevitably occurs with cadaveric specimens. This resultant plastic deformation may change the ulnar variance between measurements, leading to change in force sharing between ulnar and radius. This is likely the reason a decrease in an ulnar variance was seen when comparing 45 to 90 N when the fovea was transected. Furthermore, this increasing loading protocol likely introduced nonuniform variance across each subsequent loading condition, inflating the error observed across conditions and groups. The study was conducted on all male cadaveric specimens under the age of 50 and thus the effects of gender or degenerative changes with age are unknown. We also did not perform further imaging studies to confirm the integrity of the TFCC structures. However, prior to transection we did examine each specimen both clinically and radiographically and only included specimens with a stable DRUJ. Additionally, specimens were not dissected at the conclusion of the experiment to confirm complete transection of the ligaments.

Our study demonstrated that the foveal attachment provides the greatest contribution to axial stability at the wrist. The DRUL appears to provide some stability under axial load as its change in ulnar variance from baseline approached significance. The VRUL did not demonstrate any appreciable contribution to axial stability. Loading of the forearm in the axial plane is an essential motion in many activities of daily living and may result in ulnar-sided wrist pain in the presence of ulnocarpal abutment. The diagnosis of ulnocarpal abutment may be challenging in neutral forearm radiographs especially in patients with negative ulnar variance as classic findings, cystic changes in the lunate, usually become evident in the latter stages of the disease process. From a diagnostic perspective, ulnar variance measurements taken from stress views may be more likely to reveal an increase in ulnar variance.

Previous authors have investigated the relationship between DRUJ stability and relative contributions of each anatomic structure. However, those studies have primarily focused on the stability in the anteroposterior plane, and not the axial plane.^{11–13} Werner et al¹⁴ evaluated 58 cadaveric arms for 7 radiographic parameters and the effect on force transmitted through the ulna. Radiographic measurements were recorded from load cells inserted within the bone as force was applied to a set of major flexor and extensor tendons. Regression analysis only demonstrated a weak correlation ($r = 0.44$) between increasing positive ulnar variance and increased load transmitted through the ulna.

Harley et al¹⁵ evaluated the effect of wrist motion on ulnar load in 9 cadaveric wrists. Physiologic forces were applied to flexor and extensor tendons throughout wrist arc of motion measuring positional effects on ulnar load transmission. The

study demonstrated a relative increase in force across the ulna with the wrist in pronation, a strong inverse relationship of TFCC thickness to ulnar variance, and no correlation between the force transmitted through the ulna and ulnar variance. Shen et al¹⁶ longitudinally applied a traction load at the proximal radius of 8 cadaveric specimens with sequential transection of the superficial and deep fibers of the TFCC to determine the effects on ulnar variance. Transection of just the superficial fibers had no significant change in ulnar variance; however, transection of both the superficial and deep fibers demonstrated significant change in positive ulnar variance.

The results of our study demonstrate that axial loading of an intact or uninjured wrist results in a significant change in ulnar variance. The above-mentioned studies applied load either through tendon units or traction along a single bone which does not simulate external forces encountered and applied to the wrist on a daily basis. By applying an external compressive load, we were able to analyze the ulnar variance under common clinical scenarios such as pain with pushing oneself out of a chair or pushing against an object such as a door. Interestingly, Friedman et al demonstrated that the daily clinical scenario of gripping increased ulnar variance on radiographs concluding that repetitive grip may contribute to ulnar impaction syndrome.⁵ In addition to change in ulnar variance, we evaluated the contribution of each of the three components of the TFCC to axial stability. Our results supported the work of Shen et al¹⁶ demonstrating disruption of the deep TFCC fibers, foveal attachment, results in a significant increase in ulnar variance.

The TFCC plays an important role in axial stability of the wrist. The foveal attachment of the TFCC contributes the most to axial stability while the DRUL appears to also contribute to a lesser degree. The VRUL has no appreciable contribution to axial stability. Disruption of the TFCC, the foveal attachment in particular, leads to dynamic changes in ulnar variance under axial load which may contribute to ulnar impaction syndrome.

Conflict of Interest

None.

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