Ligament strains in wrist-joint motions

LIGAMENT STRAINS IN WRIST-JOINT MOTIONS

A. de Lange, J.M.G. Kauer and R. Huiskes

Dept. of Anatomy and Embryology, and Dept. of Orthopaedics,
University of Nijmegen, Nijmegen, The Netherlands

1. INTRODUCTION

The human carpus consists of seven carpal bones (Fig.1) and enables the hand to perform relatively large motions, while providing adequate stability. The passive stability of the wrist is ensured by capsule, ligaments and the geometry of the articulating carpal bones. In the clinical literature, carpal instabilities are usually related to lesions of the ligamentous structures (7,9). Based on anatomical dissection and conventional Roentgenography the possible functions of various wrist ligaments in relation to specific carpal motions were speculated upon (1,6,7,10). The purpose of the present investigation is to evaluate the precise 3-dimensional motions of the individual carpal bones in flexion and deviation of the hand and to measure the strains of various ligaments, using a newly developed method. Results describing the individual carpal bone motions were presented earlier (4,5).

2. MATERIAL AND METHOD

Using a Roentgen stereophotogrammetric measurement system (4,11), the motions of the individual carpal bones and the strains of the selected ligaments of five human upper extremity specimens were measured. For obtaining motion information, a minimum of three tantalum pellets (0.5 - 1.0 mm diameter) were inserted in the seven carpal bones (excluding the pisiform) using a special spring-actuated syringe. Using tantalum pellets as well, three different methods have been used to represent the fibre lengths of selected ligaments, of which two methods accounted for the actual courses of the ligament fibers: 1.a) by glueing 0.5 mm tantalum pellets at intervals of 3 mm along the fibre bundles over the ligament length, 1.b) by glueing a silicon tube, filled with tantalum pellets at intervals of 3 mm, over the ligament. In method 2, the distances between origo and insertion of the ligaments were measured only, using one pellet on either side. The ligaments selected for the investigation were, at the palmar side, radio-capitate (RCP), radio-lunate (RLP), lunato-triquetrum (LTP), and triquetro-capitate (TCP), and at the dorsal side the radio-triquetrum (RTD). In the radio-lunate ligament and in the lunato-triquetrum ligament two parts were distinguished each. In one specimen two more ligaments were marked: the short ligament between the radius and the lunate (RLPS) and the radio-triquetrum ligament (RTP) both at the palmar side (Fig.1). Cleavage of both the palmar and dorsal retinacular tendon sheets was needed in order to reach the ligaments. After the marking procedure the tendon sheets and skin were closed by suturing. Each of the five human upper-extremity specimens were positioned into a motion rig in which the radius was fixed. The tendons of the muscles crossing the wrist were connected to stainless-steel wires, each loaded by

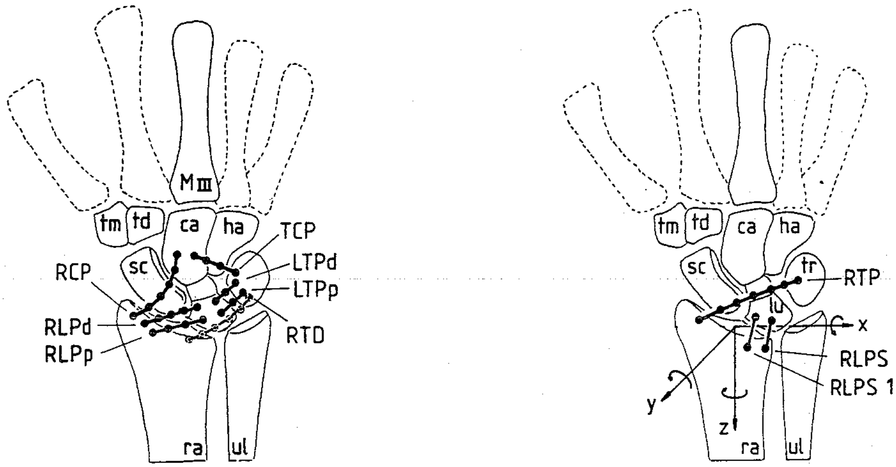

FIGURE 1:
Selected ligaments in a left wrist. At the palmar side:
RCP = the radio-capitate ligament; RLPD = the distal part of the radio-lunate ligament; RLPP = the proximal part of the radio-lunate ligament; TCP = the triquetro-capitate ligament; LTP = the lunato-triquetrum ligament; RTP = the radio-triquetrum ligament; RLPS = the "short" radio-lunate ligament.
At the dorsal side: RTD = the radio-triquetrum ligament.
Movement around the x-axis: flexion; around the y-axis: deviation.

a 20 N constant force spring. Using a mechanical motion-constraint device the hand was moved through dorso-palmar flexion and radio-ulnar deviation, starting from the neutral position (in which the long axis of the third metacarpal is parallel to the radius), in motion steps of appr. 4 degrees.

After each step, stereo Roentgen exposures were made and measured to determine the 3-D positions of the landmarks. From the landmark configurations in the carpal bones, their Euler rotations and translations as well as the helical motion axes were determined, using principles of rigid-body kinematics(4,5). The elongations in the ligaments after each motion step relative to the neutral position, were calculated from the ligament landmark configurations, by determining the elongation in each interval of the landmark series and were evaluated as functions of flexion or deviation of the hand using the rigid-body motion of the capitate as a reference.

The accuracy of the experimental method is influenced by several error sources such as the quality of the digitizer, the experience of the operator and bending effects of the image planes in the cassettes. By remeasuring one series of Roentgenograms and comparing the recalculated kinematic parameters and ligament strains with the corresponding initial values in terms of standard deviations, the error dependency of the first two error factors were quantified. In addition, an additional test was performed with special constructed "ideal" flat image planes together with the conventional image planes. Again, both sets of duplicate values of the kinematic parameters and ligament strains were used to calculate standard deviations for each parameter (Table I).

3. RESULTS

For the relatively short ligaments (RLP, LTP, RLPS, TCP, RTD) all the three strains descriptive methods resulted in equal tendencies, although in quantitative aspect differences occured. Apparently, non-linear geometry effects appeared in the longer ligaments (RCP, RTP), by which for these ligaments the bone-to-bone representation method is unsuitable. Equal trends were observed in different specimens. For the short RLPS ligament strains were measured upto 30%, relative to the neutral position, whereas in all other cases ligament length changes did not exceed 20%. In dorsal flexion the palmar ligaments RLP, RCP, TCP and RTP increased in length (Fig.2), and in palmar flexion they decreased. The dorsal RTD showed an inverse behaviour. The palmar LTP remained practically unchanged. The short RLPS showed a specific length behaviour. In dorsal flexion it increased in length; in palmar flexion upto 40 degrees, it decreased rapidly to a particular minimal length, after which, with increasing palmar flexion, it increased (Fig.3.b). In deviation of the hand, the palmar LTP remained, generally speaking, unchanged again. The RCP increased in radial and ulnar deviation (Fig.4), while the TCP and RTD both decreased. The RLP ligament showed to have two functional parts (Fig.4). Both the RTP and the RLPS increased in length from radial to ulnar deviation.

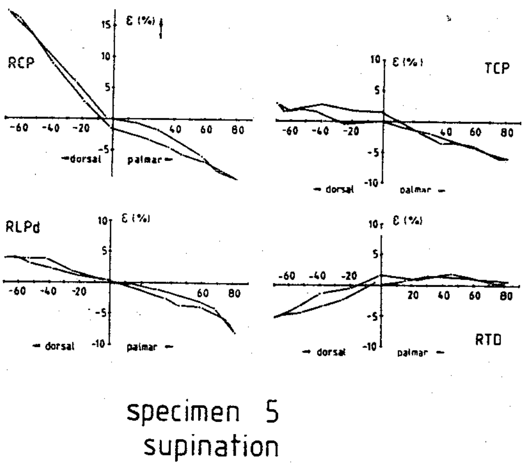

FIGURE 2:
Ligament strain as function of capitate flexion; tantalum pellets glued into the ligaments.

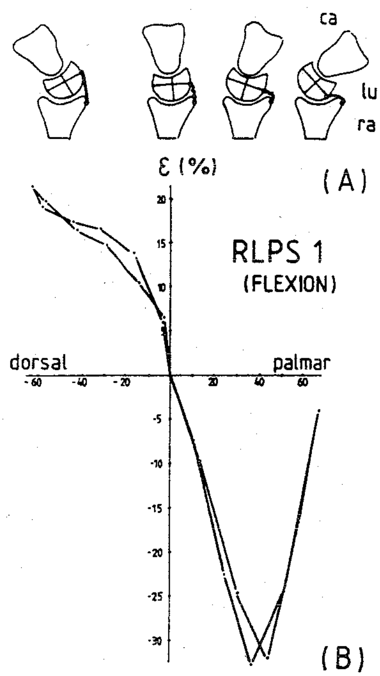

FIGURE 3:
A) Schematical representation of the attitudes of the lunate and capitate at various positions of the hand during flexion
B) Ligament strain as function of capitate flexion; RLPS ligament of specimen 6 ; supination.

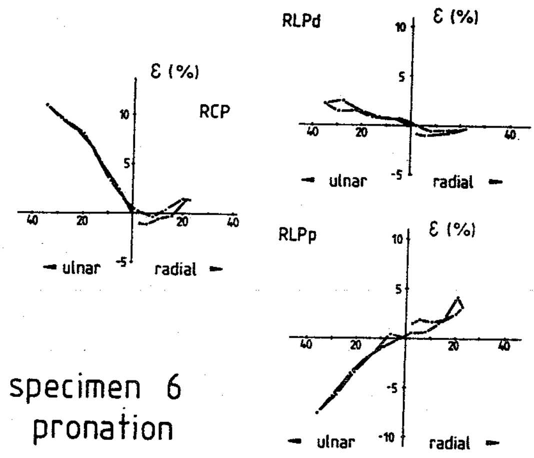

FIGURE 4:
Ligament strain as a function of capitate deviation; tantalum pellets glued into the ligaments. Specimen 6; pronation.

		Repeated Reconstruction n=12	Flat/Bended Image Planes n=23
flexion	(degrees)	0.36	0.33
deviation	"	0.20	0.39
pronation/ supination	"	0.22	0.44
Strain	(%)	0.1	0.3

Table I: Standard deviations of the Euler rotations and ligament strains.

4. DISCUSSION

The results show that precise analyses of ligament strains is possible by using Roentgen stereophotogrammetry and glued landmarks, although the strains measured are relative to the initial strain, the value of which is unknown. In addition, the ligament strains could be related with the spatial displacements of the carpals. As an example, in Fig.3.a the lunate motion during flexion is graphically represented and related with the ligament length behaviour of the RLPS ligament. Even more than in flexion, in deviation of the hand the carpal displacements were strongly 3-dimensional of nature. In particular, in deviation of the hand, the present findings mostly invalidate the qualitative speculations on carpal ligament functions. This might be explained by the fact that in the qualitative studies fixed motion axes for the carpal motions were assumed, which is not warranted according to the present results.

Briefly, the RCP ligament resists the displacements of the capitate in radio-ulnar deviation and in dorsal flexion of the hand. For these hand-motions the RLP ligament has the same effects for the lunate. Both the RTD and the TCP ligament seem to play a stabilizing role in the neutral position of the hand, while the RTD ligament has also a function in palmar flexion of the hand helping to ultimately resist this motion. The LTP ligament seems to control the minor relative displacements between the lunate and the triquetrum. The relative long RTP ligament assists to resist dorsal flexion of the lunate during dorsal flexion and/or ulnar deviation of the hand. Relatively seen the RLPS ligament shows large strain values, by which it is believed that this ligament functions more for nutricient supply rather than stabilizing the wrist joint. In addition, the measured strain patterns were not influenced by the position of the hand in the forearm. Together with geometric models (3) these findings may be used as a database for developing quantitative models of the wrist joint.

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