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BASIC RESEARCH

Peripheral Triangular Fibrocartilage Complex Tears Cause Ulnocarpal Instability: A Biomechanical Pilot Study

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Abstract
Background Instability at the ulnocarpal joint has many causes, but the common thread among these causes is the presence of abnormalities in the triangular fibrocartilage complex (TFCC). However, the biomechanical consequences at the ulnocarpal joint after detachment of the TFCC from the ulnar styloid are not clearly defined. Better delineation of whether peripheral TFCC detachments cause ulnocarpal instability will help to design surgical treatments.

Questions/Purposes We asked whether detachment of the peripheral TFCC from the ulnar styloid causes ulnocarpal instability.
Methods Using 20 fresh-frozen below-elbow cadaver specimens, the distal ulna was cycled volarly and dorsally with the carpus held firmly. The load-displacement curve was analyzed to determine the resistance of the ulnocarpal joint against dorsal-volar displacement of the ulna (stiffness) and the amount of dorsal-volar excursion with minimal resistance before reaching firm end points dorsally and volarly. A standardized 3-mm transection of the attachment of the TFCC from the ulnar styloid was created with a scalpel using arthroscopic observation. Mechanical testing was repeated and paired Student's t-tests conducted.
Results The mean stiffness of the ulnocarpal joint was decreased after detachment. The amount of dorsal-volar excursion was similar after detachment of the peripheral TFCC.
Conclusions There is decreased stiffness at the ulnocarpal joint after detachment of the peripheral TFCC, but there is no biomechanically detectable difference in dorsal-volar excursion.

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Each author certifies that his or her institution approved the human cadaveric protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
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Clinical Relevance The findings of the current study can be used to develop and evaluate innovative surgical techniques, such as capsulorraphy or ligamentous reconstruction, that specifically address laxity at the ulnocarpal joint after peripheral TFCC detachment.

Introduction

Ulnar-sided wrist pain is a challenging complaint for the hand surgeon to address largely because of its complex differential diagnosis [16, 18]. The patient's clinical complaints of pain may be accompanied by sensations of the wrist giving way or apprehension when rotating the wrist against resistance [7], both of which are consistent with a diagnosis of ulnocarpal instability. Instability at the ulnocarpal joint can result from numerous etiologies, including direct trauma [3], chronic degeneration [4], and ulnocarpal impaction [7]. These various causes for ulnocarpal instability are linked by the presence of damage to the triangular fibrocartilage complex (TFCC).

Integrity of the TFCC is critical to maintaining stability at the distal radioulnar joint (DRUJ) and the ulnocarpal joint [9, 10]. Melone and Nathan [9] proposed that peripheral disruption of the articular disc of the TFCC is an initial stage in a continuum of wrist disorders that ultimately results in progressive instability of the DRUJ and ulnocarpal joint. Although instability at the DRUJ after peripheral disruption of the articular disc of the TFCC has been well established clinically [1, 12] and biomechanically [11, 15], investigation of ulnocarpal instability after peripheral TFCC disruption has consisted of a retrospective chart review after ulnar shortening osteotomy [7] and cadaveric dissection [10], but not biomechanical evaluations. Köppel and colleagues reported their clinical experience using ulnar shortening osteotomy to treat ulnocarpal instability, but acknowledged an absence of biomechanical studies to substantiate their clinical results [7]. The anatomic evaluation by Nakamura et al. further shows the importance of the TFCC as a structural support for the ulnar-sided carpus [10], but there is no biomechanical evidence to corroborate the clinical experience and anatomic findings.

We therefore asked whether disruption of the peripheral TFCC causes ulnocarpal instability.

Materials and Methods

Twenty fresh-frozen human cadaveric specimens from 10 males and 10 females (mean age, 64 years) intact distal to the midhumerus were used. After baseline testing of the stiffness and the amount of dorsal-volar excursion at the ulnocarpal joint before reaching a firm end point in each direction, the deep and superficial portions of the TFCC insertion were detached from the base of the ulnar styloid using direct arthroscopic observation. The dorsal and volar radioulnar ligaments, ulnocarpal ligaments, ulnar collateral ligament, and the extensor carpi ulnaris subsheath were left intact. The capsule and arthroscopic portals were repaired using interrupted sutures. Mechanical testing then was repeated to evaluate stiffness and the amount of dorsal-volar excursion of the ulnocarpal joint after detachment of the peripheral TFCC. We defined instability as a significant increase in dorsal-volar excursion or a significant decrease in ulnocarpal stiffness after detachment of the peripheral TFCC. An a priori power analysis was not conducted for this pilot study.

Plain radiographs of each specimen were taken with the wrist and forearm in neutral position to exclude previous fractures, osseous abnormalities, and joint misalignments. The distal half of the humeral diaphysis was stripped of soft tissues so the humerus could be held securely in a vise. The soft tissues about the elbow were left intact.

We used mechanical testing to evaluate the ulnocarpal stability of the DRUJ for each specimen. The upper extremity specimens were fixed to an MTS Model 858 MiniBionix II machine (MTS, Eden Prairie, MN, USA) with the elbows in 90° flexion, the forearm in 90° pronation, and the wrist in neutral position. We placed a polyaxial pelvic fixation screw in the dorsal aspect of the distal ulna (1 cm proximal to the distal ulna) and secured it to the MTS actuator. The pisiform rested on a spacer that was sufficiently sized (19 mm) to prevent any contact of the ulna with the MTS table during the volar excursion of the load cycle. A carbon fiber rod was clamped over the dorsal aspect of the lunate and triquetrum to hold the carpus firmly to the table (Fig. 1). We then cycled the MTS actuator, and subsequently the distal ulna, in a volar-dorsal direction at a rate of 0.25 Hz with initial amplitude of 2 mm with respect to the pisiform. This biomechanical testing protocol is an attempt to objectively measure the clinical examination performed by the senior author (EAO) to evaluate the ulnocarpal stability. In the clinical examination, the ulnocarpal joint is stressed in a volar-dorsal direction to assess for excessive translation (laxity) and pain. An analogous situation is increased anterior translation of the tibia relative to the femur after an injury to the ACL of the knee (a positive Lachman examination). There was no visible movement of the lunate and triquetrum underneath the carbon fiber rod during the load cycling. Instead of applying a constant number of load cycles, we increased the amplitude of dorsal-volar translation (excursion as measured in millimeters) of the distal ulna in a carefully controlled manner while monitoring the load-displacement curve until the firm end points (a point on the x-axis in the dorsal and

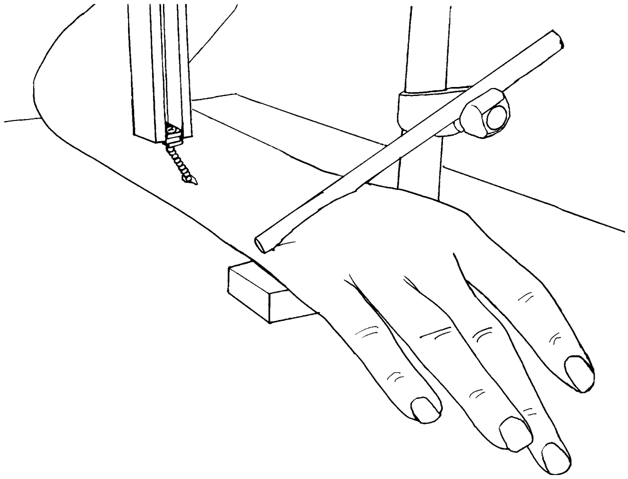

Fig. 1 The upper extremity testing setup with the elbow and forearm in 90° flexion and pronation, is shown. A metal rod was clamped to immobilize the carpus and a multiaxial pelvic fixation screw was placed in the distal ulna to allow passive motion.

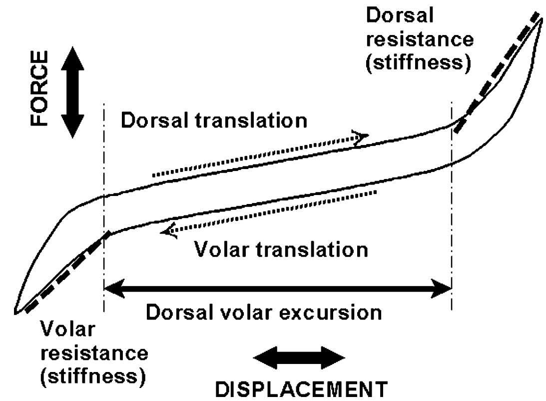

Fig. 2 The diagram shows the dorsal-volar excursion measurements as reported in the Materials and Methods section.

volar directions, depending on the testing cycle) were reached, as indicated by a sudden change in the slope of the load-displacement curve (Fig. 2). Thus, the cycling was continued through this process of carefully defining the dorsal-volar excursion and a steady state of force-displacement was achieved. Because of creep in the soft tissues that control this motion, the cycling would continue for several minutes to reach steady state. Although we refer to this measurement as "dorsal/volar excursion", it originally was described by Panjabi as the "neutral zone" in a study of the spine [14]. An amount of dorsal-volar excursion is present in the normal joint before a firm end point is reached in both directions. In our experiment, the distal ulna was translated dorsally until a firm end point was reached. The amount of translation was recorded as the dorsal excursion. This was repeated with volar translation. If there is laxity or compromise of the soft tissue stabilizers of the joint, there will be more excursion.

We determined the resistance of the ulnocarpal joint against displacement of the ulna with respect to the carpus from the slope of the load-displacement curves at the maximum dorsal displacement of the ulna recorded by the MTS. This hereafter is referred to as ulnocarpal stiffness.

Descriptive statistics, including skewness and kurtosis, were calculated to determine whether the stiffness and dorsal-volar excursion data were normally distributed. Because our analysis showed all data to be normally distributed, standard parametric statistical tests were chosen. Two separate paired Student's t-tests were used to compare the ulnocarpal stiffness and dorsal-volar excursion, respectively, before and after creation of the TFCC tear. Statistical analysis was performed using SPSS 16.0 (SPSS Inc, Chicago, IL, USA).

Table 1. Results of mechanical testing before and after creation of a peripheral tear

Mechanical test	Mean	SD	p value (paired t-test)
Coronal plane translation: intact	1.8 mm	0.6	
Coronal plane translation: posttear	2.3 mm	1.4	0.08*
Stiffness: intact	4.9 N/m	3.7 N/m	
Stiffness: posttear	3.1 N/m	2.5 N/m	0.003†

N = 20 specimens; * higher amount of coronal plane translation indicates more instability; †lower stiffness indicates more instability.

Results

The mean ulnar variance was 3.2 mm ulnar negative (SD, 6.1 mm). Disruption of the peripheral TFCC decreased the mean stiffness of the ulnocarpal joint ($p = 0.003$) (Table 1), but did not destabilize the dorsal-volar motion (excursion) at the ulnocarpal joint ($p = 0.08$).

Discussion

Integrity of the TFCC is essential to maintaining stability of the distal radioulnar and ulnocarpal joints [6, 8–10]. Previous biomechanical [11, 15] and clinical [1, 12] studies have established TFCC disorders as contributory to DRUJ instability, but less attention has been directed to the potential for instability at the ulnocarpal joint. Although Palmer [12] and Melone and Nathan [9] mentioned the presence of ulnocarpal instability in their clinical experiences of treating patients with TFCC disorders, no previous biomechanical study has attempted to substantiate their clinical findings. We therefore asked whether disruption of the peripheral TFCC causes ulnocarpal instability.

The current study carries limitations inherent in ex vivo biomechanical studies. First, it is difficult to recreate the in vivo behavior of the tissues and the proprioceptive feedback of the examiner during a clinical evaluation. Although the former is a limitation we must accept, we attempted to address the latter by designing a biomechanical test that objectively measures the amount of dorsal-volar excursion detected by the senior author (EAO) in a clinical encounter. We did not design the biomechanical test to emulate any specific loading conditions aside from this examination maneuver, which potentially could limit the clinical applicability of these findings. Second, the specimens were only tested with the forearm in 90° pronation. Forearm rotation affects the tension on the dorsal-volar radioulnar ligaments [2, 5, 17]. However, repetitive testing of the cadaveric specimens in different positions of forearm rotation can result in substantial alterations in the properties of the soft tissues [15]. Although we measured ulnar variance on baseline radiographs, forearm rotation may affect the relative ulnar variance [12]. Third, we had a limited number of specimens. Although the study was adequately powered (93.5%) to detect a difference in ulnocarpal stability using the ulnocarpal stiffness test, the power of the dorsal-volar excursion analysis was inadequate (74.8%). The difference in the dorsal-volar excursion before and after creation of the TFCC tear was suggestive of increased laxity, and this difference may have reached statistical significance if more specimens were tested. Fourth, we decided not to explore an isolated assessment of ulnocarpal joint stability. Although the carpus was constrained during testing, the TFCC's biarthrodial nature allows motion to occur at the ulnocarpal joint and DRUJ during cycling of the ulna. We did not attempt to restrict motion at the DRUJ because this would have resulted in a testing scenario that could not be recreated clinically and therefore is less clinically relevant. Furthermore, the use of one screw to manipulate the distal ulna may introduce slight amounts of proximodistal instability as the ulna pulls away from the carpus. We accepted this limitation given the fact that this slight amount of potential proximodistal instability is likely within the laxity of the universal joint mechanism.

Although the TFCC is composed of many contiguous structures, we chose only to transect the peripheral attachment of the articular disc of the TFCC, which is representative of a Palmer 1B lesion [13]. This injury often is seen on MRI in patients who undergo DRUJ reconstructions [1] and reflects the initial stage of TFCC disease described by Melone and Nathan [9]. In their anatomic study, Nakamura et al. [10] described the importance of the articular disc of the TFCC as part of the hammock structure that stabilizes the ulnar carpus, but other anatomic and biomechanical studies have instead emphasized the role of the ulnotriquetral and ulnolunate ligaments in stabilizing the ulnocarpal joint [6, 8, 13]. Further transection of the ulnocarpal ligaments and the other remaining components of the TFCC in the current experimental model would likely propagate the destabilization of the ulnocarpal joint and DRUJ following the spectrum of instability proposed by Melone and Nathan [9].

Although these findings may seem intuitive in view of prior anatomic [10] and clinical speculations [9, 12], our findings help define the pathomechanics underlying ulnocarpal instability: the presence of ulnocarpal instability after an isolated lesion of the articular disc suggests that the distal radioulnar and ulnocarpal joints should be evaluated and accounted for in treatment strategies for patients with disorders of the TFCC, even if the ulnocarpal ligaments, ulnar collateral ligament, and extensor carpi ulnaris subsheath appear unaffected on advanced imaging modalities. Seeing that some surgeons are currently performing DRUJ reconstruction [1] to treat patients with irreparable TFCC tears, one should evaluate the stability of the ulnocarpal joint after reconstruction is complete and consider using an adjunctive procedure to stabilize the ulnocarpal joint if necessary.

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