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ORIGINAL STUDY

The role of the transverse carpal ligament in carpal stability : An *in vitro* study

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A biomechanical *in vitro* study was performed on 16 fresh frozen cadaver forearms to investigate the role of the transverse carpal ligament (TCL) in carpal stability.

The distance between the scaphoid and hamate was measured, as a reference for the length of the TCL. Distances were recorded in both loaded and unloaded conditions after gradual sectioning of the transverse carpal ligament, the palmar scapholunate, long radiolunate ligament and radioscapholunate ligament.

The largest increase in spread of the carpal bones (55.3% of total spread) was noted after loading with the ligament intact. Thereafter, sectioning of the TCL resulted in a further 32.9% increase in the distance between the scaphoid and the hamate.

We conclude that the intact carpal bones-ligament complex displays some elasticity. Progressive sectioning of the TCL ligament under loading further opens the palmar arch.

Nevertheless it appears that the carpal arch will still retain reasonable intrinsic stability even without an intact TCL.

Keywords : carpal tunnel ; transverse carpal ligament.

INTRODUCTION

Carpal stability is achieved by the congruency between carpal bones, transcarpal tendons, negative intra-articular pressure and interosseous, intrinsic and extrinsic ligaments (*3,7,11,15-22*). A thorough understanding of these anatomical structures and their role in wrist stabilisation is important in clinical practice.

The transverse carpal ligament (TCL) has been proposed as an important pulley to prevent bowstringing of the flexor tendons and to promote economy and efficiency in finger flexion (*1,8*). Some investigators believe this ligament is also an important contributor to maintaining the transverse carpal arch (*2,6*). However, others did not find the TCL to be a major factor in maintenance of the carpal arch (*4,5*).

The success of sectioning the TCL has been well documented in the treatment of carpal tunnel

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syndrome (*1,10,14*). However, the effect of releasing this ligament on carpal stability has not yet been quantified.

In the study presented, the effect of sequential loading and sectioning of the TCL on the carpal arch was investigated in a human cadaveric model, by measuring the changing distances between markers positioned in the hamate and scaphoid bones.

MATERIALS AND METHODS

Sixteen fresh frozen upper extremities, nine left and seven right, from cadavers with no macroscopic evidence of pathology or signs of surgery were used. Range of motion and stability of the cadaver wrists were tested clinically and were considered to be within normal range. The humerus was transected above the elbow, leaving forearm muscle attachments about the elbow intact. The specimens were thawed overnight at room temperature.

Specimens were placed with their dorsal aspect flat on a wooden plate. The palmar skin of forearm, wrist and hand was removed. The volar side of the radial diaphysis was dissected free of its soft tissue coverage and two 4.5 mm screws were drilled through the radius in order to firmly fix the specimens to the plate. The distal screw was positioned 60 mm proximal to the radiocarpal joint line and the second screw was fixed 50 mm proximal to the first.

The hand was fixed to the plate using a 4.5 mm Hoffman pin drilled through the third metacarpal bone.

The hook of hamate and the scaphoid tubercle were palpated and marked using a 16G needle. An eyelet screw (25 × 3.3 mm) and 2.0 mm K-wire were drilled just proximal to the hook of hamate and into the scaphoid at the cross section between the flexor carpi radialis tendon and the scaphoid waist. Care was taken to preserve soft tissue coverage of the carpal bones. The eyelets were drilled onto the surface of both carpal bones and directed perpendicular to the longitudinal axis of the fixed arm. The K-wires were positioned central and proximal to the eyelet of the screw (fig 1).

A cable system used to apply loading forces, was constructed with two pulleys attached to a second wooden plate. Traction cables were attached to both eyelets and their line of pull was adjusted until they were aligned with the direction of the eyelet (fig 1), essentially parallel to the fibres of the TCL. Results of a pilot study permitted the development of the apparatus and the arrangement that was used in the actual experiment.

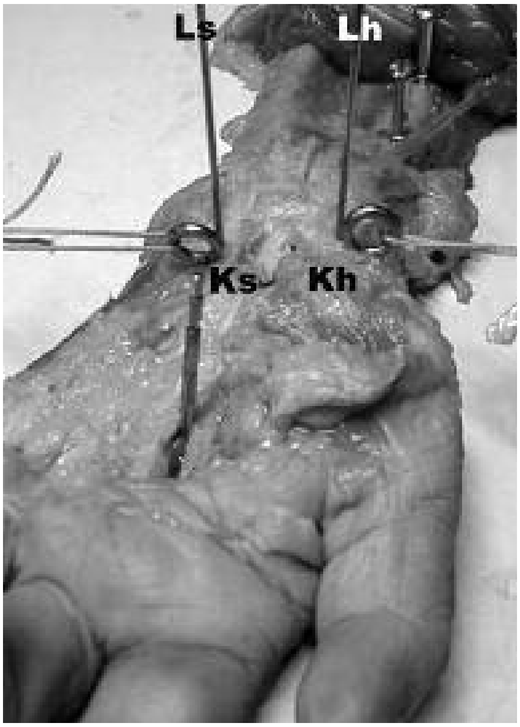

Fig. 1. — Shows both the eyelet screw and K-wires in the scaphoid and hamate bone after precise anatomic dissection of the palmar side of the wrist. The K-wires were marked at the base (Ks and Kh) and 50 mm higher (Ls and Lh). Traction cables are fixed to the screws and load is applied orthogonally.

Distances between the hamate and scaphoid K-wires were measured at two marks made on the wires. The K-wires were marked at their point of insertion into the hamate (Kh) and the scaphoid (Ks) and at a distance of 50 mm from the insertion point (Lh and Ls). Lh and Ls were used as an extra measure to amplify and validate the results. A handheld electronic calliper (Mitutoyo, Japan, accuracy 0.05 mm) was used for all measurements. All measurements in the experiment were performed independently by three observers and all measurements were repeated three times by each observer. The steps followed in this study are shown in table I.

The first measurements were performed without loading the traction cables. Following these measurements, the cables were loaded using 3 kg (30 N) weights on each side.

The loaded TCL was then sectioned sequentially from proximal to distal using one-third increments. The ligament was first sectioned in its proximal one third (step 3), then in its second third (step 4) and finally in its complete cross section (step 5).

Table I. — Segmence of experimental steps 1 through 7. TCL : transverse carpal ligament ; S-L : interosseous scapholunate ligament ; LRL : long radio-lunate ligament ; RSL : radio-scapho-lunate ligament

step 1	unloaded TCL
step 2	loaded TCL
step 3	loaded TCL + sectioning 1/3 of the TCL
step 4	loaded TCL + sectioning 2/3 of the TCL
step 5	loaded TCL + sectioning 3/3 of the TCL
step 6	loaded TCL + sectioned TCL + section S-L, LRL
step 7	loaded TCL + sectioned TCL + section S-L, LRL, RSL ligaments

After this the palmar scapholunate (SL) and long radiolunate ligament (LRL) were sectioned (step 6), followed by the radioscapholunate ligament (RSL) (step 7).

Following every consecutive step a new set of measurements of distances was performed between markings Kh to Ks and Lh to Ls.

Fluoroscopic images of each specimen were obtained at the end of each experiment and were analyzed for traumatic, arthritic or anatomic abnormalities of the carpal bones and the position of screws and K-wires was checked (fig 2).

Statistics

To determine the deviation of the carpal bones, the mean, standard deviation and coefficient of variation were calculated from the measured distances between markers Ks and Kh at the bases of the K-wires (table II).

To quantify the pattern of distension of the carpus, the percentages of deviation between both Kh and Ks and Lh and Ls were calculated from the mean of the measured distances at each of the consecutive steps. The increase in the distance after each additional step was calculated as a percentage of the final increase in the distance measured after step 7.

Comparison between the two groups was made by considering the percentile increases.

In order to assess whether every consecutive step in the procedure made a significant difference with the previous steps, we performed a repeated measurements ANOVA for the measurements at the marking points both at the base (Kh and Ks) and 50mm higher (Lh and Ls) from step 2 until step 7. Significance level was set at $p < 0.05$.

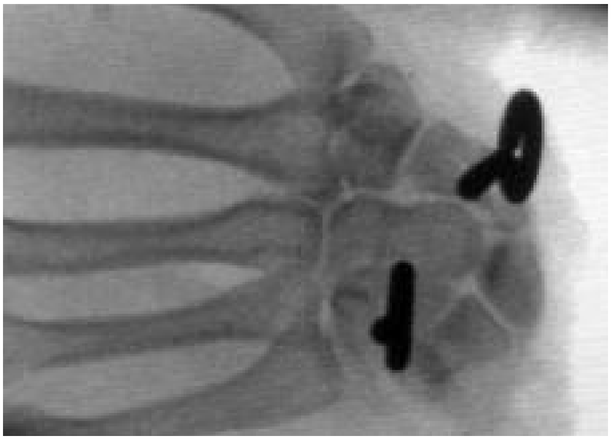

Fig. 2. — Traumatic, arthritic or anatomic abnormalities of the carpal bones and correct positioning of the K-wires and screws were evaluated on post-experimental fluoroscopic images.

RESULTS

During the experiment the screws pulled out in one specimen. In the other 15 specimens the post-experiment radiographs showed that the screws were positioned correctly in 12 scaphoids and in 13 hamates. Ultimately, 10 specimens had completely correct screw positioning in both scaphoid and hamate and data gathered from these specimens were used in the final analysis.

Table II summarizes the mean and standard deviation of the measurements between markings Ks and Kh at the bases of the K-wires.

The mean distance between Ks and Kh with an intact TCL was 27.8 mm without loading (step 1) and 30.1 mm with loading (step 2), a nominal increase of 2.3 mm. After sectioning one third (step 3), two thirds (step 4) and finally the whole of the TCL (step 5) the mean distances between Ks and Kh increased by an average of 0.4, 0.5 and 0.6 mm respectively. Total cross sectioning of TCL increased the distances between the K-wires by a mean of 1.4 mm with respect to the loaded situation with an intact TCL.

Additional sectioning of both SL and LRL ligaments increased the mean distance measured between Ks and Kh to 32.0 mm. Finally sectioning the RSL ligament increased this mean distance to 32.1 mm.

Table II. — Step by step changes in the mean absolute distance (in mm) between the scaphoid and hamate bones, measured at the point of entry of two K-wires (Ks-Kh) inserted in both carpal bones. Consecutive changes in the distance are also expressed as percentages (%) of the final increase in the distance between Ks and Kh noted at step 7. The table also shows the results of similar measurements made between the other two landmarks on the K-wires, Ls and Lh.

Steps	1	2	3	4	5	6	7
Mean distance Ks-Kh (SD) mm	27.8 (3.3)	30.1 (3.7)	30.5 (3.6)	31.0 (3.6)	31.5 (3.6)	32.0 (3.6)*	32.1 (3.7)*
Mean total increase Ks-Kh (%)	0	55.3	63.7	75.5	88.2	97.5	100
Stepwise increase Ks-Kh (%)		55.3	8.4	11.8	12.7	9.3	2.5
Mean total increase Ls-Lh (%)	0	51.7	60.9	74.1	85.6	96.2	100
Stepwise increase Ls-Lh (%)		51.7	9.2	13.2	11.5	10.6	3.8

The mean percentages of spread of the carpal bones after each consecutive step in the procedure and their stepwise increment at the marking points are summarized in table II.

On average, loading of the intact TCL resulted in an increase in the Ks to Kh distance of 55.3%. Total transsectioning of the TCL resulted in an additional 32.9% of opening of the carpal arch. Sectioning the SL along with LRL and ultimately the RSL respectively released the carpal bones by a further 9.3% and 2.5%. Similar results were found when measuring the distances between Ls and Lh (table II).

When comparing the percentages of increase in distance between Lh and Ls to the percentages of increase between Kh and Ks, a similar pattern was observed (table II).

ANOVA analysis showed statistically significant differences between consecutive steps, starting from step 2 ($p < 0.05$). No significant difference was found between measurements performed at the base of the wire (K-markings) following sectioning of the SL and LRL ligament (step 6) and sectioning of the RSL ligament (step 7).

DISCUSSION

Carpal bones form an arch with its concave side directed towards the palm of the hand. The palmar arch is bridged by the TCL. Some authors attribute a role to the TCL in maintaining stability of the concave arch of the carpus (*2,6*). Stability of the carpal bones is the result of the congruency of joint surfaces, the transiting transcarpal tendons, the negative intra-articular pressure and the interosseous, intrinsic and extrinsic ligaments, and the contribution of the broad and robust TCL should also be taken into account. Data about this contribution are sparse in the literature.

Surgical treatment of volar wrist pathology, such as the very common carpal tunnel syndrome, often includes sectioning of the TCL. There are no clinical reports of subsequent carpal instability following release of the TCL. Some studies also confirm that the carpus remains relatively stable even in the absence of an intact TCL (*4,5*).

With the present study we tried to quantify the influence of sectioning the TCL and specific ligaments (SL, LRL and RSL) on the carpal arch by measuring the distance between markers fixed in the scaphoid and hamate bone, in loaded and unloaded situations. The insertion of the TCL on the scaphoid and hamate bones seems to make the changes in positions of both bones appropriate for studying the effects of interventions on the TCL on the carpus.

A distraction force of 29.43N (3000 g) on the TCL was exercised through screws placed in the scaphoid and hamate bone. The amount of weight was determined rather arbitrarily during the pilot study, aiming to produce a noticeable distraction without pull-out of the screws and without failure of the carpal ligaments. Logan *et al* (*12*) demonstrated that in cadavers, the important carpal ligaments elongate approximately 30 to 100% before failure, and failure occurs between 100 N for the most vulnerable ligaments and as high as 350 N for the triquetro-lunate interosseous ligament (*17*). Kuhlmann *et al* (*9*) reported that the stress force necessary for rupture of the TCL is nearly 10 N/mm². Stresses applied in our experimental model remained below these values.

The measurements at the marking points of the K wires can be considered to be a reflection of the resulting separation between scaphoid and hamate bones at the palmar aspect of the wrist.

Our results indicate that the greatest distension (55.3%) of the TCL *in vitro* will occur while loading the intact ligament, and total crosssectioning of the ligament has a markedly smaller (32.9%) effect in widening the scaphoid – hamate distance. Sectioning of the RSL ligament only had a minimal effect on the spread of the carpal arch (2.5%), not significantly different from the previous step according to the ANOVA ($p = 0.107$).

Although incremental sectioning of the TCL significantly increases the distance between the scaphoid and hamate, current clinical observation does not support the hypothetical occurrence of carpal instability after TCL release. It appears that, *in vivo*, even without the integrity of the TCL, the carpal arch will still have reasonable intrinsic stability. Our experiment quantifies a progressive opening of the loaded carpal arch during sectioning of the TCL and specific carpal ligaments. This suggests that, in the clinical setting, there are potential compensatory mechanisms that act to stabilize the carpal arch once the TCL has been cut. If this compensation is insufficient, this opening phenomenon could be an explanation for pillar pain sometimes found following carpal tunnel surgery (*13*).

We conclude that the intact carpus bones-ligament complex features some elasticity. Progressive sectioning of the TCL under loading further opens the palmar arch. A clear correlation between the laxity induced by sectioning the TCL and clinical implications is yet to be identified.

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