Correlation of Wrist Ligamentotaxis With Carpal Distraction: Implications for External Fixation

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Cadaver forearms were tested to measure carpal bone separation and wrist ligament tension in response to MTS-based incremental wrist distraction. Distraction of 2 mm separated the proximal carpal row from the radius and transmitted an average tension of 8 N. The mid-carpal joint also began to widen at this level of distraction. Distraction of 4 mm resulted in an average tension of 20 N. At this level of distraction, radioscaphoid separation started to exceed radiolunate separation. A transition from low- to high-stiffness response was observed over a range of 4–8 mm distraction for the 12 specimens tested, with an average tension of 80 N associated with 8 mm distraction. Average values of carpal height ratio, revised carpal height ratio, and carpal height index were found to be poor indicators of distraction, owing to their high variability between specimens. (J Hand Surg 1997;22A:1052-1056.)

The principle of ligamentotaxis is central to the application of external fixation for the treatment of intra-articular fractures. It can be used to assist in and to protect the reduction of distal radius fractures. Recent reports have raised concern that overdistraction of the wrist through external fixation may lead to wrist and finger stiffness.[1-4] A biomechanical study by Moran[5] has shown that larger distractions may cause a decrease in the range of motion at the metacarpophalangeal and proximal interphalangeal joints. Several authors have proposed specific guidelines for attaining adequate distraction to maintain fracture reduction.[1,6,7]

Before a level of adequate distraction can be clearly defined, the response of the wrist during tensile loading should be examined more closely. No previous studies have investigated the relationships among distraction, force, and carpal bone separation. We have developed an experimental model that correlates incremental hand–forearm distraction with resultant carpal ligament tension. To provide a clinically useful method to assess ligamentotaxis, we further evaluated the relationships among carpal bone separation, applied distraction, and the tension carried across the wrist.

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Materials and Methods

Twelve cadaver forearms were thawed overnight prior to testing. All skin and soft tissue proximal to the carpometacarpal (CMC) joints were removed except the wrist capsular ligaments. Light longitudinal traction was applied manually across the third metacarpal and the radius to establish the longitudinal axis. While traction was maintained, 3.0- to 3.3-

mm tapered, cortical half-pins (EBI Medical Systems, Parsippany, NJ) were placed in the second and third metacarpals and in the radius at the manufacturer's recommended locations, achieving 6-cortex purchase in the metacarpals and 4-cortex in the radius. While predrilling and inserting the pins, we used an alignment jig that constrained all pins to lie parallel to the plane defined roughly by the radius, ulna, and third metacarpal.

The specimens were mounted vertically in an MTS servohydraulic machine (MTS Systems, Eden Prairie, MN) for tensile testing by gripping the pins with MTS wedge-type tensile grips (Fig. 1). The third metacarpal and the radial shaft were colinear and along the axis of distraction. The undistracted (0 mm) position was defined by clamping the forearm in the grips and then allowing the carpus to seat on the distal radius via gravity. Wrist distraction was applied using a single computer-controlled protocol for all specimens. Starting from the undistracted position, the MTS actuator was in turn displaced and held at positions of 1, 2, 4, 6, 8, 10, and 12 mm. The loaded positions were held for an average duration of 15 seconds, which was the approximate time needed to acquire a radiograph. Load and actuator displacement were continuously recorded. The maximum load that was recorded for each increment of distraction was used as the measure of tension across the wrist (ie, no attempt was made to account for viscoelastic behavior). Anteroposterior radiographs were obtained prior to mounting and during testing at all positions of distraction. Preparation and testing of each specimen were completed in approximately 2 hours once the specimen was completely thawed.

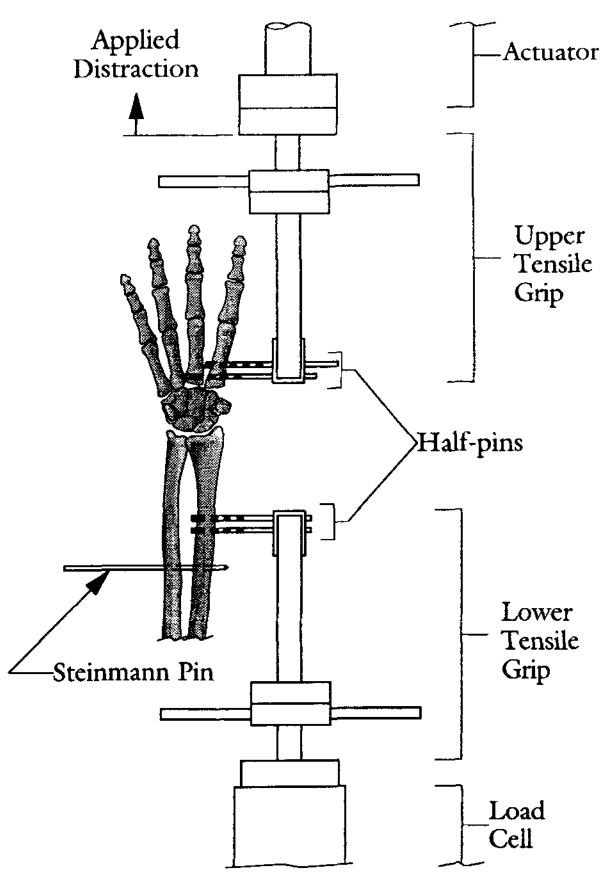

Figure 1. Diagram of the experimental setup showing specimen mounted in tensile grips via cortical half-pins. The radius and ulna were fixed with a 3-mm Steinmann pin as shown. The thumb and remaining soft tissues are omitted for clarity.

The apparent widths of the radiolunate (RL), radioscaphoid (RS), capitolunate (CL or midcarpal), and third CMC joint spaces were measured from plain radiographs at each increment of distraction. These measurements were taken parallel to the axis of the third metacarpal, which was aligned with the axis of distraction. This allowed consistent measurement of joint spaces that might otherwise be oblique to the axis of distraction, such as the RS joint. The RL space was measured from the proximal apex of the lunate to the subchondral plate of the distal radius. The RS space was measured from the proximal apex of the scaphoid to the subchondral plate of the distal radius. The midcarpal space was measured from the proximal apex of the capitate to the distal subchondral plate of the lunate. Values for the carpal height ratio (CHR),[8] revised carpal height ratio (RCHR),[9] and carpal height index (CHI)[10] were calculated. (CHR is the carpal height divided by the length of the third metacarpal, RCHR is carpal height divided by the length of the capitate, and CHI is the ratio of bilateral carpal heights.) The change in each value from the undistracted level was also calculated for each increment of applied distraction.

Results

The relationship between observed carpal tension and overall wrist distraction was characteristic of typical soft tissue load versus distraction behavior (Fig. 2). With overall wrist distraction of 2 mm, the carpus was lifted off of the radius, producing carpal tension averaging 8 N (2 lb.). On average, overall wrist distraction of 4 mm produced an increased carpal tension, averaging 20 N (4.5 lb.). At 6 mm of distraction,

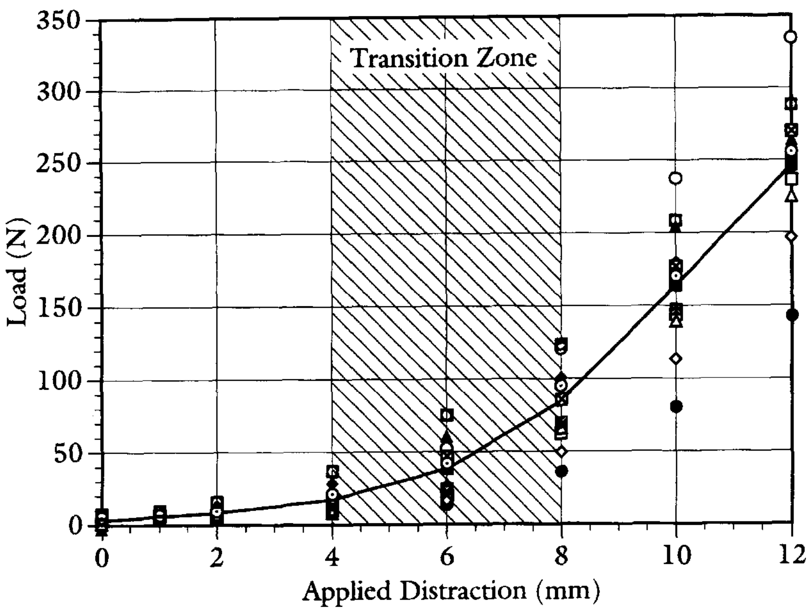

Figure 2. Load versus applied distraction for individual specimens and the mean across all 12 specimens. The transition zone is identified by the vertical hatched area.

the average tension was 40 N (9 lb.), and at this level of distraction, transition from the initial "toe" region to the linear portion of the load versus displacement curve became apparent. The toe region is the initial low-stiffness region of the load–displacement curve. The transition zone is the region where the load–displacement response changes from low to high stiffness. This region on the curve is described as the "transition zone" (Fig. 2) and encompasses a range of distraction from 4 to 8 mm. The transition zone is of note because small increases in distraction beyond this range result in much larger increases in tension.

All carpal joint spaces as measured from radiographs were found to increase simultaneously and linearly with applied distraction (Fig. 3). From 0 to 2 mm of distraction, the average radiolunate joint (RLJ) space was equivalent to the average radioscaphoid joint (RSJ) space. With overall distraction of 4 mm and above, a distal shift of the scaphoid relative to the lunate was observed. The average midcarpal joint (MCJ) space was initially smaller than the RLJ but became larger as applied distraction increased. On average, the RSJ was wider than the MCJ, but analysis of variance revealed no significant difference.

The average values of the carpal height parameters for undistracted wrists agreed with published values for normal wrists (Table 1). All parameters were found to increase linearly with wrist distraction (Fig. 4), but the response curve had a low slope, or low sensitivity to distraction. There was high variability in the correlation of all parameters with overall distraction, with CHR demonstrating the highest variability. Analysis of variance revealed no statistical difference between RCHR and CHI in assessing distraction. The changes in the carpal height parameters (Δ values) were independent of the values at 0 mm of distraction and consistent for all specimens.

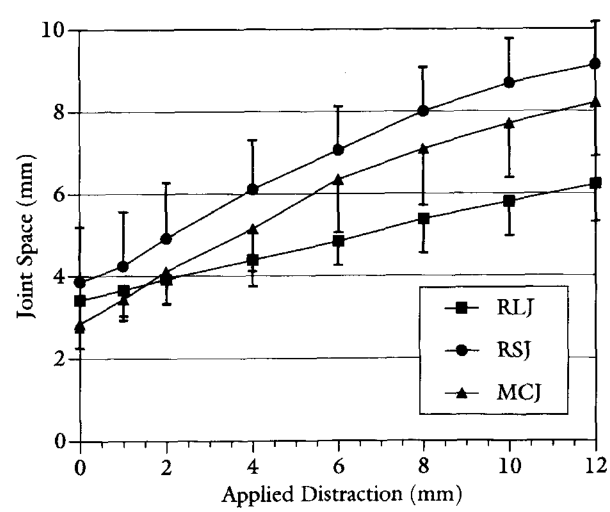

Figure 3. Magnitude of radiographically measured joint spaces versus applied distraction (mean ± SD). MCJ, midcarpal joint; RLJ, radiolunate joint; RSJ, radioscaphoid joint.

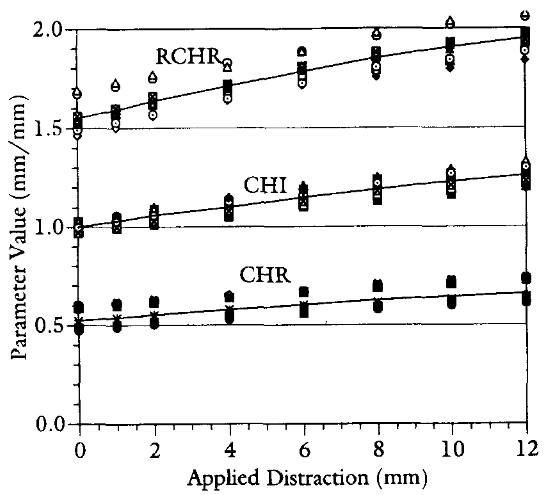

Figure 4. Plot of all radiographic parameters versus applied distraction. Individual specimen measurements shown as symbols; means shown as lines. CHI, carpal height index; CHR, carpal height ratio; RCHR, revised carpal height ratio.

Discussion

Hand stiffness following treatment of distal radius fractures with external fixation has been attributed to excessive wrist distraction.[3] Clinical observations based on radiographic measurements have provided proposed guidelines for achieving adequate distraction but have not been experimentally substantiated. In the present study, human cadaver forearms were mechanically tested to correlate progressive distraction with carpal tension and associated widening of carpal joint spaces.

This study was conducted to determine the response to applied distraction of uninjured wrists in order to provide a basis for further investigation. The long-term objective was to establish a basis for defining the amount of distraction that provides adequate but not excessive ligamentotaxis of the wrist for the treatment of distal radius fractures using external fixation. A secondary objective was to evaluate the accuracy of various methods that have been used clinically for radiographic assessment of wrist distraction.

The wrist joint is a complex mechanical linkage of bones, ligaments, and other soft tissue structures. The load distribution between various carpal ligaments was not considered in this study. Our conclusions are based on the assumption that the tension transmitted across the wrist is a factor only of the magnitude of carpal distraction, which is identical to the applied distraction in this study. In the presence of a fracture, however, the natural restraint to applied distraction is disrupted. Applied distraction in the presence of a fracture would not be identical to carpal distraction because a portion of the applied distraction would occur between the proximal and distal fragments of the fractured distal radius, resulting in decreased tension across the carpal ligaments. This assumes that there is negligible resistance to distraction between the fractured portions of bone. This assumption would be verified in future studies. Despite these limitations, several important observations can be made from our data.

Substantial increases in tension across the wrist did not develop until 6 mm of applied distraction, suggesting that the various carpal ligaments were not substantially loaded at levels of distraction below 6 mm. This level of distraction may be the minimum that is necessary to assist in reduction, but this cannot be verified without knowledge of the forces opposing ligamentotaxis. The transition to a higher stiffness response of the wrist ligament complex occurring between 4 and 8 mm of applied distraction suggests that distraction beyond 8 mm may be excessive and unnecessary for maintaining fracture reduc-

Table 1. Variations in Carpal Height Parameters at Extremes of Wrist Distraction

	Mean ± SD		*Range*	
Applied Distraction (mm)	*0*	*12*	*0*	*12*
RCHR	1.53 ± 0.04	1.93 ± 0.05	1.46–1.58	1.84–1.98
ΔRCHR	0	0.40 ± 0.04	0	0.35–0.45
CHI	1.00 ± 0.02	1.26 ± 0.04	0.97–1.03	1.20–1.30
ΔCHI	0	0.26 ± 0.03	0	0.23–0.30
CHR	0.52 ± 0.03	0.66 ± 0.04	0.47–0.58	0.61–0.72
ΔCHR	0	0.13 ± 0.01	0	0.12–0.15

CHI, carpal height index; CHR, carpal height ratio; RCHR, revised carpal height ratio.

tion. The forces opposing ligamentotaxis must be further examined to verify these conclusions. This range is consistent with the findings of Bartosh and Saldona,[6] who observed that the volar radiocarpal ligaments attained full unstretched length at 3 mm of distraction. Their conclusion that this value of distraction was independent of the magnitude of applied traction was not substantiated by our data.

Dissociation of the proximal carpal row at the scapholunate joint, appearing as a distal shift of the scaphoid relative to the lunate, was observed on radiographs for 10 of the 12 specimens as the applied distraction increased. This was apparent at an average of 4 mm of applied distraction and was associated with 20 N of carpal tension. Interestingly, Fortems et al. saw no such dissociation in 17 of 20 anesthetized patients subjected to 49 N (11 lb.) applied traction.[11]

The carpal height parameters that we evaluated (CHR, RCHR, and CHI) were found to poorly reflect overall carpal distraction, but relative carpal height parameters can be used to assess distraction when a baseline value is calculated for each patient. Without *a priori* knowledge of the normal radiographic appearance of a patient's wrist, our data suggest that errors as high as 4 mm can result when using these parameters to assess overall distraction. Because significant changes in carpal tension can result from changes in distraction of 1 to 2 mm, careful assessment of the normal wrist appearance is recommended. This is best accomplished by obtaining a radiograph of the contralateral wrist if it is uninjured or by measuring the injured wrist if the carpus appears undisturbed. The amount of distraction applied to the injured wrist can then be directly calculated. The use of published "normal" values of any of the carpal height parameters as the baseline value for all patients may result in overdistraction because of their high variability.

These results remain to be reproduced in specimens with an intact soft tissue envelope and a simulated distal radius fracture. Useful clinical correlation could be derived from a clinical study measuring distraction before and after ligamentotaxis in distal radius fractures treated with external fixation. The addition of a fracture and the resting tension of extrinsic tendons may alter the relationship between tension and carpal distraction and may clarify the discrepancies between our current results and other studies.[6,7] If the experimental findings apply clinically, we can more adequately define how much distraction is detrimental to final outcome. This experimental model serves as a starting point for future studies to determine if there is a relationship between carpal distraction and clinical outcome in the treatment of distal radius fractures treated with external fixation.

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