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The capsular ligaments of the wrist: morphology, morphometry and clinical applications

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Summary: Variable wrist ligament descriptions and nomenclatures have been presented, but the dimensions of these ligaments have not yet been extensively investigated. To verify the numerous concepts advanced and to provide a better understanding of individual variations in carpal biomechanics, and the numerous pathomechanical concepts reported in the literature, this study aimed to determine capsular carpal ligament anatomy, their dimensions and variations. The origin, insertion, and number of fascicles of the capsular wrist ligaments were observed in precise dissection of 66 anatomic preparations. The dimensions of several capsular wrist ligaments were measured using a calliper : the parameters analysed being length and width at three levels each, from which mean length and width and approximate mean surface (product of mean length by mean width) were determined. The anatomy of the capsular ligaments of the wrist showed, besides relatively constant structures, considerable individual variations, particularly of the ulnocarpal and dorsal ligaments. The standard deviations of ligament lengths and widths were mostly less than 20% of the average value. Some measurements, however, showed larger variations, such as those associated with the dorsal scaphotriquetral and ulnocarpal ligaments. Ligament widths generally showed larger variations and less interdependency than did ligament lengths. The capsular wrist ligaments display morphologic and morphometric variations, which could explain the biomechanical variations reported in the literature, and the diversity of classifications and treatment methods proposed for carpal instability. Further studies, however, are needed to confirm this hypothesis.

Les ligaments capsulaires du poignet : morphologie, morphométrie et applications cliniques

Résumé : Des descriptions et nomenclatures variables des ligaments du poignet ont été présentées. Les dimensions de ces ligaments n'ont pas encore été étudiées en détail. Afin de vérifier les multiples concepts avancés et de fournir une meilleure compréhension des variations individuelles de la biomécanique carpienne, et des nombreux concepts pathomécaniques trouvés dans la littérature, cette étude a tenté de rapporter l'anatomie, les dimensions et variations des ligaments capsulaires carpiens. La dissection précise de 66 préparations anatomiques a permis l'observation de l'origine, de l'insertion, et du nombre de faisceaux des ligaments capsulaires du poignet. Les dimensions de plusieurs ligaments capsulaires du poignet ont été mesurées à l'aide d'un pied-à-coulisse. Les paramètres analysés étaient la longueur et la largeur à trois niveaux chacune, la longueur et la largeur moyenne et la surface moyenne approximative (produit de la longueur moyenne par la largeur moyenne). L'anatomie des ligaments capsulaires du poignet présentait, outre des structures relativement constantes, des variations individuelles considérables, particulièrement des ligaments ulno-carpiens et dorsaux. Les écarts-type des longueurs et largeurs ligamentaires étaient le plus souvent inférieurs à 20 % de la valeur moyenne. Certaines mesures, cependant, présentaient des variations plus importantes, tel que les ligaments scapho-triquetral dorsal et ulno-carpiens. Les largeurs présentaient en général des variations plus grandes et une moindre interdépendance que les longueurs. Les ligaments capsulaires du poignet présentent des variations morphologiques et morphométriques, qui pourraient expliquer les variations biomécaniques rapportées dans la littérature, et la diversité des classifications et méthodes de traitement proposées pour l'instabilité carpienne, bien que des études complémentaires soient nécessaires pour confirmer cette hypothèse.

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Key words: Wrist joint – Ligaments – Morphology – Gross anatomy – Biometrics

Classical anatomy textbooks describe more than 30 different ligaments associated with the wrist. The differences in the description, classification, and nomenclature increase the complexity of understanding this region [2, 9, 14, 21, 24, 35]. More recently, investigators have tried to simplify this description using various classifications [2, 6, 14, 21, 24, 30, 34], with several authors mentioning a variability of wrist ligamentous anatomy [5, 6, 14, 20, 26, 32] to explain the differences reported in the literature. Sennwald and Segmüller [30] classified the ligaments of the wrist into five groups. More recently, Sennwald et al. [31] emphasised the palmar scaphotriquetral lig. which fell into oblivion eighty years ago.

The lack of unanimity concerning carpal ligament anatomy might have repercussions for the diagnosis and treatment of wrist ligament injuries. Evidence for this hypothesis can be found in the various classifications of carpal instability and the therapy proposed for pathologies [12, 13, 22, 23, 35]. Berger and Amadio [1] showed that a knowledge of ligament insertions on the distal radius could contribute to the evaluation of functional implications following distal radius fractures.

Morphometric studies on wrist ligaments are rare. Mayfield et al. [25], Nowak and Logan [27], Kooloos and Savelberg [18] and Savelberg et al. [29] measured the cross-sectional area of several capsular ligaments to determine their mechanical properties. The lengths of the carpal ligaments were measured by Savelberg et al. [29] on bone-ligament-bone specimens, and by Smith [32, 33] *in vivo* and Kim et al. [17] *in vitro* by magnetic resonance imaging. The real dimensions and the variations of the capsular ligaments of the wrist *in situ* have, to our best knowledge, not been analysed precisely.

Such a study could help to enhance our knowledge of wrist anatomy and pathology, refine therapy and provide a partial explanation to the individual variations of wrist motion revealed in recent studies [3, 4, 8, 28, 29], since the capsular ligaments are probably the major structures which limit and control motion of the wrist. As with muscles, ligament dimensions might be directly related to their biomechanical characteristics.

The present study considers only the morphological and morphometric aspects of carpal ligamentous anatomy. For a better understanding of carpal biomechanics and pathologies, this study needs to be complemented by a quantitative morphological and kinematic analysis.

Material and methods

Sixty-six forearms and hands (29 right and 37 left) taken from embalmed cadavers (modified Dankmeyer's technique, [36]) were used in this study. No information concerning the age of the donors or carpal trauma or rheumatoid history was available. However, radiological screening excluded visible pathological changes.

After removal of the skin, muscles and flexor and extensor retinacula, the articular capsule was carefully dissected under a magnifying glass (magnification : x2) ; the capsular ligaments being thickenings of the capsule. Within the fibre layers of the capsule fibre bundles displaying a well oriented, recognisable organisation between two of the carpal bones were considered to represent ligaments.

The origin, course, insertion and number of fascicles for each ligament identified were recorded. The most frequent configuration and variations were expressed as percentages.

The dimensions of the following ligaments were determined : palmar radiolunate (RLP), radiocapitate (RCP), ulnolunate (ULP), ulnocapitate (UCP), lunotriquetral (LTP), and triquetrocapitate (TCP) and dorsal radiotriquetral (RTD) and scaphotriquetral (STD). The greatest distance between insertions (length, L) at both extremities and in the middle of the ligaments as well as the width (W) of the insertions and of the middle of the ligament were measured. All lengths measurements concerned the superficial layers of the ligaments. All measurements were taken using a calliper (resolution 0.01 mm) to the nearest 0.1 mm. Pins were placed in the extremities of the insertions, and used as a landmark for measurements.

Normalised dimensions were computed in addition to the absolute dimensions, in order to overcome differences in specimen size. The dimension chosen for normalisation was the middle length of the dorsal radio-triquetral lig., as it showed the lowest variation coefficient (standard deviation/average=0.11). These normalised dimensions were obtained by dividing the measured dimension by the normalising dimension (middle length of the dorsal radio-triquetral lig.). The mean length and width of a ligament were taken as the mean of the two or three measured lengths or widths of the ligament. The approximate mean surface area of a ligament was calculated as the product of the mean width and the mean length. Normalisation was obtained by dividing the computed mean dimension by the mean length of the RTD, and the computed surface by the square of the mean length of the RTD.

Results

Morphology

Detailed description of the morphological aspects of the ligament is reported elsewhere [6].

Most frequent configuration : The palmar "V's" described by Sennwald and Segmüller [30] were completed by the lunotriquetral, pisocapitate and ulnocapitate ligg. (Fig. 1). Dorsally, the radiotriquetral lig. was single in 36% of the specimens, had two bundles in 52% and three in 13% of the wrists. The variations of the distal portion [30] were confirmed. A triquetrohamate lig. completed the dorsal lig. complex in 72% of the wrists. Two thick, fibrous bundles joined the pisiform to the hamate and to metacarpal V (Fig. 2), the superficial fibres of which, classically referred to as the piso-hamate and piso-metacarpal ligg., were continuous with fibers of the distal flexor carpi ulnaris (FCU) tendon. This observation clearly confirms that the pisiform is a sesamoid bone in the distal FCU tendon, because of the continuation of its distal tendon to the distal carpal row and the metacarpus.

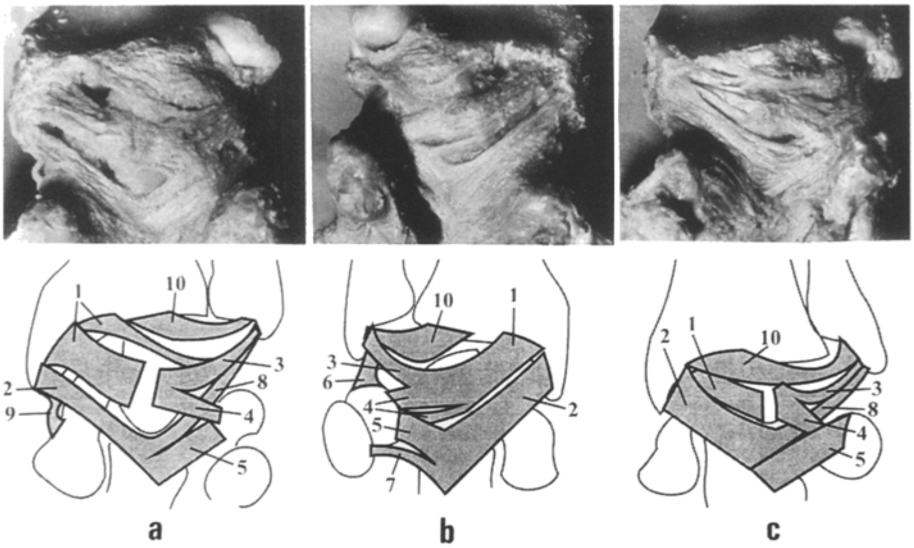

Fig. 1 a-c
Palmar ligg. **a** Two radiolunate fascicles, ulnocapitate and radioscaphoid ligg. present, pisocapitate and ulnar collateral ligg. absent ; **b** One radiolunate fascicle, pisocapitate and ulnar collateral ligg. present, ulnocapitate and radioscaphoid ligg. absent ; **c** One radiolunate fascicle, ulnocapitate ligament present, radioscaphoid, ulnar collateral and pisocapitate ligg. absent. *Abbreviations :* ligaments : *1*, radiolunate ; *2*, radiocapitate ; *3*, ulnolunate ; *4*, lunotriquetral ; *5*, triquetrocapitate ; *6*, ulnar collateral ; *7*, pisocapitate ; *8*, ulnocapitate ; *9*, radioscaphoid ; *10*, palmar radio-ulnar

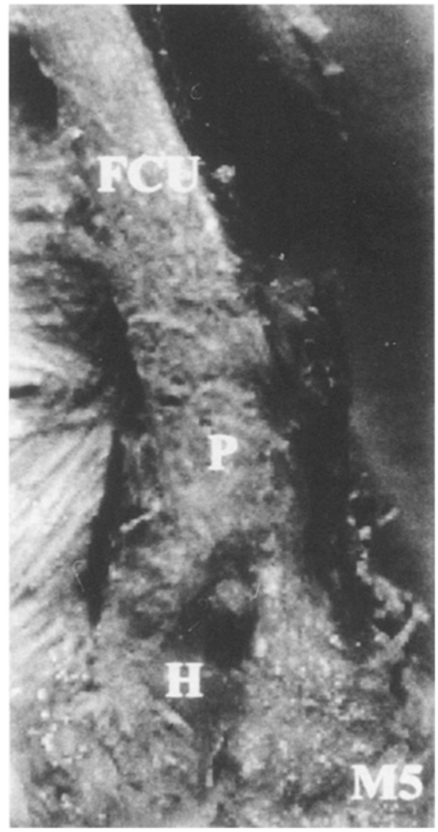

Fig. 2
Insertion of the distal flexor carpi ulnaris tendon Abbreviations : *FCU*, flexor carpi ulnaris ; *P*, pisiform ; *H*, hamate ; *M5*, metacarpal V

Variations : These mainly concerned components of the ulnar ligament complex. The most constant part of this complex comprised the sheath of the distal extensor carpi ulnaris tendon and the ulnolunate lig. Fascicles joining the ulna to the pisiform (present in 28%), and to the triquetrum palmarly (present in 24%) or dorsally (present in 56%) were much less constant. Variations were also noted in the palmar group, especially at the level of the medial components (Fig. 1). The palmar pisocapitate lig. was observed in only 59% of specimens. The description of Sennwald and Segmüller [30] encountered in only 21% of specimens. Dorsally, variations appeared at the level of the lateral insertion of the distal branch of the dorsal "V" (on the scaphoid and sometimes also to the trapezium and trapezoid), and of the radiotriquetral lig. Besides variations in fascicle number of the latter, its radial origin was not the same in all specimens, being medial to Lister's tubercle in 54%, and on both sides of the tubercle in the remaining specimens.

Morphometry

Measured (Table 1) *and normalised dimensions :* Ligament widths showed larger individual variations than did ligament lengths. For most measured dimensions, the standard deviation was within 20% of the mean dimension. However, the widths of the STD were highly variable, with their standard deviations ranging from 32 to 57% of the mean. In most cases (30 cases out of 39), variations increased after normalisation.

Mean dimensions and approximate mean surface areas (Table 1) : As with the measured dimensions mean lengths were found to be less variable than the mean widths. For most parameters normalisation resulted in an increase in variability, except for the mean width of the LTP and STD and the mean length of the RTD. The total surface area of palmar radiocarpal ligg. (335 mm^2) was twice as large as the total surface area of the palmar ulnocarpal ligg. (176 mm^2). Approximate surface area variability was in general greater than for isolated dimensions (standard deviations between 21% and 52% of averages), and again tended to increase after normalisation. The surface of the STD lig. showed the largest individual variations, confirming the results of measured dimensions.

Discussion

This study of the capsular ligaments of the wrist, based on dissection of 66 specimens, has revealed the existence of a number of individual variations. These differences were related to the number of bundles present and their dimensions. A detailed account of the ligament morphology can be found in Feipel and Rooze [6].

The possible relationship of ligament dimensions and of the approximate mean surface to ligament biomechanics has not been established yet and needs further investigation. This last parameter provides a simple and unique biometric information on the planar dimensions of a ligament. The hypothesis of the existence of such relationships between morphometric and functional aspects relies on the use of certain morphometric parameters in muscle physiology.

Table 1. Average (±1SD) measured dimensions, mean dimensions and approximate mean surfaces of the carpal ligaments

Ligament	Dimension	Dimensions (mm)	Mean L (mm)	Mean W (mm)	S (mm²)	Ligament	Dimension	Dimensions (mm)	Mean L (mm)	Mean W (mm)	S (mm²)
RLP	pL	12.9 ± 2.4	17.2 ± 2.2	7.8 ± 1.3	135 ± 28	RCP	pL	24.0 ± 2.8	25.4 ± 2.7	7.8 ± 1.7	200 ± 51
	mL	19.4 ± 2.7					mL	26.0 ± 3.0			
	dL	19.5 ± 2.7					dL	26.3 ± 3.1			
	pW	8.8 ±1.9					pW	7.9 ± 2.2			
	mW	6.9 ± 1.1					mW	5.5 ± 1.4			
	dW	7.8 ± 1.6					dW	10.1 ± 2.4			
ULP	pL	22.7 ± 2.6	22.7 ± 2.6	3.3 ± 0.9	74 ± 22	LTP	pL	11.3 ± 2.4	11.2 ± 2.2	5.2 ± 1.4	60 ± 21
	dL	22.6 ± 2.9					dL	11.2 ± 2.5			
	pW	2.6 ± 1.2					latW	5.9 ± 1.6			
	dW	3.9 ± 1.5					medW	4.6 ± 1.4			
TCP	pL	11.9 ± 2.2	12.6 ± 1.6	6.5 ± 1.8	83 ± 29	UCP	pL	27.4 ± 3.6	28.5 ± 3.3	3.2 ± 1.3	93 ± 40
	dL	13.3 ± 2.54					dL	29.6 ± 3.3			
	pW	5.9 ± 1.6					pW	2.9 ± 0.9			
	dW	7.1 ± 2.4					dW	3.7 ± 1.8			
RTD	pL	21.1 ± 3.1	22.4 ± 2.6	7.9 ± 1.5	177 ± 42	STD	pL	28.7 ± 4.8	32.9 ± 4.7	6.5 ± 2.1	215 ± 81
	mL	22.5 ± 2.4					dL	37.0 ± 5.3			
	dL	23.6 ± 3.9					latW	8.2 ± 4.3			
	pW	10.0 ± 2.5					mW	5.2 ± 1.7			
	mW	6.6 ± 1.5					medW	5.9 ± 2.2			
	dW	7.1 ± 2.0									

Abbreviations : *RLP,* palmar radiolunate lig. ; *RCP,* palmar radiocapitate lig. ; *ULP,* palmar ulnolunate lig. ; *LTP,* palmar lunotriquetral lig. ; *TCP,* palmar triquetrocapitate lig. ; *UCP,* palmar ulnocapitate lig. ; *RTD,* dorsal radiotriquetral lig. ; *STD,* dorsal scaphotriquetral lig. ; *SD,* standard deviation ; *L,* length ; *W,* width ; *p,* proximal ; *m,* middle ; *d,* distal ; *lat,* lateral ; *med,* medial ; *S,* surface

The major variations observed were on the ulnar aspect of the wrist, and concerned the ulnocarpal lig. complex itself and the ulnar parts of the palmar and dorsal ligg. These observations presented here are in agreement with those of most authors [5, 6, 14, 20, 26, 32]. The dorsal radiocarpal ligament also showed a variable morphology, confirming previous observations [26, 32].

Besides the variations mentioned above, individual differences in the size of the capsular ligg. of the wrist were also observed. The orientation of these ligaments with respect to motion axes has a major impact on the functional role of the ligaments. This aspect has, however, not been assessed quantitatively in our work, but requires further investations aimed at evaluating its potential variations.

The observation of increased variations of ligament dimensions after normalisation (for 50 out of 63 parameters) suggests that the relative dimensions of the capsular wrist ligaments were even more variable that the absolute dimensions.

The ulnocarpal ligg. exhibited larger variations and smaller surface area than did the radiocarpal ligg., confirming that the carpus is suspended from the radius [11]. The radiocarpal ligg. have formerly been described as the major stabilisers of the wrist [11].

Morphometric data concerning the carpal ligaments are rare in the literature. In a magnetic resonance imaging study, Smith [32, 33] and Kim et al. [17] determined the dimensions of the palmar and dorsal wrist ligg. Some of the data presented here are in good agreement with their findings, others, however, not. There were, however, considerable differences between the *in vivo* results of Smith [33] and the *in vitro* ones of Kim et al. [16] for some ligaments, eventhough both were obtained with magnetic resonance imaging. Although the experimental methods of Smith [32, 33] and the present work were very different, the differences observed can be explained by the planar measurements obtained using MRI, compared to the curved ligament morphology. Furthermore, the anatomic aspect of a ligament does not necessarily correspond to the limits identified on MRI.

Savelberg et al. [29], using a similar method to the one used here, measured the length of the capsular wrist ligaments on bone-ligament-bone preparations, whereas our measurements were made *in situ.* Some data showed good agreement, whereas others did not, possibly due to difference in specimen preparation used The use of a preservation solution containing formalin, as in our study, may have resulted in an underestimation of ligament dimensions (especially lengths) due to formalin-induced collagen retraction. However, verification of this would require measurements to be taken from unembalmed specimens prior to embalming and remeasuring.

The observations of the present study are of anatomical interest as they may explain the diversity of descriptions concerning the ligamentous system of the wrist, e.g., the anatomical variations of the ulnocarpal ligamentous complex [14], or the controversial existence of an efficient collateral ligament system at the level of the wrist [16, 34, 35].

The variety of descriptions of the palmar ligaments of the wrist is potentially confusing, as are the differences in nomenclature. For example, Berger and Landsmeer [2] described two palmar radiolunate ligg. (long and short), while in the present study a single palmar radiolunate lig. was observed in 59% of the specimens. However, the remaining specimens (41%) had at least two bundles, which corresponded to the description of Berger and Landsmeer [2], the ulnar bundle (short radiolunate lig.) having a more vertical orientation than the radial bundle.

The palmar scapho-triquetral lig., recently re-described by Sennwald et al [31], has not been considered in the present study. Indeed, this ligament is located deep to the palmar capsular ligaments, so that its observation would have required removal of the latter. It would however be of great interest to verify the existence and variations of this ligament in a larger population, especially as transverse fibres are occasionally found deep to the palmar radiocapitate and triquetrocapitate ligg. during wrist MRI examinations.

Such variations in ligament morphology could be important in carpal biomechanics, since they are liable to act as guides or checks controlling carpal bone movement [21, 30], although this function remains controversial [29]. The variations in ligament dimensions could partially explain the functional variations observed by several authors [3, 4, 7, 8, 28, 29]. For example : Could there be a difference in capitate extension in presence or absence of an ulno-capitate lig. ? Does a second palmar radio-lunate lig., which is usually more vertical, influence lunate flexion-extension and deviation motion ? Further studies combining anatomical and kinematic aspects of the wrist are required to confirm or deny the existence of a relationship between anatomical variations of the ligaments and the mechanical variations in the carpus [3, 4, 8, 28, 29].

As important as ligament dimensions are the biomechanical properties of ligaments. Kuhlmann et al [19] has shown that these vary from ligament to ligament in the wrist, with the palmar radio-carpal ligg. being less elastic, less extensible and more resistant than the medial radio-carpal ligg. The deep radio-carpal and mid-carpal ligg. are the most elastic, most extensible and least resistant. Further investigations are therefore required to determine whether such differences are also a function of ligament dimension.

Variations of the ligaments of the wrist might also help in the understanding of differences in classification, involved ligaments and therapies for carpal instability [10-13, 15, 22, 23, 24, 31, 35]. A more precise knowledge of ligamentous anatomy and functioning will provide a better insight into the pathomechanics, diagnosis and treatment of wrist pathology. Although further investigations are obviously needed, it is possible that, depending on the configuration of the carpal ligaments, predisposition to different types and patterns of carpal injuries could exist.

The present study showed variation in relative dimensions of several carpal ligaments, which could be related to variations of skeletal dimensions, intracarpal relationships and/or ligament insertion sites. However, the increased variability of several dimensions after normalisation, besides casting doubt on the choice of the normalising factor, may indicate the existence of different ligament morphologies. Such variations confirm the variability of wrist ligament anatomy as already reported by several authors [5, 6, 14, 20, 26, 32].

Although further studies are required, e.g., to determine the relationship between ligament morphology and biomechanical properties, the results of the present study will provide a new insight on instability mechanisms and lesion characteristics. Further investigations might reveal that it is not only the identity of the ligament(s) damaged that has to be taken into account, but also differences in their dimensions and/or mechanical properties. In addition, certain morphologic characteristics, yet to be determined, could also constitute features predisposing to wrist lesions. The existence of differences in the ligaments of the wrist provides a basis to the hypothesis that several populations could be identified and characterised by their ligamentous morphology and/or dimensions. It would, in this respect, be interesting to search for correlation between ligament configuration and osseous morphology, which can easily be assessed by radiology. Such a correlation, if it exists, would enable the ligament configuration, difficult to assess *in vivo* by the techniques currently available, of a certain subject to be presupposed. This type of information could be of benefit clinically, if the exact relationships between ligament anatomy, their function and pathology are known. Further investigations are needed before this can be ascertained. Clearly, the variability observed in the present study casts doubt on the validity of a unique functional model of the wrist.

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