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The Mechanism of the First Carpometacarpal (CMC) Joint

An Anatomical and Mechanical Analysis

by

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To my wife Henriette
and my children
Cornelia Anna
Maria Andriette
Olga Paulien
Pieternella Marijke

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INTRODUCTION TO THE ANALYSIS OF THE LIGAMENTS AROUND THE FIRST CARPOMETACARPAL JOINT

Current anatomical knowledge and methods are insufficient to explain the rather complicated first carpometacarpal joint (*Grant,* 1962; *Anson,* 1950, 1963; *Spalteholz,* 1971). The main reason is that, although others (*Fick, A.*, 1856; *MacConaill*, 1946; *Bausenhardt*, 1949) have stressed the bony shape of this joint in order to explain joint motion, we have observed very little joint contact during motion (see chapter IV). Due to this deficiency of joint contact the metacarpal I always seems to be balancing on the trapezium, while the ligaments apparently prevent a subluxation taking place.

In a multidisciplinary approach by the staff of the Anatomy department of the University of Leiden and the staff of the Mechanical Engineering department of the Eindhoven University of Technology we were able to build a model which could give a reasonable explanation of the anatomical first carpometacarpal joint on mechanical principles.

Although the first carpometacarpal joint, trapezium and metacarpal I have been described before, an adequate detailed documentation was not encountered. We soon detected a great discrepancy of nomenclature, anatomical data and of the physiology or, preferably, biomechanics of the first carpometacarpal joint.

To overcome the discrepancies just mentioned we have in first instance in chapters II and III, given an extensive microscopic and macroscopic description of the bones, the ligamentous system around the first carpometacarpal joint and the joint surfaces. Previously little has been said about the course of the fibres and the length of the ligaments.

Although it might be possible to stretch a thin joint capsule easily, the elasticity of the ligaments is so limited that stretching is of minor importance. We have called the full length of a ligament, the span of that ligament. We assume that the span remains constant. On mechanical principles with the aid of a vector analysis we are able to build a joint model. In this model the direction rather than the magnitude of the applied force R is the most important factor.

We will use the diagram *Ebskov* (1970) developed for the thumb, which has been slightly modified for our purposes. By means of this diagram we are able to reproduce some extreme positions of the first carpometacarpal joint.

After surveying the literature it became clear that the motion pattern of the first carpometacarpal joint is still ill understood.

Although locomotion involves certain unknown and incalculable factors, which preclude a strictly mathematical presentation (*Steindler*, 1955), it has been our aim to gain an insight into the kinesiology of the first carpometacarpal joint regarding the relationship between joint shape and ligaments, based on mechanical priciples.

CHAPTER I

REVIEW OF LITERATURE

"One candle lights another"
BUNNELL

A great deal of literature is written on the anatomical and functional aspect of the thumb as a whole. Even larger numbers of papers are written on the clinical aspects of the thumb. Relatively fewer publications go into detail analysing the first carpometacarpal joint itself. Most deal with a simple description of the joint surfaces and the many different anatomical positions of the thumb. This has been summarized by *Ebskov* (1970). Historically two ways of approaching the first carpometacarpal joint of the thumb have been developed. The first and oldest is the descriptive type, the second is the mechanical or kinematic type. Most authors have added observations in either way.
We have chosen to follow the literature according to the two main trends described above.

a. The descriptive approach

According to *Kaplan* (1965), *Weitbrecht* (1742) was the first to describe four ligaments around the thumb. For historical interest we would like to quote from *Kaplan's* translation of *Weitbrecht's* work under the heading of special connections (page 48).
"The thumb metacarpal is connected to the fifth bone by a capsular membrane that surrounds both bones. This is very fine; vessels pass through it, and some fat can also be seen. It is reinforced by the tendon of the abductor muscle, which is inserted laterally so tightly that it is difficult to separate them; there are also four accessory ligaments: 1. the dorsal, 2. the palmar, 3. the external lateral, and 4. the internal lateral.

1. The dorsal ligament, which unites the dorsal process of this bone to the fifth bone of the carpus, is conspicuous on the dorsum of the hand. This is usually very strong and is simular to the ligaments that unite the metacarpals with the phalanges.
2. The Palmar ligament inserts into the palmar tubercle of the metacarpal and is very conspicuous on the palm.
3. The lateral external ligament comes out obliquely from the side of the fifth bone beside the base of the metacarpal; it advances towards the palm of the hand and inserts into the superior palmar tubercle. These two ligaments form an angle on the dorsum of the metacarpal and also limit the extension of the thumb.
4. The lateral internal ligament runs alongside the abductor tendon which was described earlier (page 48 l.c.)."

The thumb in relation to the rest of the hand

The literature of the first half of the 19th century is rather sketchy and incomplete about the carpometacarpal joint of the thumb. Most authors have given a rather casual description of the anatomy of the first carpometacarpal joint. Even the nomenclature was not uniform enough to allow proper discussion of the trapezium-metacarpal joint. This is demonstrated by *Blumenbach* (1807), who regrets in a footnote the confusion of nomenclature since some authors have interchanged the names of the trapezium and trapezoid.

Bichat (1819, 1830) noted the oblique position of the trapezium in relation to the other carpal bones of the four articulating surfaces.

Du Bois-Reymond (1895) measured the angle and considered 455° the average forward position of the trapezium.

The first carpometacarpal joint

Blumenbach (1807) considers the distal joint surface of the trapezium and the proximal surface of the first metacarpal as each other's positive and negative without further mention of the shape of the articular surfaces.

Bichat (1819, 1830) expands the description of the trapezium. The lower joint facet is convex and concave in an opposite sense. In front there is a little notch in which the anterior radial tendon lies. There is also a pyramidal eminence shaped for the insertion of the "annular" ligament.

The ligaments around the first carpometacarpal joint

Although *Bichat* later discusses the nature of connective tissues between the joints, the possible motions still occur according to the *shape* of the joint surfaces.

Henle (1856) pays attention mainly to the anatomical description of the ligaments and joints in general. With regard to the first carpometacarpal joint, although not discussed in the text, he shows a picture on page 96, fig. 82, with a ligament running from the base of metacarpal (M) II towards the base of metacarpal (M) I. The picture is not his own and according to the legend it shows a dorsal view. The ligament is drawn volarly from metacarpal II to the dorsal aspect of metacarpal I. In another picture on page 99, fig. 85, a separate carpometacarpal ligament arises outside the volar ligaments of the rest of the hand, from the radial aspect of the tuberosity of the trapezium going to a volar prominence on the base of the first metacarpal.

Cruveilhier (1862) gives essentially the same description of the first carpometacarpal joint. He calls it an: "emboîtement réciproque" enclosed by a lax orbicular ligament. This "emboîtement réciproque" allows the motions flexion, extension, abduction and adduction and consequently circumduction because of the angular direction of the articular facets. This makes it an angular "Arthrodie" with obscure gliding motions.

Virchow (1898) is very brief in his discussion on the thumb. He just noticed a peculiar gaping between multangulum majus and metacarpal I on the radial aspect without indicating in what position the thumb is held. His conclusion is that one can take for granted that a better contact in radial direction only takes place with a very marked abduction of the thumb. Furthermore he recognises the importance of the ligaments without further analysis; he merely states that these ligaments control joint motion, especially when the joint surfaces are becoming incongruent.

Also *Morris* (1879) stresses the importance of the ligaments and points out their function as to give stability to the skeleton at the points of articulation. For the carpometacarpal joint of the thumb however he finds it unnecessary to describe four separate ligaments and merely observes that the dorsal band is stronger than the palmar. The first limits flexion, the second limits extension. The internal is stronger than the external. The former limits abduction, the latter limits adduction of the thumb. These bands are tense enough to hold the bones in close contact. He obviously does not agree with *Cruveilhier* (1862) who talks about a lax orbicular ligamentous system.

According to *Gray* (1901) the first metacarpal joint is only surrounded by a capsular ligament without further differentiation. He recognises motion as flexion, extension, abduction, adduction and circumduction. He denies *axial* rotation, thereby contradicting *Duchenne* (1885) and later *Grünkorn* (1932). Both were mainly interested in the muscle physiology of the thumb. *Duchenne* is one of the first to note a rotation about the longitudinal axis during abduction.

Rouvière (1924) describes a very lax articular capsule around the entire joint. The important ligament is the *posterior external ligament* which runs in an oblique direction.

Haines (1944) considers himself the first to detect the radial, anterior oblique and posterior oblique ligaments. Although it is true that the ligamentous structure often is ignored, we must disagree with *Haines* that these structures were not recognized earlier. We must give credit however to *Haines*, who pointed at the importance of the ligaments. *Haines* furthermore introduced a useful nomenclature which is commonly used in the subsequent literature. *Napier* (1955) confirms *Haines'* findings in 48 dissections.

Kaplan (1965) describes the trapezium as being more or less pentagonal. The distal articulating surface which is referred to as saddle shaped. The distal surface relates to the base of metacarpal I and has a *crest* running in oblique direction medially and distally. This crest varying in size is sometimes called the tubercle of the trapezium.

The posterior aspect shows two prominent areas with a shallow groove. The groove shows foramina for vascular supply. It serves as a guide for the extensor pollicis longus tendon. Furthermore *Kaplan* recognizes the problem of a precise definition of opposition. This subject of opposition was approached by many investigators who attempted to establish whether opposition was due to a rotatory or combined motion, and whether it took place in the carpometacarpal joint or whether other carpal bones were involved in the process. This remark is followed by a summing up of fourteen characteristics of opposition. He also misses an adequate description in the literature of the first carpometacarpal joint. After his own dissections he gives the following description. "The base of the first metacarpal shows a triangular beak which in *neutral* position of the thumb is oriented towards 'the ridge' of the trapezium. These two bony prominences are united by a strong ulnar ligament. The lateral side of the base of the first metacarpal immediately proximal to the insertion of the tendon of the abductor pollicis longus is the site of insertion of the lateral ligament. Thus the capsule, which in itself is lax, is reinforced by two strong ligaments on this volar aspect. On the dorsal aspect there is a dorsal ligament covered by the tendons of the extensor pollicis brevis and longus." Furthermore he recognized the variable double (or triple) insertion of the abductor pollicis longus.

b. The kinematic approach

Sömmering (1839) appears the first to be concerned about the kinesiology of joints. He gives a general classification of joints. He mentions a few joints and lists the carpometacarpal joint of the thumb as a ball and socket type joint. In his work no clear description of this joint is encountered.
A. Fick (1854, 1856) tries to analyse the kinesiology of the saddle joint in more detail. In contrast to *Virchow* (1898) he believes that joint surfaces generally speaking must be congruent. He realises that the skeleton, although geniously shaped, is mechanically poorly built, so that everything totters and rocks a bit.
He generally recognizes two types of joints, "Ein Arthrodie und das Charnier". Yet another type is the joint with saddle shaped surfaces. He points at the error in the literature to call this joint a ball and socket type joint. It is however understandable since a more or less spatial cone can be described. *Fick* concludes that an "Arthrodie" without ball and socket joint surface is a geometrical impossibility. He compares the motions with a symmetrical hyperboloid around an imaginary central axis. Around this axis one gets an "Umdrehungs Hyperboloid". If the joint were built in a similar fashion with two such surfaces one would get a simple hinge motion. The axis of rotation would be the same one as the axis of the "Hyperboloid". But there are other motions taking place as well around the second axis at right angles with the first. The result is also a coneshaped motion pattern but quite different from an "Arthrodie". This can now be applied to the trapezium metacarpal joint. This view is mainly followed throughout the subsequent literature.
It is obvious because of the symmetry of such a mathematical model, that this approach is too simple for the complexity of the first carpometacarpal joint. This fact is amply confirmed by the number of studies which followed. *A. Fick* coined the term "saddle joint" and he designates this joint as a separate entity on the basis of a thourough mechanical analysis.
Henke (1863) approaches the carpometacarpal joint of the thumb from a mechanical point of view. In general joints are considered with congruent and incongruent joint surfaces. The latter is represented by the saddle joint. There are two directions of motion which are against the rules of complete congruency. Although the capsule is lax, it is not an "Arthrodie" since is fails to have the third axis, the axis of rotation. Furthermore the two axes present do not meet in one point.
Du Bois-Reymond (1895, 1897) measured the curvatures of the carpometacarpal joint of the thumb and found a theoretical rotation of 13°. Plain observations show clearly that more rotation takes place. This is then accounted for in the other joints of the thumb.

R. Fick (1911) finds it easier to look at the thumb motions as a whole. The main shape as outlined by a "Ringwurst" gives a hyperboloid model on the inside which is satisfactory. The term "reposition" is introduced as opposed to opposition. Furthermore the terms "supination" and "pronation" are used for movement in radial and ulnar direction. In this connection the importance of ligaments is considered. Opposition is inhibited by the dorsal trapezoid – metacarpal ligament. At the same time, because of its central as well as its radial insertion, pronation is promoted. In reposition the volar ligaments appear to favour supination. However that in spite of the saddle shape a rotation takes place, is due to the loose connection of this joint. Although some thought has been given to the function of the ligaments the end conclusion remains unsatisfactory.

Strasser (1917) mainly describes the thumb from the available literature and refers to *Duchenne's* work about the mechanism of the saddle joint by muscle motion. He accepts a rotatory movement of the first metacarpal around its longitudinal axis. The ligaments are called the collateral and accessory ligaments; these ligaments have slightly excentric attachments.

Walmsley (1928), investigating the hip, rightly pointed at two important factors which, he says, are two articular mechanisms. These are the inelastic non-contractile fibrous tissues and the articular shape. The ligaments are functional when tight. Whether or not the ligaments are really inelastic is a matter of importance that cannot be discussed in this context. He believes also in the adaptability of the articular surfaces but recognizes that organic joint surfaces, unlike artificial joints, are not completely contiguous. In one position (the position of weight bearing for the hip) total contact should be achieved.

Haines (1944) discusses the function of the ligaments in the classical way. He passively moves the thumb to the extreme positions of flexion and extension. The axial rotation which is observed at the end of these movements is caused not by muscular activity but by the ligamentous arrangement.

MacConaill (1953) defines with the aid of what he calls *Walmsley's* Law of Incongruence, a close packed position (C.P.P.) which is characteristic for each joint. Per definition the joint surfaces should be congruent in this close packed position. Thus "The CPP of the first carpometacarpal joint is that of full opposition of the thumb" (*MacConaill*, 1969, p. 37 l.c.). *MacConaill* (1946, 1953, 1969) introduces a new terminology for his analysis of sellar joint surfaces. This terminology gives the impression of a difficult analysis which in fact only confuses the reader easily. These terms are therefore preventing many from reading and a fortiori from understanding *MacConaill's* work. Furthermore the geometry and algebra of articular kinematics may be true in itself but we lack the correlation and application of these principles with the real anatomical situation.

As to the actual observations *MacConaill* already noted a clockwise and anticlockwise rotation. However the statement: "a clockwise diadochal displacement upon a sellar surface is accompanied by an anticlockwise conjunct rotation of the displaced body, and conversely" (*MacConaill*, 1946, p. 224, l.c.) is partly true and does not depend on the articular surface only. We will come back to this later.

Kivilaakso (1949) mainly follows the classical trend of thought. He goes back to the early 19th century opinion of considering the first carpometacarpal joint as a functional ball and socket articulation. He therefore believes, that, if a tendontransplant is done to compensate for the loss of opposition, the pull must come from a direction which will give both as strong an opposition movement as possible, as well as internal rotation. This implies that axial rotation is thought to be due to muscle action on the thumb.

Bausenhardt (1949) finds it impossible to work with an axis of rotation if no special "Hilfsannahmen" are taken. After a brief consideration of the shape of the joint surfaces the motion pattern is analysed. In principle the joint surfaces are still rotation hyperboloids, however on a curved cone surface. An attempt is made to explain the directions of the axes of rotation. The conclusion is that not all the motions can be explained by the joint surfaces but that important factors such as muscles, ligaments as well as reinforcements of the joint capsule should be taken into account. By this teamwork of skeleton, ligament and muscular systems it is possible that a joint shape develops which is not perfect according to the theoretical ideal rotatory body. In spite of such discrepancies the joint works effectively. In *Bausenhardt's* analysis a striking example of a symmetrical model with an excursion of the metacarpal I describing a symmetrical curved surface has been presented. It has been admitted that the anatomical specimen does not completely follow this theoretical model. However, the observations on the anatomical specimen, as will be demonstrated later, do not at all have such a simple relation to the pattern of motion pictured in this model. It has been just this very lack of correlation between a theoretical model and the anatomical structure that has stimulated us to further investigate the typical nature of this joint.

Söderberg (1953) gives an account of the motion of the thumb by clinical observations only. He divides motion into two types of movements, namely angulatory motion and rotatory motion, from watching the thumb performing the opposition movement. The tip of the thumb describes the circular arc of about 120°, that is the angulatory motion. The thumb then rotates at the same time about 90°; this we can ascertain through observation of the plane of the thumbnail. The combined motions are assumed to take place in the radio-scaphoid, intercarpal, carpometacarpal and metacarpophalangeal joints.

Gedda and Moberg (1953) and *Gedda* (1954) found in many posttraumatic cases of a Bennetts-fracture (*Bennet,* 1882), a subluxation of the first carpometacarpal joint. They do not believe, as others have in the past, that due to the traumatic insult the saddle shape of the joint has been lost. In their own anatomical dissections of this joint they describe the anterior oblique, the posterior oblique and the radial ligaments. The fundamental lesion of a typical Benetts-fracture without a fracture is a rupture of the dorso- (=posterior) oblique ligament causing the disturbance of function. Thus the position in the joint must be maintained by other factors than its shape alone. *Napier* (1955) recognized the wide disparity of joint contact at the first carpometacarpal joint in midposition. In this position only point contact exists. He finds that the joint is most congruous in fully abducted or adducted position. He comes to this conclusion mainly because he is unable to passively rotate the thumb in these two positions. This already contradicts *Mac-*

Conaill's close packed position, because *MacConaill* only recognizes one position in which the joint surfaces are most congruous. The terms medial and lateral rotation are used. The rotations are named medial rotation after moving the thumb from the fully abducted position in ulnar direction through circumduction and lateral rotation when the thumb is moved back again in radial direction.
Furthermore *Napier* is influenced by *MacConaill* using the term conjunct rotation as well. His main aim is to clarify two routes of motion, an indirect and a direct route. Since this rotation cannot be explained by mathematical laws *Napier* jumps to the opponens pollicis muscle. This would then be the rotator of the thumb causing a so-called adjunct rotation. His theories are demonstrated with a living thumb which picks up a small or a large object.
It clearly sounds contradictory, when *Napier* later discusses movements, that during the indirect motion of the thumb the congruent joint surface only requires the posterior oblique ligament without a rotator muscle and during the indirect motion the opponens pollicis does all the axial rotation. He does not mention any antagonist rotator muscle to recover from this rotated position. Also he ignores the function of all the other ligaments.
Huson (1961) analysed the function of the movements of the tarsal bones. He pointed at the theory of the "solids of revolution" which became a dominating concept, especially in the German but also in the French and British literature, on kinesiology of joints. The actual anatomical movements could not be explained adequately because the axis of motion does not always if at all coincide with the axis of revolution. The tarsal bones must shift in relation to each other, with a complex movement and as such rotate around a characteristic "moving axis". Although *Huson* worked mainly on the "closed chain" principle of the joints of the foot, his method has emphasized the importance of the ligaments as well as the limitation of a theoretical model with one axis of rotation.

CHAPTER II

MICROSCOPIC DESCRIPTION OF THE HUMAN FETAL FIRST CARPOMETACARPAL JOINT

a. Description of transverse sections of the first carpometacarpal joint

In order to study the ligamentous structures of the first carpometacarpal joint of the thumb, we have tried to follow their continuity in microscopic serial sections. It is necessary to study the bordering structures as well. Therefore, we will follow the ligaments starting from proximal to distal in the area to be studied. In order to limit our description we will not consider the skin, superficial fascia, superficial fat, the skin vessels and nerves. Only the larger vessels, tendons and bone structures that are of importance will be mentioned. In our description we will try to define the interrelationship of these structures. It will be necessary to have a certain point of orientation. It was the easiest to take the first ray of the hand as centre of orientation. Secondly it will be easier if we define also different levels. For this purpose one can take a structure which is centrally located and which will be present in each section. The latter is not always possible, for many structures disappear outside the field under study, or structures abruptly change in direction (e.g. the radial artery). According to *De Leeuw* (1962) it is most useful to relate structures to tendons or rather to tendinous layers. For the first carpometacarpal joint area we have used some series of transverse sections. In this way the topographic microscopic relations can be seen in detail and the structures such as bones and ligaments as well as their surrounding tissues can be followed in longitudinal direction. For these purposes sections of human fetuses were used. The structures of an early fetus, that is after eight weeks of gestation, and the topographical relation in the extremities are considered the same as in adults.

Material used

series 1931 – frontal sections. R.hand – homo fetus – (11 cm C.R. length) W.K. 2379
series 1900 – transverse sections. R.hand – homo fetus – (14 cm C.R. length) W.K. 1142
series 1899 – transverse sections. L.hand – homo fetus – (23 cm C.R. length) W.K. 1261
series 2318 – transverse sections. R.hand – homo fetus – (17 cm C.R. length) W.K. 3167

(collection of the Department of Anatomy and Embryology, University Leiden, Holland).

For our particular purpose series no. 2318 was cut perpendicular to the longitudinal axis of the first metacarpal, the staining used: Azan.

For orientation purposes a few slides proximal to the area of discussion will be described first. The first section will be arbitrarily called level O. The following sections will be numbered, and if multiplied by ten, the distance in μ's can be obtained. For simplicity we will refer to levels rather than to figures in our following description, starting with fig. II-1 as level O.

Section level O is a transverse cut through the distal end of the forearm and proximal part of the wrist. The bony structures concerned are first of all the radius. Straight lateral are the tendons of the abductor pollicis longus with on its dorsal aspect the extensor pollicis brevis. Both tendons appear to be surrounded by the same tendinous sheath. On its dorsal lateral surface there are two tendons which represent the extensor carpi radialis longus and brevis. A marked hump on the dorsal aspect of the radius, the proximal end of Lister's tubercle, borders on these tendons. Medial to Lister's tubercle are the extensor pollicis longus in a separate sheath and next to it the finger extensors. On the volar aspect one finds the musculus pronator quadratus, the flexor carpi radialis, the finger flexors and the median nerve. Medial to the radius, on the volar part, the lunate and more dorsally the distal part of the ulna which is still connected with its styloid process, can be seen. On the volar aspect the ulnar nerve and the flexor carpi ulnaris are situated the latter being slightly more superficial. The extensor carpi ulnaris as well as the extensor digiti quinti are situated dorsal to the ulna.

Level 72. This section is taken well into the proximal carpal row on the ulnar aspect of this slide. The distal part of the radius has however changed little. The relations of tendons, fascia and vessels on the radial aspect are the same.

Level 146. On cross section the radius is pentagonal, its medial border is concave and in close relation to the scaphoid. The extensor pollicis longus sheath and the extensor carpi radialis longus and brevis sheath border onto each other. Laterally are the extensor pollicis brevis (dorsal) and the abductor pollicis longus (volar) tendon, occupying the entire lateral aspect of the radius. The dorsal branch of the radial artery is located more superficially.

Level 179. The radius is becoming smaller and on its dorsal aspect the extensor pollicis longus is starting to move superficially over the extensor carpi radialis longus and brevis. The sheath of the extensor pollicis longus fuses with the sheath of the radial wrist extensors. The radius is becoming smaller and moves in dorsal direction. The scaphoid is still becoming larger in size, moves in volar direction and in this way comes in closer relation to the flexor carpi radialis and to the flexor pollicis longus tendons.

Level 201. This section is close to the distal end of the radius. The scaphoid is still becoming larger in size. At the lateral volar aspect the abductor pollicis longus and the extensor pollicis brevis have a different relation to the radius, because the radius is becoming smaller. The radius also moves thereby in dorsal direction away from the volar aspect. This allows the abductor pollicis longus and extensor pollicis brevis tendon to "shift" in ulnar direction. The styloid process of the radius is invested by a thick fibrous layer on its lateral aspect, it separates thereby the extensor pollicis brevis from the extensor carpi radialis longus and brevis. The latter two are each constained in a separate cleft. This cleft also contains the extensor pollicis longus which is now moving superficially over the extensor carpi radialis brevis.

Level 274. In this section the scaphoid is pushing in volar direction. The distal end of the radius, situated dorsally, is only visible as a whorl of tissue. Tissue fibres coming from the remnants of the distal extremity of the radius appear to run in ulnar volar direction to become attached to the scaphoid on its volar aspect. More superficially fibres are running around to the retinaculum of the carpaltunnel by-passing the scaphoid. These fibres engulf the flexor pollicis longus tendon taking part in the formation of the radial wall of the carpal canal. More superficially in a notch on the lateral aspect of the radial remnant the radial artery can be seen.

Level 290. In this section the radius has completely disappeared. The scaphoid, capitate and hamate are the only three bones left. On the radial side of the scaphoid there is a marked irregular fibrous capsular structure, which is well vascularized. There is a small branch of the radial artery separating the abductor pollicis longus and extensor pollicis brevis tendon sheath from the wrist capsule. This artery moves through the anatomical snuffbox and in this way arrives at the dorsal aspect of the wrist. In later sections the larger branch of the radial artery moves superficially to the tendons rather than through the infratendinous area alone. Dorsal to the scaphoid the extensor carpi radialis longus and brevis as well as the extensor pollicis longus are separated from the scaphoid by the dorsal carpal ligament. On the volar aspect the flexor pollicis longus appears to lie in the carpal tunnel and shows some tendinous fibrous attachments to the volar capsular structures of the scaphoid. The flexor carpi radialis lies separate in its own cleft. There are also superficial fascial fibres running from the peritendinous sheath of the abductor pollicis longus in volar direction to the flexor carpi radialis. These tendons therefore are situated in the same fascial layer.

Level 362. The scaphoid on the radial side has completely changed its shape. Its dorsal aspect is oval shaped. The volar extremity has pushed forward and lies directly against the subcutaneous tissues. Due to this fact the abductor pollicis longus and the extensor pollicis brevis are now located in dorsal relation to the scaphoid. Furthermore the extensor carpi radialis longus and brevis and the extensor pollicis longus have "shifted" in the direction of the capitate. On the volar aspect the flexor carpi radialis is contained in its own sheath and now starts moving deeper into the volar aspect of the wrist structures. On the dorsal aspect the extensor carpi radialis brevis and longus tendons are moving further apart.

Level 441. The trapezoid is commashaped. In the empty space volarly a small bony piece indicates the very first sign of the trapezium. More superficially there are ligamentous structures running in the direction of the capitate in continuity with the deep volar structures of the carpal ligament. The flexor carpi radialis is well separated from the carpal tunnel flexors. The thenar muscles are now developing and becoming larger. On the radial aspect the joint between the trapezium and scaphoid is bounded by a strong capsular ligamentous structure. Superficially fibres are running across to the trapezoid. Laterally the larger branch of the radial artery is moving out of the notch between the extensor pollicis brevis and the extensor carpi radialis longus.

Level 521. The whole wrist forms a bony arcade, the trapezium representing the most prominent bone in volar direction. The degree of volar "angulation" cannot be determined from the microscopy slides. The trapezium is separated from the skin by the thenar muscles. It has a prominence in ulnar direction which is the volar ridge (see later). From this ridge ligamentous fibres run in ulnar direction to become attached to the flexor retinaculum. This structure together with the volar ridge of the trapezium creates a tunnel in which the flexor carpi radialis is "protected".

On the radial aspect volar and medial to the trapezium the flexor carpi radialis in its own sheath has moved deeper into the wrist. On both sides fibrous structures are running in ulnar direction forming part of the superficial and deep retinacular structures of the carpal tunnel. The thenar muscles are now in close relation to the trapezium on the volar aspect. On the lateral aspect the abductor pollicis longus tendon sheath on its deep surface is closely related to the trapezium. Except for the trapezium and trapezoid, which have become larger, the relation of the lateral structures has changed a little from the previous slide. On the dorsal aspect the extensor carpi radialis brevis is now moving deeper in between the infratendinous fascia of the extensors of the fingers and the dorsal wrist joint capsule.

Level 604. The trapezium has considerably changed its shape and appears as a pear in this slide. The trapezium is very small and elongated. On the volar medial aspect of the trapezium the flexor carpi radialis has moved deeper. It is separated from the trapezium by a synovial cleft. It appears to get its vascular supply at its medial aspect. At the volar medial aspect of the trapezium a rather vascular but still strong fibrous retinaculum is attached. The fibres run from the trapezium in ulnar direction transversely and also slightly oblique towards the deeper aspect of the carpal tunnel.

On the palmar aspect the abductor pollicis longus tendon has elongated in width somewhat, moving between the thenar muscles and the trapezium. The infratendinous layer of the sheath is attached to the trapezium. More laterally is the second part of the abductor pollicis longus, dorsal to this tendon lies the extensor pollicis brevis and at the same level over the dorso-radial tubercle of the trapezium lies the extensor pollicis longus.

Summary levels 0-622

The changes that have taken place throughout the levels 0-622 in the radial part will be briefly reviewed. The radius is getting smaller in distal direction and with this development the extensor pollicis longus and the extensor radialis brevis and longus are located at the dorso-lateral aspect at level 179. The flexor carpi radialis and flexor pollicis longus are getting closer together.
Further distal the radius is being replaced by the scaphoid. At the same time the extensor pollicis longus is moving across the extensor radialis brevis and longus. The abductor pollicis longus and extensor pollicis brevis are located on the radial aspect and the flexor carpi radialis and flexor pollicis longus are located on the volar aspect of the scaphoid (level 290). The scaphoid is pushing in palmar direction and comes to a subcutaneous position at level 362 causing a clear separation between "volar" and "dorsal" structures in this area.
The very first sign of the trapezium appears on the palmar aspect of the scaphoid at level 441. The trapezoid at this level has already developed to a fair size on the dorsal aspect of the scaphoid. Therefore, the relations of the extensor carpi radialis longus and brevis have changed. They are now in a dorso-lateral position to the trapezoid. Furthermore these two tendons have separated and are now lying at a distance from each other. The extensor carpi radialis longus moved to a more lateral position of the wrist.
At level 521, the trapezoid is pushing itself in between the extensor carpi radialis longus and brevis separating these tendons further apart. The trapezium has developed to a fair size in front of the trapezoid. The trapezium in this way forms the lateral aspect of an "arch" of the wrist bones, "angulating" in volar direction. On its palmar aspect the thenar musculature is developing so that this bone lies at a deeper level than the scaphoid in relation to the skin. The flexor carpi radialis is located on the volar aspect of the trapezium, it is partly protected by its volar ridge. The abductor pollicis longus and extensor pollicis brevis are in a radial position to the trapezoid.
At level 604 the trapezium has altered its shape. Its volar angulation appears to have been accentuated. At its volar ridge it has a strong attachment with the flexor retinaculum. The flexor carpi radialis has taken a position deeper into the palmar aspect of the wrist. On the dorso-lateral aspect in close relation to the trapezium lies the extensor radialis longus with somewhat more superficial the extensor pollicis longus.
Before entering into a more detailed description of the first carpometacarpal joint area, it seems appropriate to comment on certain landmarks, which will be referred to in the following description.

The position of the trapezium

As we just have seen the trapezium forms the radial volar extremity of the carpal arch. Its longitudinal axis which is at an angle with the rest of the carpus, runs in an oblique volar direction (fig. II-11).

Terminilogy and landmarks

Although the position of the trapezium is not in the same plane with the rest of the carpal bones, its facies with the trapezoid and metacarpal II will be referred to as ulnar and the opposite as radial. Consequently there remains a dorsal facies which is virtually dorso-radial and a volar facies which is really ulno-volar. The area deep to the thenar musculature, which forms the superficial aspect of the first ray will conveniently be referred to as palmar.

There are at this level 4 points to which fibrous structures are attached: on the volar aspect radially or superficially the volar ridge and deep, close to metacarpal II, what we have termed the ulnar notch of the trapezium and on the dorsal aspect the dorso-radial and the dorso-ulnar tubercle. With these introductory remarks we will continue the description of the subsequent levels.

Level 622. This section is taken at the proximal extremity of the first carpometacarpal joint. On the dorsal aspect of the trapezium, the joint space is visible as a cleft. The joint capsule bridges together with reinforcing fibres over a dorsal depression or notch between the dorso-ulnar and the dorso-radial tubercle. Furthermore a heavy bundle of fibres arises from the dorso-radial tubercle. Some of these are cut in transverse and others in an oblique direction. They represent the proximal attachment of the radial ligament (*Haines,* 1944) of the first carpometacarpal joint. More superficially lies the abductor pollicis longus. It consists of two tendons. These tendons are "curving" around in ulnar direction pushing between the trapezium and the thenar musculature on its deep aspect. The ulnar part of the abductor pollicis longus is getting inserted into the palmar aspect of the trapezium. The dorso-ulnar tubercle also has a broad area from which fibres arise. On the ulnar aspect most fibres run in dorso-ulnar direction, forming a dorsal reinforcement of the trapezium -- metacarpal II joint. In the centre of this tubercle, fibres are cut transversely across. More superficially runs the extensor carpi radialis longus and the extensor pollicis longus, separated from the trapezium and its investing structures by their tendon sheaths only. On the volar aspect fibres are arising from a broad area of the volar ridge of the trapezium. From the superficial area fibres run in an ulnar direction and fuse with the volar part of the flexor retinaculum. Somewhat deeper fibres are running in an oblique direction fusing with the floor of the carpal canal.

On the volar aspect of the flexor carpi radialis there is an increasing amount of fibres which are cut transversely across. These fibres are putting themselves in a position between the tendinous sheath of the flexor carpi radialis and the trapezium as will be shown later on (fig. II-17). These fibres will compose the anterior oblique ligament. In the area of the ulnar volar notch fibres arise, running in an ulnar direction, deep to the flexor carpi radialis tendon, to become attached to the capitate. These fibres belong to a system covering the volar aspect of the distal row of the carpal and proximal part of the metacarpal bones.

Level 652. At the volar ridge the fibrous structures are getting organized into systems. From the superficial part fibres still run in ulnar direction fusing with the

flexor retinaculum of the carpal tunnel. The deeper fibres, in contrast to the previous level, which were running in an oblique direction *to* the floor of the carpal canal have disappeared. They are more or less "replaced" by fibres which run exactly in opposite direction, that is from radial and deep to ulnar and superficial. These fibres are thus situated volar to the flexor carpi radialis and from the distal part of the radial root of the flexor retinaculum.
From the deeper aspect of the volar ridge a ligament is developing. Its fibres are cut across obliquely as they run in distal direction and penetrate deeper into the palm. They curve around the volar aspect of the first carpometacarpal joint space. This is the beginning of the anterior oblique ligament, as mentioned above. At the same time a narrow cleft becomes obvious separating this anterior oblique ligament at its volar aspect from the flexor retinaculum.
At the dorso-ulnar tubercle of the trapezium, fibres are cut across transversely. This was found to be the very first sign of the posterior oblique ligament. The fibres are still intermingled with the attachments of the capsular fibres of the first carpometacarpal joint and become more obvious at later distally situated levels.

Level 661. The trapezium has altered its shape slightly; it is now beanshaped with a convexity on the volar side. In its "waist" we see both on the volar and on the dorsal aspect the first carpometacarpal joint space developing. On the dorsal aspect the very first sign of the metacarpal I, which we have termed the dorsal styloid process (see later), is present as a small bony fragment. The joint between metacarpal II and the trapezium is somewhat irregularly shaped.
On the volar side of the trapezium the fibrous structures are somewhat more arranged in bundles. The anterior oblique ligament, that has emerged in the previous level discussed above, has simply more encroached upon the volar joint capsule. The distal part of the radial root of the flexor retinaculum although still closely related remains separated from the anterior oblique ligament by the above mentioned cleft. The bundle of transverse fibres, from the ulnar notch of the trapezium to the capitate, is diminishing in size. On the palmar aspect the abductor pollicis longus is "moving" medially (ulnarward). Its sheath has firm connections with the ligaments covering the trapezium. The dorso-radial tubercle is covered with and gives origin to strong fibrous ligaments. Fibres are running both in transverse and longitudinal direction. The dorsal interosseus ligament connecting the trapezium and the metacarpal II is well developed.

Level 681. The trapezium rapidly changes its shape. Except on the ulnar side, the joint cleft surrounds the trapezium throughout.
On the volar aspect the volar styloid process of the first metacarpal appears as a small bony fragment in the joint space. In contrast to the dorsal aspect, where a fairly wide contact exists between the dorsal styloid process and the trapezium, there is no contact of the volar styloid process with the trapezium. It is clear that the articular surface areas of the trapezium as well as the first metacarpal are not in contact with each other over their entire extension. Even on the dorsal aspect where the first metacarpal and the trapezium entertain a fairly wide area of contact,

the articular surface of the latter extends in lateral direction, well beyond metacarpal I, so that on both sides of the base of this bone a wedge-shaped interval becomes apparent. Outside this joint area on the volar aspect the anterior oblique ligament is cut transversely across, it surrounds the first carpometacarpal joint from volar penetrating deeper into the area between the flexor retinaculum and the jointcapsule. The ligamentous connection of the trapezium with the carpal tunnel, dorsal to the flexor carpi radialis tendon, has become much thinner. On the palmar aspect of the trapezium the abductor pollicis longus is approaching its insertion. It reinforces the palmar aspect of the jointcapsule.

The first metacarpal, on the dorsal aspect, shows a strong fibrous ligamentous structure inserting into bone. This is the distal attachment of the dorso-radial ligament.

The dorso-ulnar capsule of the joint at this level shows the organisation of the fibrous structure which is the posterior oblique ligament of the first carpometacarpal joint of the thumb. This ligament is difficult to follow. At times it appears as if it originates from metacarpal I. However, following this ligament in both distal and proximal direction, it must already be stated, that it remains a separate entity. It has however some loose attachments to the dorsal jointcapsule as well as some connection directly to the dorsal styloid process of metacarpal I. Further distal it is situated directly against the capsule of the trapezium – metacarpal II joint; here again loose attachments are present.

The dorsal aspect of the second metacarpal also shows a bundle of fibrous structures of a ligamentous nature. The extensor carpi radialis longus is nearing its insertion and only a very small infratendinous cleft separates it from the second metacarpal. The extensor pollicis longus tendon in its own sheath is again situated dorso-radial to the extensor carpi radialis longus tendon and the radial artery is laying superficial to it.

Level 687. The first carpometacarpal joint is still rapidly changing. The trapezium is narrowing in its "waist" and the first metacarpal is becoming larger. Again we see that the trapezium is almost completely intracapsular. There is articular contact both on the radial and on the ulnar side of the trapezium with the first metacarpal. Again it is clear that the contact does not involve all the available articular surface. The ligamentous structures surrounding the joint have changed a little in relation to each other.

At this level we have reached the "junction" of the distal extremity of the trapezium with the proximal part of metacarpal I, therefore, it is convenient to keep in mind the structures we are following to their distal attachments as well as some aspects of the joint itself. In short:

1. The abductor pollicis longus is nearing its insertion reinforcing the volar capsule of the first carpometacarpal joint.
2. There is lack of complete articular contact between trapezium and first metacarpal.
3. The clearly organized ligament on the volar aspect of the joint, the anterior oblique ligament, curves around the volar aspect from superficial to deep.

4. A strong dorso-radial ligament of the first carpometacarpal joint, having a proximal attachment to the dorso-radial tubercle of the trapezium and a distal attachment to the dorsal styloid process of the first metacarpal has been passed completely.
5. The first signs of the organization of the posterior oblique ligament of the first carpometacarpal joint are situated in the dorso-ulnar jointcapsule. The first metacarpal dominates the picture from this section onward in distal direction.

Level 688. The two metacarpal fragments have now become one. The trapezium has a small volar and a large dorsal fragment. On the palmar aspect the reinforcement of the jointcapsule is mainly due to the deep layer of the sheath of the abductor pollicis longus tendon. Slightly deeper on the volar aspect the anterior oblique ligament still reinforces the capsule.
The flexor carpi radialis tendon is surrounded by vascularised connective tissue volarly. A bundle of fibres appears to develop that intervenes between the joint-capsule of the carpometacarpal joint and the flexor carpi radialis tendon. These fibres run from the capsule in an oblique ulnar direction towards the flexor retinaculum. In this area, in the flexor retinaculum, a fibrous system develops. These fibres are cut transversely across. They seem to separate themselves from the fibrous system which runs in ulno-volar direction to the superficial aspect of the carpal tunnel. This represents the first indication of the first palmar interosseus, which takes origin from the distal part of the radial root of the flexor retinaculum. The dorso-radial ligament inserts already firmly into the dorsal styloid process. The posterior oblique ligament is moving in the ulnar direction to the space between the trapezium and metacarpal II.

Level 701. We are still in the first carpometacarpal joint. Only the dorsal fragment of the trapezium is present, the radial fragment has disappeared. At this level, on cross-section metacarpal I is elongated in dorso-volar direction. The volar aspect is the area proximal to the volar tubercle of the first metacarpal base to which the jointcapsule is attached.
The abductor pollicis longus is firmly adherent to the capsule and reinforces almost the complete volar aspect of the first carpometacarpal joint; there is a little thinning of these structures in ulnar direction. The anterior oblique ligament is fully developed. There are some fibrous adhesions bridging over and running in ulnar direction to the volar aspect of the carpal tunnel retinaculum. In this retinacular quadrangular space some individual ligaments are getting more organized. The most conspicuous fibrous structure is directly volar to the flexor carpi radialis tendon. The fibres of the trapezio-metacarpal III ligament are becoming very thin. Another ligament has appeared which runs obliquely from the ulnar aspect of the trapezium in volar direction to the volar aspect of metacarpal II. On the radial aspect of the first carpometacarpal joint the radial ligament has fused with metacarpal I. The extensor carpi radialis longus tendon is nearing its insertion and becomes adherent to the fibrous coverage of the metacarpal II. The posterior oblique ligament lies as a definite organized ligament in the dorso-ulnar part of the jointcapsule.

Level 713. Since the trapezium rapidly diminishes in size we will just have a brief look at this section. Most structures and relations are the same. In the area volar to the flexor carpi radialis tendon and the first metacarpal, the radial root of the flexor retinaculum is becoming more defined and organized into bundles.
On the dorsal aspect the posterior oblique ligament is still pushing into a dorso-ulnar direction. In the space between metacarpal II and the trapezium a large bundle of fibres derived from the latter bone borders on the joint cleft with metacarpal II. These fibres reinforce this capsule and will eventually insert into metacarpal II. This system of fibres borders onto, but is not involved in the ligamentous capsular system of the first carpometacarpal joint.

Level 730. The palmar aspect of metacarpal I only shows the remnants of the joint space. The abductor pollicis longus is getting inserted into the first metacarpal. More volarly the anterior oblique ligament gets firmly attached into the first metacarpal, which is the volar ulnar tubercle of the base of metacarpal I. In the interspace between metacarpal II and the trapezium the ligamentous system described in the previous level, already diminishes in size, it becomes inserted into metacarpal II on the radial aspect.

Level 752. The palmar volar aspect of metacarpal I has reached the final distal level of the first carpometacarpal joint. The thenar musculature is covering most of this area.
On the dorsal aspect the extensor pollicis brevis lies in a separate sheath in close relation to the first metacarpal. The extensor pollicis longus still lies in close relation to the posterior oblique ligament with the radial artery at a more superficial level.
The remaining description will mainly be concentrated on the interspace between metacarpal I and II following the posterior oblique and intermetacarpal ligament. In this area the remnants of the trapezium are still visible in the remaining joint space as a fibrous structure. The posterior oblique ligament is at present the only ligament in the dorsal aspect of the interspace.

Level 774. The posterior oblique ligament is located in the center of the interspace between metacarpal I and II. Furthermore it is fused with a strong ligamentous structure coming from the dorso-radial aspect of metacarpal II, the intermetacarpal ligament. Both ligaments are running together to form a conjoint ligament and as such become inserted into the volar-ulnar tubercle of the base of metacarpal I. On the dorsal aspect of the interspace the origin of the first dorsal interosseus muscle is developing, at present mainly on the side of metacarpal I. On the volar aspect loosely arranged connective tissue and the insertion of the flexor carpi radialis into the proximal volar metacarpal II can be observed.

Level 812. Section of the intermetacarpal space I and II just at the area of the conjoint intermetacarpal and posterior oblique ligament inserting into the volar-ulnar tubercle of the base of metacarpal I. The last distal remnants of the intermetacarpal ligament are close to their attachment to the dorso-radial aspect of metacarpal II. In the same area more dorsally are the muscle fibres of the first dorsal interosseus muscle, contained in its fascia between the radial artery and metacarpal I.

the extensor pollicis brevis and longus, has not been seen in an immediate relation to the posterior oblique ligament. This, however, is an exception because usually the radial artery lies immediately against the posterior and intermetacarpal ligament. Therefore the slide of series 1900 was included. (fig. II-23).

Summary levels 622-812

The changes that have taken place distal to level 622 will be briefly reviewed.

Level 622-661. The main points of attachment of ligaments are indicated on the trapezium. On the volar aspect: the volar ridge to which the radial root of the flexor retinaculum is anchored and the volar notch where the deep ligaments of the wrist joint find its attachment. The flexor carpi radialis tendon runs in close volar relation to the trapezium.

On the dorsal aspect the dorso-radial tubercle from which the dorso-radial ligament arises and the dorso-ulnar tubercle where the posterior oblique ligament starts to develop. The joint cleft of the first carpometacarpal joint is already visible on this side and at level 652 becomes obvious volarly. The abductor pollicis longus tendon is pushing around the trapezium ulnarward and increases in width. The extensor carpi radialis "touches" onto the dorsally investing structures of the trapezium. The extensor pollicis longus tendon "moves" further in lateral direction, in order to end also in dorsal relation to the trapezium at a more distal level. The radial artery is situated in an "abnormal" superficial position to the extensor pollicis longus, in the subcutaneous area.

Level 661-688. The trapezium is changing its shape very rapidly and finally is seen as two fragments, a larger or dorsal and a smaller or volar fragment. At level 661 the dorsal styloid process and at level 681 the volar styloid process of metacarpal I appears. The trapezium becomes to lie intracapsular except for its ulnar extremity. On the volar aspect the radial root of the flexor retinaculum becomes detached from the trapezium, while the anterior oblique ligament becomes obvious in this area, originating from the distal part of the volar ridge that is the volar tubercle of the trapezium. This ligament is rather short and it "curves" around "deeper" into the wrist passing the volar aspect of the first carpometacarpal joint. The abductor pollicis longus tendon becomes attached to the palmar jointcapsule and at the same time, "pushes" in medial direction between the joint structures and the thenar musculature. In the ulno-volar area the deep ligament of the wrist attaching to the volar notch of the trapezium decreases in size while at the same time the flexor carpi radialis nearing its insertion, becomes to lie in closer relation to metacarpal II. On the dorsal aspect the radial ligament starts to develop at the dorso-radial tubercle. It is a short ligament and finds its insertion in the dorsal styloid process of metacarpal I at level 687. The posterior oblique ligament originates from the dorso-ulnar tubercle. At first it is intermingled with the dorsal capsular structures of the first carpometacarpal joint. At level 687 it becomes obvious as a separate entity running in an almost straight distal direction.

Level 688-752. The metacarpal I fragments fuse together and become the dominating bony structure. At first the metacarpal base is elongated in dorso-volar direction but becomes more circular at level 752. At first the trapezium is present as two fragments. The radial fragment soon disappears while the ulnar fragment extends further distally till it has vanished at level 752. On the volar aspect the anterior oblique ligament inserts into the volar aspect of the base of metacarpal I just proximal to the volar-ulnar tubercle. The abductor pollicis longus becomes firmly attached to the palmar aspect of the base of metacarpal I.
Dorsally the posterior oblique ligament moves ulnarward in the direction of the interspace between metacarpal I and II. The capsule and fibrous structures of the trapezium and metacarpal II ligament remain clearly separated from the capsular and ligamentous structures of the first carpometacarpal joint. The extensor pollicis brevis and longus are coming into a dorsal position in relation to metacarpal I. The abnormal superficial course of the radial artery has been noted.

Level 752-846. The first metacarpal remains more or less circular and the remainder of the joint space has vanished at level 774.
The volar aspect of the first metacarpal becomes occupied mainly by the thenar musculature. On the dorsal aspect the relation to the extensor pollicis longus and brevis changes little.
The area of main concern is the interspace between metacarpal I and II. The posterior oblique ligament starts to move into this space and at level 774 fuses with the first intermetacarpal ligament which runs from the dorso-radial aspect of metacarpal II in volar-radial direction to form the conjoint part of these two ligaments. This conjoint ligament finally becomes inserted into the volar-ulnar tubercle of the base of metacarpal I at level 812. This actually means that we have reached the most distal point of the first carpometacarpal joint structures.
Finally the normal dorsal relation of the radial artery to the posterior oblique ligament has been shown in figure II-23. Also the origin of the first dorsal interosseus muscle at level 774, its further development and its relation to the radial artery has been demonstrated.

b. Description of frontal sections of the first carpometacarpal joint

In order to further analyse the ligamentous system around the first carpometacarpal joint and the joint itself, also series of frontal sections were studied. The terminology used for the indication of the positions of the structures involved were mainly followed as indicated previously. To repeat, the term:

a. Volar and palmar are used to indicate a position of structures in front of the wrist and metacarpals. Many of the structures described actually lie "on the inside" in relation to the trapezium.

b. Dorsal is the area behind the trapezium, which corresponds to the dorsal aspect of the wrist in general.
c. Ulnar indicates structures which are situated in the direction of metacarpal II.
d. Lateral is mainly used for structures which are located actually in antero-lateral position to the trapezium.
e. Radial is used for structures which are situated in the opposite direction of the ulnar structures.

It must be understood however that even with the above outlined terminology it is difficult to indicate the proper position of one structure in relation to the other, because the relation in space can change and this change in position cannot readily be seen in the sections. The sections in these series are being followed from palmar to dorsal. The first slide is taken through the trapezium and the thenar musculature just palmar to metacarpal I. This slide will be arbitrarily called level O.

Level 0. This section shows the bony nucleus of the pisiform on the ulnar and of the trapezium on the radial aspect. Since the thumb is located in a more forward position then the rest of the fingers, it is cut across almost completely in its full length, where as the other digits are still being missed. Proximal to the trapezium there is a fibrous structure in which the scaphoid will develop. More proximal to this structure lies the flexor carpi radialis tendon. The centre of this section shows a wavy fibrous structure, the superficial part of the flexor retinaculum of the carpal tunnel. Distal to the trapezium in the thenar musculature a spherical bundle of fibrous tissue represents the most palmar extremity of the base of the first metacarpal.

Level 21. The trapezium is enlarging in size and is somewhat irregular in shape. Proximal the flexor carpi radialis tendon sheath borders onto the proximal volar aspect of the trapezium. The tendon in its sheath is cut in a longitudinal direction. Therefore it is not surprising that it can be cut more then once indicating the area where the flexor carpi radialis curves around into the wrist from relatively superficial to deeper in distal direction. The flexor carpi radialis tendon on its lateral aspect has shifted further ulnarward with respect to the fibrous structure now at its outer side. On the lateral aspect of the trapezium a bundle of fibres is cut in a slightly oblique direction. These fibres become attached to the trapezium. They represent the infratendinous layer of the sheath of the abductor pollicis longus. We must remember that these structures actually become inserted into the front of the trapezium. More lateral and distal a second fibrous structure is visible. Its fibres are also cut in a slightly oblique direction. It is separated from the previous structure by a narrow slit. This structure is a second component of the infratendinous layer of the sheath of the abductor pollicis longus and becomes inserted into the base of the first metacarpal. The tendon merges with its sheath, to become inserted both into the trapezium and metacarpal I. The first metacarpal is visible as a small bony piece situated distal to the trapezium. Between the two bony pieces, the trapezium and metacarpal respectively, there is at present a wide articular lumen of the first carpometacarpal joint. A fold of synovium is crossing this lumen transversely. The jointcapsule volarly is seen as a small as yet not clearly defined fibrous structure. On the lateral aspect the jointcapsule appears to be reinforced by the infratendinous layer of the sheath of the abductor pollicis longus.

Level 34. The bony structures are increasing in size. The trapezium is still somewhat irregular in shape. It has a prominence on its volar and inner aspect which is the beginning of the volar ridge. The term "inner" will be used more often to indicate a relation of the structures in a position "toward" the carpal tunnel. In this area of the volar ridge there is a strong fibrous structure developing. The fibres are cut in a transverse direction perpendicular to their longitudinal axis. The flexor carpi radialis tendon is still situated on the volar aspect of the trapezium, and can be seen at present as three pieces. Proximal to the trapezium in the fibrous area a bony nucleus appears. This is the very first sign of the scaphoid. On the lateral aspect of the trapezium the fibrous structures are becoming more clearly defined. Proximally there is a bundle of fibres representing one of the components of the abductor pollicis longus itself. More distally there is a fibrous structure representing another component of the abductor pollicis longus, which is still inserted into the base of the first metacarpal. The infratendinous layer of the sheath of the abductor pollicis longus reinforces the jointcapsule, the latter becoming thicker and stronger. The joint gap between the trapezium and the first metacarpal is becoming smaller. The convexity of the distal articular surface of the trapezium is stronger curved than the concavity of the articular surface of the base of the first metacarpal. They are certainly not eachothers negative.

Level 50. The trapezium is still increasing in size. Throughout our sections the trapezium keeps changing its shape. At present it is multifacetted, which in the past has been the reason to name this bone multangular. On its inner aspect the firm fibrous structure connects the trapezium to the transverse carpal retinaculum. This fibrous structure has been called the *"radial root"* of the carpal tunnel by *Landsmeer*, which forms a strong anchorage to the volar ridge of the trapezium. Slightly proximal to this radial root of the carpal retinaculum the two components of the flexor carpi radialis tendon are coming closer together and at the same time move in a distal direction. Proximal to the trapezium the scaphoid is developing in size. A small cleft indicates a joint space between the trapezium and the scaphoid. The scaphoid will not be considered in our further discussion. On the lateral aspect the abductor pollicis longus tendon extends in a more proximal direction. The distal component is inserted into the base of the first metacarpal. The joint lumen appears as a small cleft and is shaped as a lazy S. The articular surfaces on both sides are still different in shape. The convexity of the distal trapezium is stronger than the concavity of the proximal metacarpal. Also there is a slight shift of the metacarpal in a radial direction in relation to the trapezium. The joint capsule on the radio-dorsal aspect is still strong, on the volar aspect the capsule is more loosely arranged. This area corresponds with the volar radial joint capsule of the first carpometacarpal joint which as we will see later, is rather thin and loose. On its inner aspect the radial part of the flexor retinaculum is increasing in size. Fibres are running from the trapezium in volar direction to become attached to the flexor retinaculum so that a firm anchorage is becoming established. This radial root of the flexor retinaculum is attached mainly to the volar ridge of the trapezium and lies "in front" of the flexor carpi radialis tendon. Its fibres are running in transverse direction from radial to ulnar. Proximally the scaphoid is enlarging in size. A narrow cleft indicates the development of the trapezio-scaphoid joint and situated more proximal is the radius. On the lateral aspect the infratendinous sheath covers the trapezium and in distal direction the jointcapsule. The two components of the abductor pollicis longus tendon are becoming more clearly defined. They are "extending" in a more proximal direction. Distally the first metacarpal is increasing in size.

Level 62. The trapezium becomes more rectangular in shape. On its inner aspect the capsular fibres are becoming more organized. These fibres are running from the trapezium in distal direction to become attached to the base of metacarpal I. On the proximo-lateral aspect there is a slight elevation, the first sign of the dorso-radial tubercle. It gives origin to a broad fibrous structure which represents the dorso-radial ligament. This ligament is attached distally to the base of the first metacarpal. There is no clear separation between the dorso-radial ligament and the infratendinous layer of the sheath of the abductor pollicis longus. These two seem to merge into eachother. The dorso-radial ligament at present reinforces the jointcapsule in this area.
The term dorsal will be more frequently used rather than lateral, since the structures on the "outside" of the trapezium in space are getting more into relation with the dorsal structures of the wrist in general. The joint surfaces are of a different curvature, with in the "centre" a good articular contact. On the radial and ulnar side of this area there is a definite gap between the two joint surfaces.

Level 90. The trapezium has altered little in shape, the dorso-radial tubercle is somewhat more pronounced. The volar ridge is no longer seen. On the inner aspect there is a strong ligamentous structure overlying the jointcapsule. This is the anterior oblique ligament. It originates from the inner aspect of the trapezium running in distal direction to become inserted into the ulnar tubercle of the first metacarpal base. The volar tubercle of the trapezium is cut in such a way that it does not appear as an elevation. It is however the point of attachment of the anterior oblique ligament. The anterior oblique ligament lies completely free from the radial root of the flexor retinaculum. The latter has lost its attachment to the trapezium and actually lies "in front" of the flexor carpi radialis tendon. On the dorsal aspect the attachment of the dorso-radial ligament is diminishing on the metacarpal side where as it is still attached firmly into the dorso-radial tubercle of the trapezium. The articular surfaces of the joint itself have good contact over a large centrally located area.
The two components of the flexor carpi radialis tendon are close together. This is usually one tendon. It lies in a "groove" of the trapezium. Just like the volar tubercle, the groove for the flexor carpi radialis tendon cannot be demonstrated.

Level 115. We are now beyond the area of the dorso-radial tubercle of the trapezium. The dorsal "shift" of the first metacarpal becomes more obvious. On the volar aspect in the intervening levels the anterior oblique ligament covering the jointcapsule has disappeared.
At its inner side the jointcapsule is at this level becoming stronger again, being reinforced by fibres running directly from the trapezium to metacarpal I from a proximal to distal direction. This area will be mentioned again in our gross description. It represents the volar ulnar aspect of the jointcapsule which indeed is very thick and strong, and covers a wide area of the capsule. On the dorsal aspect the ligamentous contact between the trapezium and metacarpal I is becoming interrupted, especially on the trapezial side, by loose connective tissue, because we have passed the area of the radial ligament. More proximal lies the radial artery and vein deep to the abductor pollicis longus tendon. At the same time the capsule becomes roomy. On the same side in relation to the base of the first metacarpal lies the extensor pollicis brevis tendon, cut longitudinally and extending in proximal direction. The area between the trapezium and extensor pollicis brevis tendon is occupied by some loosely arranged connective tissue and the radial artery and vein.

Level 134. The trapezium has changed its shape somewhat again. Comparing level 115 and 134 it is clear that we are arriving at the ulnar aspect of the trapezium. This area is characterized by the dorsal "sloping" of the articular surface. The "inner" aspect of the trapezium "remains" high. The trapezium forms a "neck" around which the metacarpal swings. The functional importance will be discussed later. It means that in this part the trapezium has its articular facet in space on both the lateral and dorsal aspect.
The concavity of the proximal articular surface of the first metacarpal is also diminishing. In contrast to the "flat" radial aspect, (levels 30 through 62) the distal articular surface is curved and has shifted into a more or less dorsal position. The articular contact between the trapezium and metacarpal I is diminishing. The trapezoid has appeared at the proximal volar aspect, it forms a "floor" to the flexor carpi radialis tendon. The reinforcement of the jointcapsule on the ulnar side has completely disappeared. The capsule is more or less loosely arranged. On the dorsal aspect it can be seen that the capsular fibres are cut in a slightly oblique direction. The insertion of the capsule is at a distance from the articular cartilage especially on the proximal side. This provides for more room for the proximal dorsal styloid process of metacarpal I. The radial artery is coming to the level of the trapezium deep to the extensor pollicis brevis tendon.

Level 148. The trapezium is getting smaller, the articular surface is flattening and its dorsal slope is increasing. On the inner aspect of the metacarpal base there is a condensation of fibrous structures. This is the area of the volar-ulnar tubercle of the first metacarpal base. The condensation of fibrous structures represents the insertion of the "conjoint" component of the intermetacarpal ligament of the first interspace and the posterior oblique ligament. Following the ulnar aspect in distal direction the princeps pollicis artery appears and is situated between metacarpal I and the thenar musculature at this level.

Level 174. Coming to the ulnar part, the trapezium becomes kidney shaped. On its proximal inner ulnar aspect the trapezium articulates with the trapezoid. The trapezoid has a small bony fragment on its distal aspect, the base of metacarpal II. In volar relation to the trapezium lies the flexor carpi radialis, which is nearing its insertion on the volar aspect of the second metacarpal. The first carpometacarpal jointcapsule on its inner side is loose and reinforced by an unnamed ligamentous structure, which swings around the jointcapsule, its fibres running in a proximo-distal direction. Distally they merge into the posterior oblique ligament. The first metacarpal is becoming smaller, only the ulnar part of its base remains. On its inner aspect the "conjoint" ligament is differentiating into its two parts, the posterior oblique and the intermetacarpal ligament.
The posterior oblique ligament is situated "proximal" to, or rather underneath the intermetacarpal ligament of the first interspace. The latter is arching over the former. Distally the princeps pollicis artery which comes into a closer relation to these ligamentous structures. On the dorsal aspect a fibrous capsular contact between trapezium and metacarpal I has been reestablished. The articular surfaces are no longer in contact with each other, they are again separated by a synovial fold.

Level 201. The trapezium is rapidly diminishing in size and becomes triangular in shape, wedged between the trapezoid proximally and the metacarpal II distally on its dorso-ulnar aspect. On the other side are the ulnar remnants of the base of metacarpal I. On the dorsal aspect the elongated lumen of the radial artery runs distal to the trapezium, the dorso-ulnar extremity of metacarpal I, with on its dorsal aspect the extensor pollicis longus tendon. On its ulnar aspect the intermeta-carpal ligament runs in ulnar direction and curves over the posterior oblique ligament into the direction of the base of metacarpal II.
Distally just "on top" of the intermetacarpal ligament the lumen of the princeps pollicis artery approaching the bifurcation of the radial artery.

Level 214. This section is taken just dorsal to metacarpal I. Just distal to the proximal radial aspect of metacarpal II the intermetacarpal ligament approaches its attachment. This area is represented in our next section. In radial direction we see the posterior oblique ligament curving in proximo-dorsal direction with already some extensions indicating their origin from the dorso-ulnar tubercle of the trape-zium. In distal relation with these ligaments lies the radial artery.

Level 230. This section shows the attachment of the intermetacarpal ligament to the dorso-radial proximal pole of metacarpal II. The radial artery, directly overlying the posterior oblique ligament, curves proximally deep to the extensor pollicis longus.
The following sections are dorsal to the area of our interest.

Summary levels 0-230

In levels 0-50 the trapezium appeared. During its development from volar to dorsal it was at first somewhat irregular in shape to become more spherical at the area of

level 50. Beyond this level there is a strong anchorage with the flexor retinaculum by means of the radial root of the latter. This radial root is mainly attached to the volar ridge of the trapezium and its fibres run transversely in ulnar direction, covering the "front" of the flexor carpi radialis tendon. The flexor carpi radialis tendon is situated on the inner side of the trapezium. In this case this tendon consisted of two components which more or less fused together before their insertion into the second metacarpal. On the dorsal aspect the abductor pollicis longus inserts into both, the trapezium and the first metacarpal base. A clear separation with the dorso-radial ligament could not be identified.
At level 90 the anterior oblique ligament appears. It can be clearly distinguished from the radial root of the flexor retinaculum. It is our impression that the latter structure has no definite connection with the ligamentous capsular system of the first carpometacarpal joint.
Throughout the levels 115 to 174 the first metacarpal shifts to a more dorsal position in relation to the trapezium. The latter changes in shape in such a way that the articular surface slopes in a dorsal direction. At the same time the ulnar part of the trapezium forms a neck around which the metacarpal swings. At level 115 the volar jointcapsule shows a strong fibrous reinforcement. The volar-ulnar tubercle with the insertion of the conjoint ligament appears at level 148. The separation of this conjoint ligament into the intermetacarpal and posterior oblique ligament starts at level 174. At the same time the relation of these ligaments with the princeps pollicis artery, as well as the relation of the trapezium and the radial artery has been pointed out. Finally, at level 214, the posterior oblique ligament can be followed to its attachment to the dorso-ulnar tubercle of the trapezium.

Discussion

That valuable information can be gained from the detailed microscopy studies has been amply proven by *Landsmeer* (1955, 1968). Following this method an accurate information as to the ligamentous and capsular system of the first carpometacarpal joint, as well as the relation to neighbouring structures has been obtained.
Some points of importance are:
1. the typical position of the first ray;
2. the outline of shape of the trapezium with its tubercles and volar ridge;
3. the shape and prominences of the first metacarpal;
4. the ligaments and capsule of the first carpometacarpal joint as a separate system;
5. the complexity of the joint itself.

It is interesting to find a complete change of constitution of the first ray from the distal extremity via the proximal and disto-radial carpal bones to arrive at the first metacarpal.

1. The typical position of the first ray

The oblique position of the trapezium was already noted by *Bichat* (1819, 1830) and later confirmed by *Du Bois-Reymond* (1895). This oblique position is not

limited to the trapezium but involves the entire first ray starting at the wrist. Indeed the scaphoid already takes up a typical position in that it forms the radio-volar extremity of the palmar arch. By pushing forward it arrives at a subcutaneous level, thereby separating the flexor carpi radialis and radial artery. The latter two structures are running distally together in a direct volar relation to the radius just proximal to the wrist. The scaphoid separates these two and thus causes the flexor carpi radialis to run distally on the *palmar* aspect, while the radial artery comes to lie on the *dorsal* aspect. Furthermore the scaphoid forms a radial point of anchorage of the ligamentous system of the carpal tunnel. More distally the trapezium forms a continuation of the typical position of the first ray on the radial aspect of the wrist. Although it is covered by the thenar musculature, thereby loosing the subcutaneous position it accentuates the volar angulation of the distal row of the carpal bones.
Due to this position the abductor pollicis longus comes to lie at its palmar aspect separated from the extensor pollicis brevis which remains in a dorsal relation to the trapezium. The extensor carpi radialis "slides" in radial direction ending in a dorsal relation to the trapezium before it gets inserted into the dorsal metacarpal III. The extensor pollicis longus shifts over the carpi radialis longus, finally taking a more radial position to the latter and dorsal to the trapezium.

2. *The shape of the trapezium*

The trapezium changes its shape from proximal to distal. At first it has a small proximal extremity articulating with the scaphoid. Soon it becomes quadrangular with three borders: dorsal, volar and radial for attachment of ligaments and a remaining ulnar aspect articulating with the trapezoid and metacarpal II more distally. Coming to a more distal level the trapezium becomes elongated in ulno-radial direction. On the volar aspect it forms the volar ridge for the anchorage of the radial root of the flexor retinaculum and the ulnar notch for the radial attachment of the deep volar ligamentous system covering the wrist. Between this ridge and the area of the notch lies a tunnel through which the flexor carpi radialis tendon runs. This tunnel is difficult to visualize in relation to this notch as we have mentioned earlier since both are depressions. This tunnel courses from proximal to distal. It is situated just beneath the volar ridge and as such it does not really form a depression on the bony surface. The remainder of this tunnel is formed by the surrounding ligamentous structures. The volar notch is an actual depression in the bone itself. It is situated at the ulnarmost part of the trapezium just volar to the trapezium metacarpal II joint.
The proximal part of the trapezium is on its volar aspect firmly attached to the superficial and to the oblique wall of the carpal tunnel and to the deep ligamentous system covering the intercarpal joints of the wrist.
On the dorsal aspect the dorso-radial and dorso-ulnar tubercle form two elevations with a depression in between (fig. IV-12). This dorso-ulnar tubercle gives origin to the posterior oblique ligament; the dorso-radial tubercle gives origin to the dorso-radial ligament. The depression could be named the dorsal notch of the trapezium. However since this notch has no specific meaning we have not introduced any more

terms. This depression forms more or less the beginning of the pouch for the dorsal styloid process of metacarpal I. The depression is bridged by a fibrous system from which the jointcapsule takes its origin. Beyond the articulation with the trapezoid the trapezium changes its shape remarkably. It becomes beanshaped in opposite sense with the concavity on the dorsal aspect. In this way it creates a longitudinal "bar" on which the first metacarpal can ride.

The shape in proximal to distal direction can best be followed in the frontal sections. It appears more regular and spherical conforming to the distal and proximal aspects of the neighbouring bones on both sides. Again however it is peculiar in that the distal ulnar part extends distally beyond the other metacarpal bones. It forms a kind of a neck indeed. This neck is narrow and touches onto the proximal radial base of the second metacarpal. On this neck "sits" the first metacarpal and if this position was not stabilized by ligaments, especially on the ulnar aspect, one could imagine that, only taking into account the shape of the trapezium, the first metacarpal would slide in a proximo-dorsal direction. This tendency as pointed out by others (*Campbell,* 1971) is further enhanced by the action of the abductor pollicis longus.

3. The shape and prominences of the first metacarpal

The first metacarpal base in its proximal to distal development appeared as two fragments, the volar and dorsal styloid process. After fusion of these two fragments the base at first was elongated in dorso-volar direction as to form a "counter bar" to the trapezium. At this stage the dorso-radial ligament becomes inserted into the dorsal and the anterior oblique ligament into the volar aspect. Soon after its fusion the base becomes circular with a slight volar prominence, the ulnar tubercle to which the intermetacarpal and posterior oblique ligaments find their attachment.

4. The ligaments and capsule of the first carpometacarpal joint

The next important point is the capsular ligamentous system of the first carpometacarpal joint. This ligamentous system arises entirely from the trapezium itself: the origin of the posterior oblique ligament on the dorso-ulnar tubercle, the dorso-radial ligament from the dorso-radial tubercle and the anterior oblique ligament from the volar tubercle of the trapezium. In this system we did not see any interference from the outside ligamentous system of the carpal tunnel area nor from the dorsal aspect of the wrist joint. Two exceptions should be obvious. The first is the abductor pollicis longus which, prior to its insertion to the first metacarpal, reinforces with the infratendinous layer of its sheath the palmar aspect of the jointcapsule. Secondly the intermetacarpal ligament which creates a direct connection between the first and second metacarpal base. Prior to its insertion it joins the posterior oblique ligament, forming a conjoint tendon. This intermetacarpal ligament forms the only connection with the neighbouring metacarpal II. In this respect the first carpometacarpal joint forms a separate unit indeed. The shape of the trapezium is noteworthy. It is rather irregular from ulnar to radial and from proximal to distal. In the proximal part its main adaption lies in its relation to the trapezoid on its volar aspect. It conforms to the general arch of the carpal bones.

5. The complexity of the joint itself

The joint itself is rather peculiar in shape, especially the levels 687 and 688 demonstrate a crosswise arrangement at the junction (figs. II-16, 17). A complete lack of congruency is obvious. This was noted already from the beginning till the end of the joint space at all levels in between. Due to the abundance of "free" articular surface a wide range of motion of the first metacarpal must be possible, both in radio-ulnar direction and in proximal and distal direction on the dorsal and volar aspect of the trapezium. Due to the different curvatures of the joint surfaces such as in level 681 (fig. II-15) one can theoretically visualize a rotation of metacarpal I around its longitudinal axis. A detailed motion analysis however is not appropriate in this context.

Fig. II-1

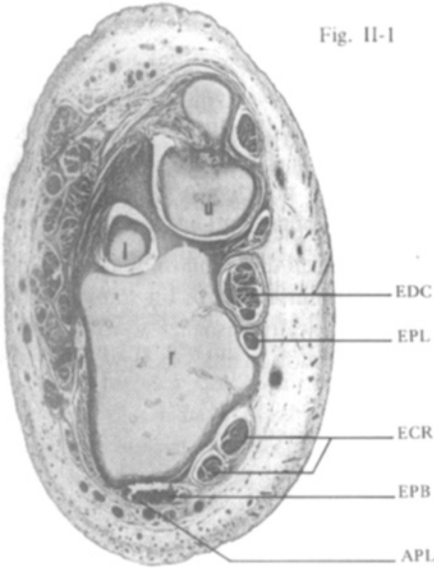


Fig. II-3

Fig. II-2

Fig. II-4

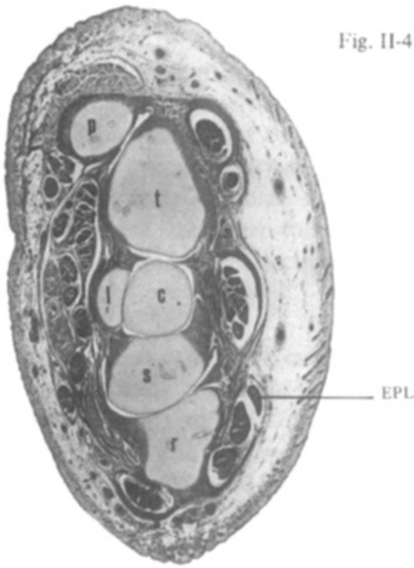


Fig. II-1. Level: 0 (neg. no. 23509)
Transverse section through the distal end of the forearm and proximal part of the wrist.

Fig. II-2. Level: 72 (neg. no. 23510)
Transverse section through the distal radius and proximal carpal row.

Fig. II-3. Level: 146 (neg. no. 23508)
Transverse section just distal to Lister's tubercle.

Fig. II-4. Level: 179 (neg. no. 23507)
Transverse section demonstrating the extensor pollicis longus (EPL) starting to move across the extensor carpi radialis (ECR). The radius separates the abductor pollicis longus (APL) and extensor carpi radialis (ECR).

Fig. II-5

Fig. II-6

Fig. II-7

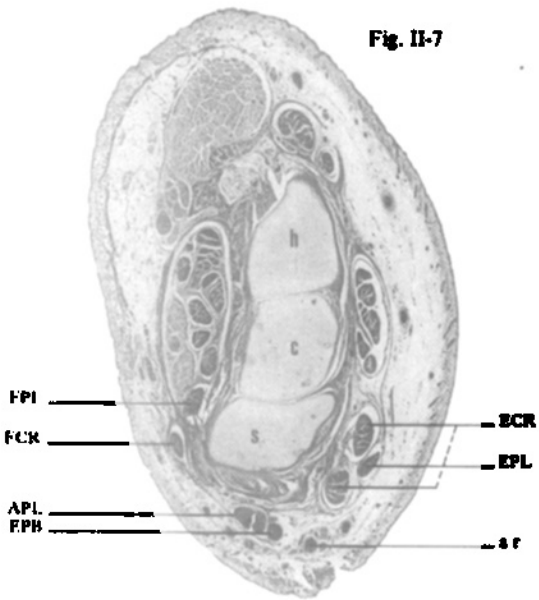


Fig. II-8

Fig. II-5. Level: 201 (neg. no. 23506)
Transverse section demonstrating the central location of the capitate in the wrist joint.

Fig. II-6. Level: 274 (neg. no. 23505)
Transverse section through the distal extremity of the radius.

Fig. II-7. Level: 290 (neg. no. 23820)
Transverse section demonstrating the relation of the tendons to the scaphoid. The radial artery (ar) is situated in the subcutaneous area.

Fig. II-8. Level: 362 (neg. no. 23504)
Transverse section showing the subcutaneous position of the scaphoid separating the flexor carpi radialis (FCR) and abductor pollicis longus (APL).

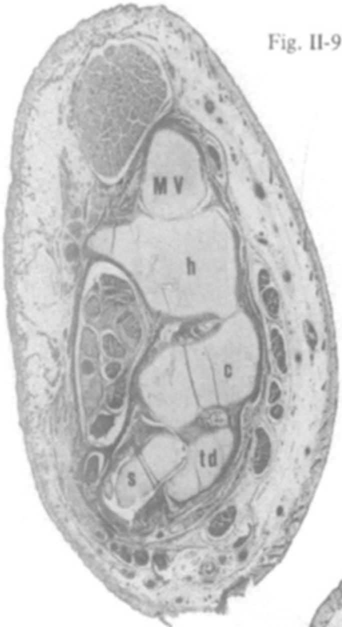


Fig. II-9

Fig. II-10

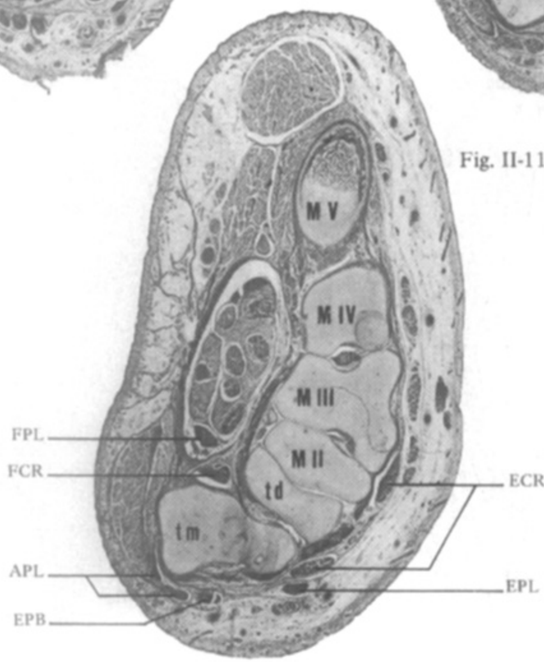


Fig. II-11

Fig. II-9. Level: 441 (neg. no. 23817)
Transverse section demonstrating the first sign of the trapezium as well as the development of the thenar musculature volar to the scaphoid and the trapezoid (td) on the dorsal aspect.

Fig. II-10. Level: 521 (neg. no. 23818)
Transverse section showing the arcading pattern of the wrist bones. The trapezium "angulating" volarly. The volar aspect "lodges" the flexor carpi radialis tendon.

Fig. II-11. Level: 604 (neg. no. 23819)
Transverse section through the mid-portion of the trapezium which is changing its shape. Note the relation of the tendons to the trapezium.

Fig. II-12

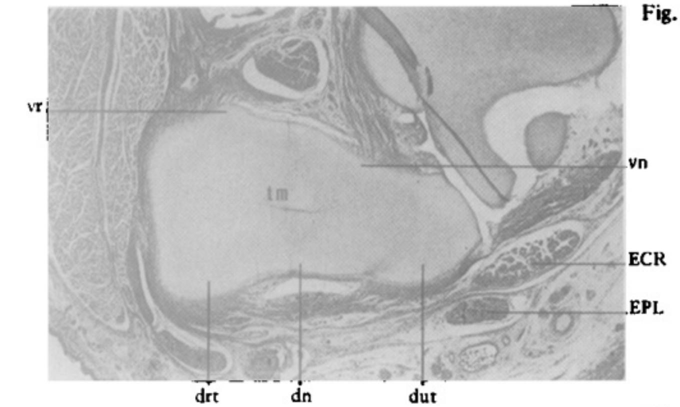


Fig. II-13

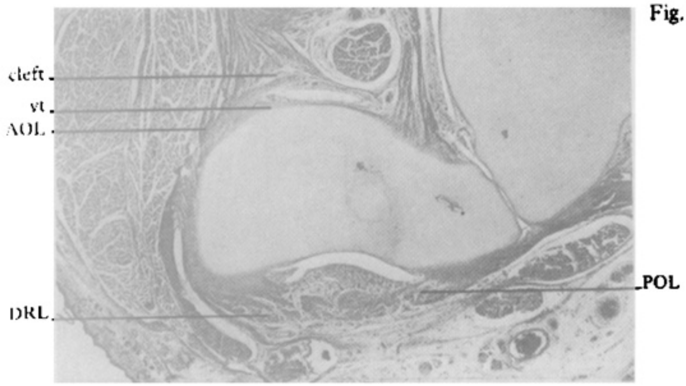


Fig. II-14

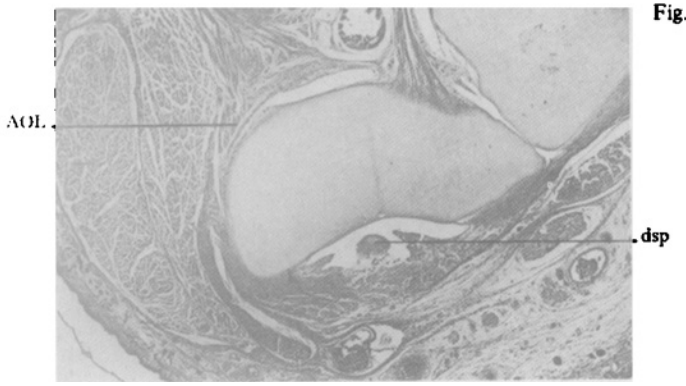


Fig. II-12. Level: 622 (neg. no. 23620)
Transverse section showing the bony details of the trapezium (tm) and the names which have been introduced (see list of abbr.)

Fig. II-13. Level: 652 (neg. no. 23632)
Transverse section demonstrating volarly the developing cleft in the radial root of the flexor retinaculum and the course of the fibres of the latter; dorsally the first sign of the posterior oblique ligament (POL) and the dorso-radial ligament (DRL).

Fig. II-14. Level: 661 (neg. no. 23633)
Transverse section showing the appearance of the dorsal styloid process (dsp).

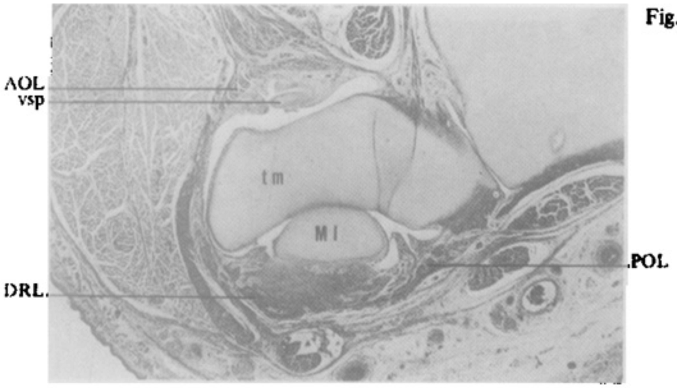


Fig. II-15

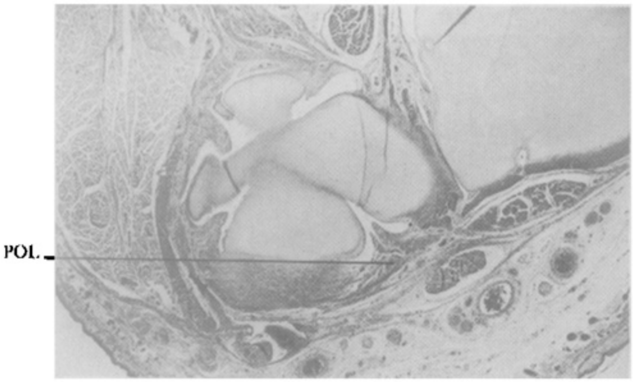


Fig. II-16

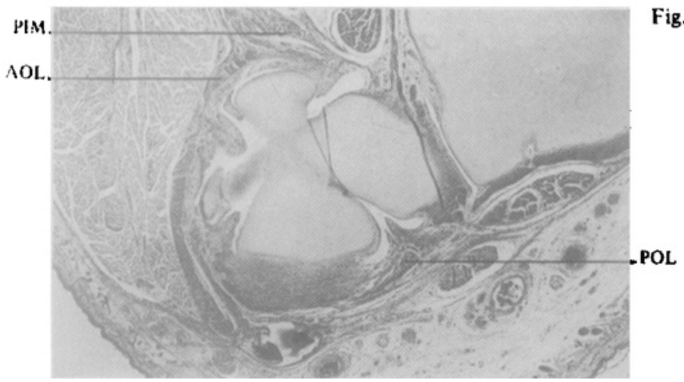


Fig. II-17

Fig. II-15. Level: 681 (neg. no. 23635)
Transverse section showing volarly the appearance of volar styloid process of metacarpal I (vsp) and the anterior oblique ligament (AOL); dorsally the insertion of the dorso-radial ligament (DRL). The greater part of the trapezium (tm) is intracapsular.

Fig. II-16. Level: 687 (neg. no. 23636)
Transverse section demonstrating the relation of the posterior oblique ligament (POL) with the dorsal jointcapsule.

Fig. II-17. Level: 688 (neg. no. 23637)
Transverse section showing the fusion of the volar and dorsal fragments of metacarpal I. A fibrous bundle representing the first palmar interosseus muscle (PIM).

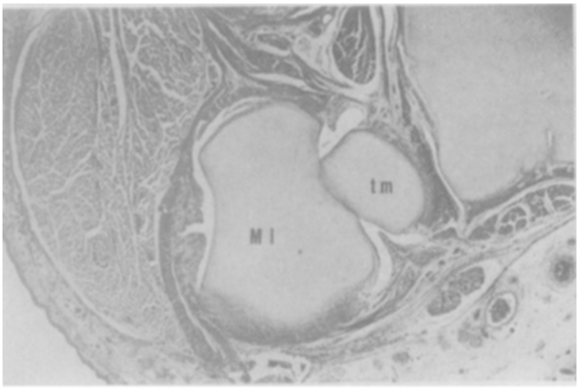


Fig. II-18

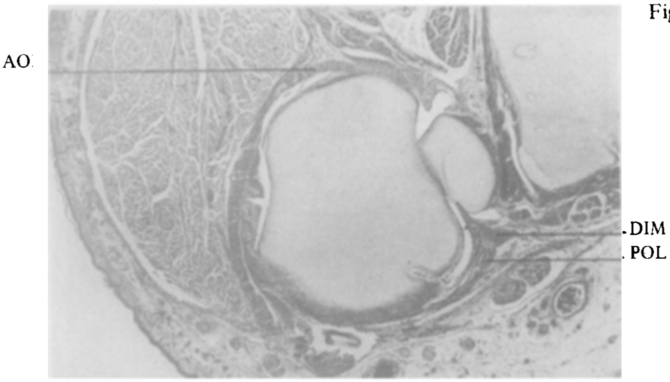


Fig. II-19

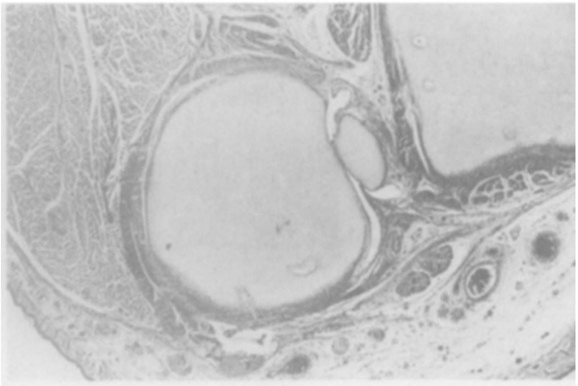


Fig. II-20

Fig. II-18. Level: 701 (neg. no. 23639)
The radial fragment of the trapezium has disappeared and the elongated shape of metacarpal I in dorso-volar direction is shown.

Fig. II-19. Level: 713 (neg. no. 23640)
The strong fibres of the trapezium–metacarpal II joint which remain separate from the first carpometacarpal joint.

Fig. II-20. Level: 730 (neg. no. 23641)
The insertion of the anterior oblique ligament (AOL) in the area proximal to the volar-ulnar tubercle. The posterior oblique ligament (POL) pushing in ulnar direction.

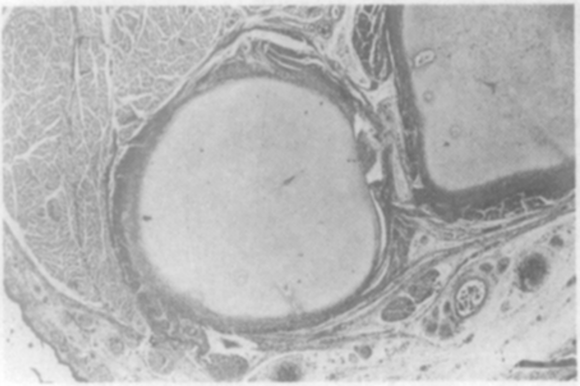


Fig. II-21

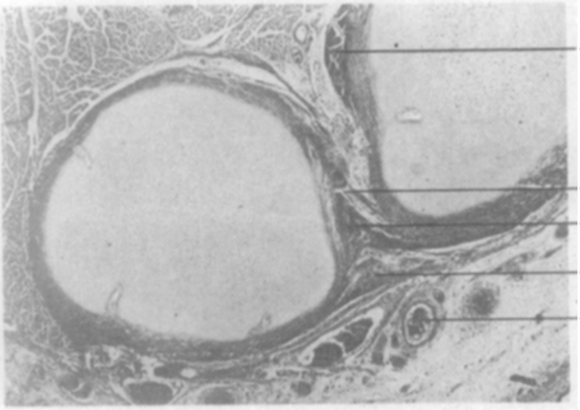


Fig. II-22

Fig. II-21. Level: 752 (neg. no. 23643)
The trapezium has vanished completely. The abductor pollicis longus (APL) inserting into the palmar aspect of metacarpal I of the posterior oblique ligament (POL) moving towards the interspace between metacarpal I and metacarpal II.

Fig. II-22. Level: 774 (neg. no. 23816)
The posterior oblique ligament (POL) in the interspace between metacarpal I and metacarpal II being joined by the intermetacarpal ligament (IML). The insertion of flexor carpi radialis (FCR) into volar aspect of metacarpal II and the origin of the first dorsal interosseus muscle (DIM).

Fig. II-23

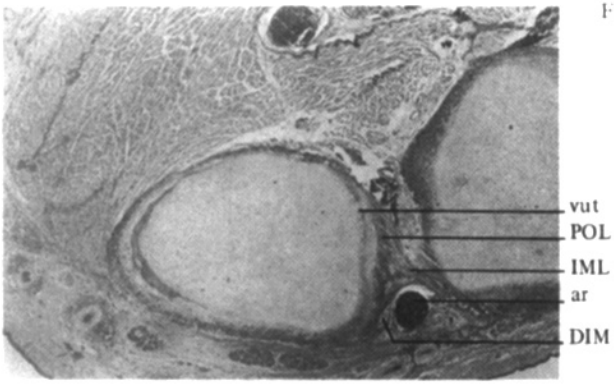


Fig. II-24

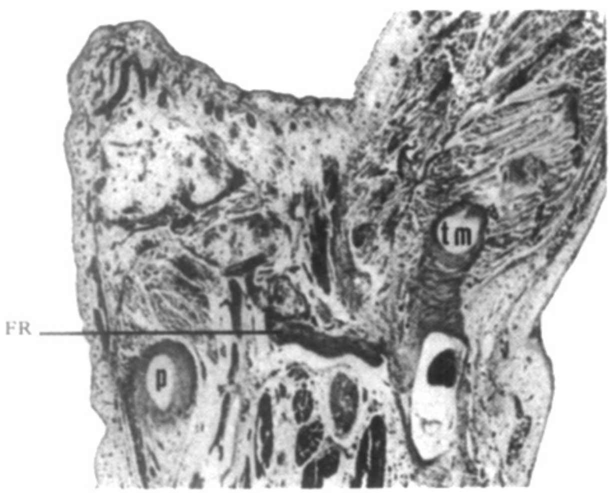


Fig. II-23. Series 1900 (neg. no. 23776)
Corresponding to level 812 of series 2318. Transverse section showing the normal direct dorsal relation of the radial artery (ar) to the posterior oblique ligament (POL). The insertion of the conjoint posterior oblique ligament (POL) and intermetacarpal ligament (IML) becoming attached to the volar ulnar tubercle of the first metacarpal base. The development of the first dorsal interosseus muscle (DIM) between the radial artery and metacarpal I.

Fig. II-24. Level: 0 (neg. no. 23815)
Frontal section through right hand at the level of the pisiforme, trapezium and flexor retinaculum (FR).

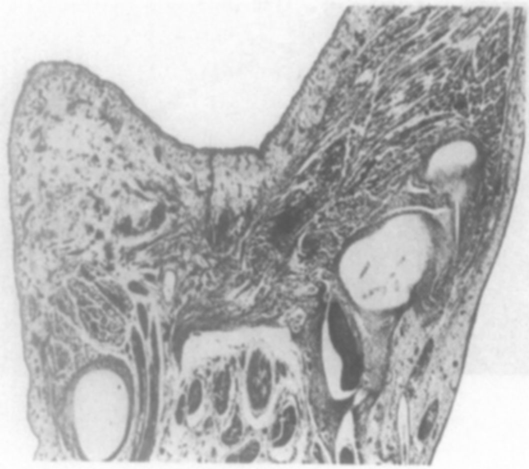


Fig. II-25

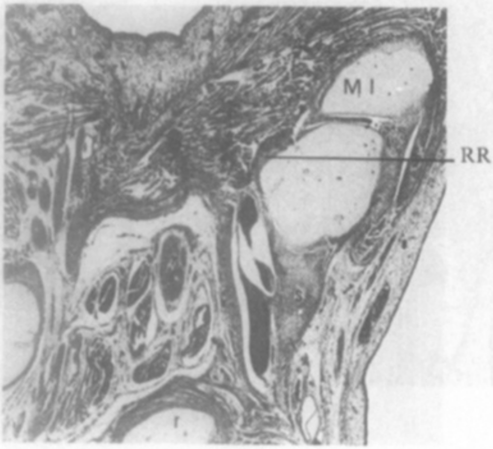


Fig. II-26

Fig. II-25. Level: 21 (neg. no. 21725)
Frontal section showing the appearence of metacarpal I.

Fig. II-26. Level: 34 (neg. no. 21731)
Frontal section showing the very first sign of the scaphoid and the volar ridge with a fibrous structure representing the "radial root" (RR) of the flexor retinaculum.

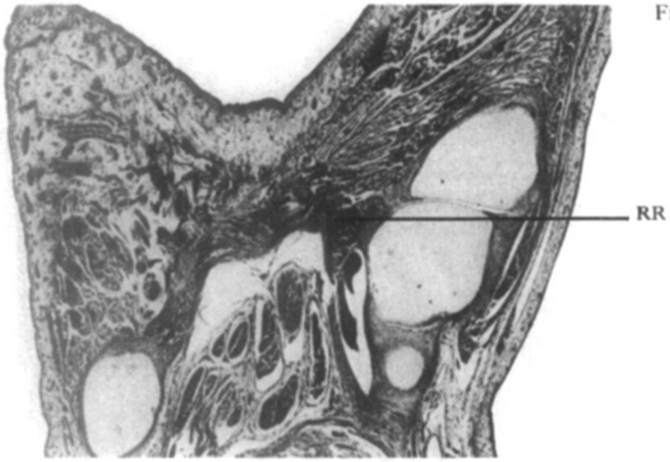


Fig. II-27

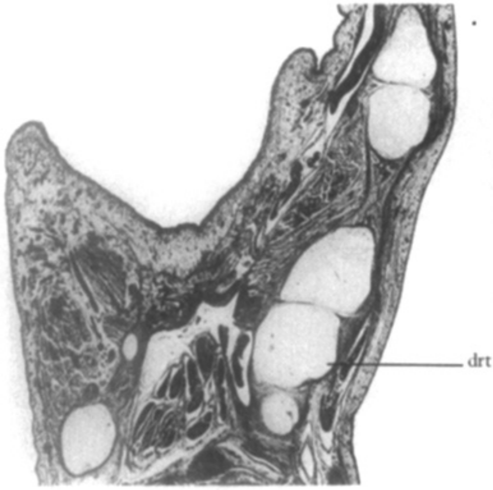


Fig. II-28

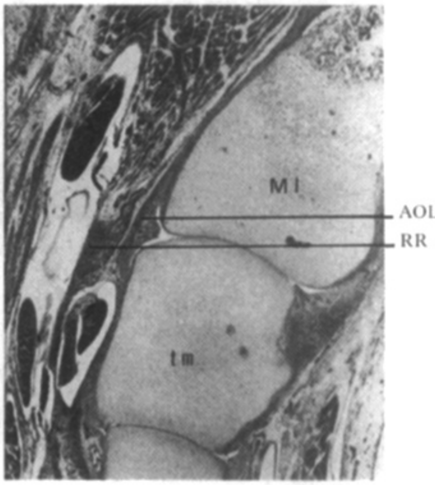


Fig. II-29

Fig. II-27. Level: 50 (neg. no. 21726)
Frontal section showing the development of the radial root of the carpal tunnel (RR).

Fig. II-28. Level: 62 (neg. no. 21727)
The appearance of the dorso-radial tubercle (drt) of the trapezium. On the volar aspect of the different direction of fibres of the radial root (RR) of the flexor retinaculum and the volar jointcapsule of the first carpometacarpal joint.

Fig. II-29. Level: 90 (neg. no. 17706)
The volar jointcapsule of the first carpometacarpal joint shows reinforcement by the anterior oblique ligament (AOL). The latter is clearly separated from the radial root (RR) of the flexor retinaculum.

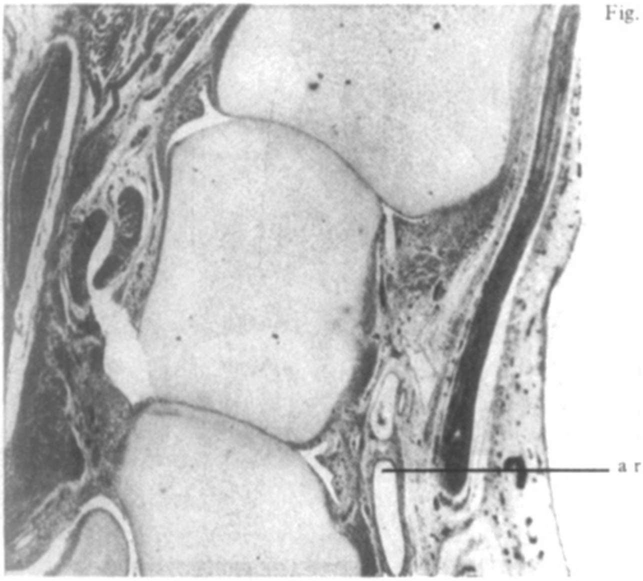


Fig. II-30

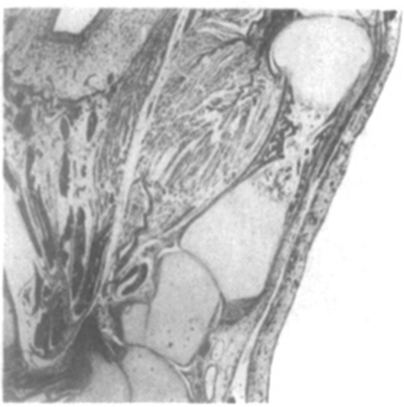


Fig. II-31

Fig. II-30. Level: 115 (neg. no. 17708)
The reinforced volar and loosely arranged dorsal capsule of the first carpometacarpal joint.

Fig. II-31. Level: 134 (neg. no. 23811)
The altered shape of the trapezium, the appearance of the trapezoid and the relation with the radial artery is shown.

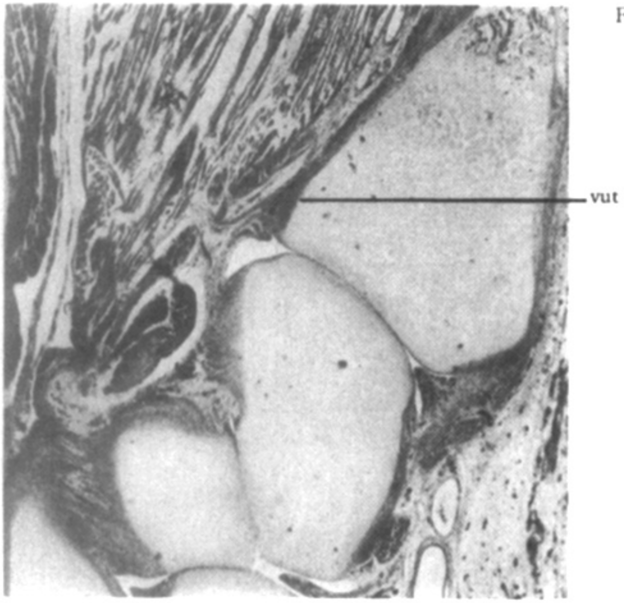


Fig. II-32

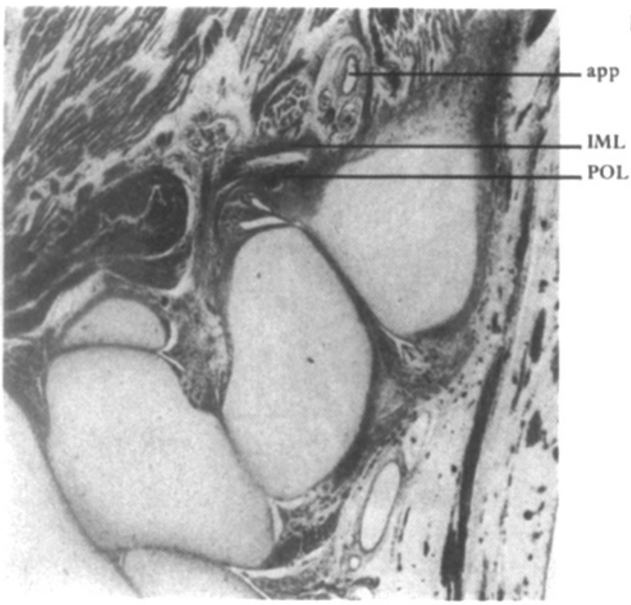


Fig. II-33

Fig. II-32. Level: 148 (neg. no. 17709)
The appearance of the volar ulnar tubercle (vut) with the "conjoint" ligament.

Fig. II-33. Level: 174 (neg. no. 17710)
The two parts of the conjoint ligament, the posterior oblique ligament (POL) and the first intermetacarpal ligament (IML).

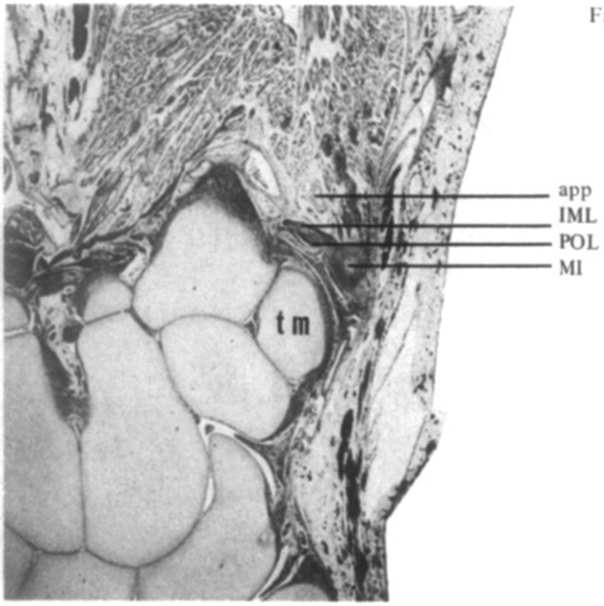


Fig. II-34

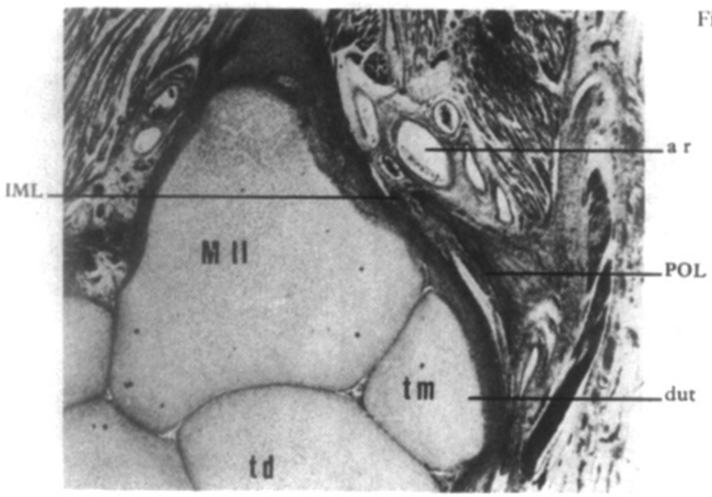


Fig. II-35

Fig. II-34. Level: 210 (neg. no. 23814)
The ulnar remnants of metacarpal I and the distal relation of the arteria princeps pollicis (app) to the intermetacarpal ligament (IML).

Fig. II-35. Level: 214 (neg. no. 17711)
The posterior oblique ligament (POL) and intermetacarpal ligament (IML) approaching their origin. The distal relation of the radial artery (ar) with these ligaments.

Fig. II-36

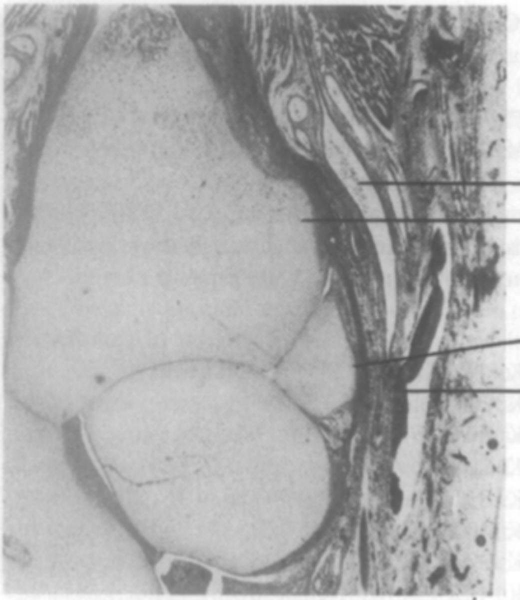


Fig. II-36. Level: 230 (neg. no. 17712)
The ulnar part of the trapezium with the attachment of some fibres of the posterior oblique ligament (POL) to the dorso-ulnar tubercle (dut). The dorso-distal relation with the radial artery "curving" over the posterior oblique ligament (POL).

CHAPTER III

SYSTEMATIC DISSECTION OF THE FIRST CARPOMETACARPAL JOINT AREA

Following the study of the microscopy we have extended our findings with gross anatomical dissection of the first carpometacarpal joint and ligaments.

Material used

1. Adult R hand, specimen 259, WK. 807
2. Adult R hand, specimen 284, WK. 1913
3. Adult R hand, specimen 287, WK. 2019
4. Adult L hand, specimen 298, WK. 2630
5. Adult R hand, specimen 312, WK. 3316
6. Adult L hand, specimen 336, WK. 4030
7. Adult R hand, specimen – WK. 3247
8. Adult R hand, specimen 356, WK. 4135

Although the bones were studied at the end of the dissection, we felt that it would be more logical to consider these first. The description of ligaments and joint capsule is thus facilitated and easier understood.

a. Trapezium and metacarpal I

The specimen used were the trapezium and metacarpal I of an adult right hand (WK. 3247).

Trapezium

The usual description given is mainly concerned with a rough outline of the joint surfaces. The trapezium forms a link in the first ray between the scaphoid proximally and the base of metacarpal I distally. On the ulnar aspect it articulates with the trapezoid mainly and it has a small articular facet situated more distally for the second metacarpal bone.

The distal half of the trapezium and the base of metacarpal I were approached in much more detail, in view of getting a clear understanding of the exact arrangement of ligaments and especially the relations with the points of anchorage to the joint surface.

It is difficult to visualize a carpal bone by itself, therefore, the position of the trapezium in relation to the other carpal bones will be outlined with the aid of a skeleton drawing (fig. III-3). Looking at this joint from a volar-ulnar direction one gets indeed the impression of a saddle (fig. III-1b). The curvatures are mainly concave in the radio-ulnar direction and convex in the dorso-volar direction. The model of a saddle implies a certain aspect of symmetry. By just looking closely at

this joint surface one will have to admit that the joint surface is assymmetrical. One can readily see that the articulating surface is mainly located at the volar aspect (fig. III-1a). Radially the volar aspect is wide and it flares out in proximal direction, forming a plateau with a slight ridge thus raising the articular surface. Against this ridge budges the volar styloid process of the first metacarpal in extreme position of "flexion". The dorso-volar convexity in this area is very slight. The convexity increases till it becomes marked very near its summit. One gets the impression of a neck around which a collar can slide. Such a motion, as will be seen later, has only a very limited application.
The concavity in radio-ulnar direction is most marked on the ulnar side (fig. III-1). In this area in proximal direction this concavity persists all the way till the volar tubercle. On the radial side the concavity changes into a convexity (fig. III-1). The dorsal surface is rough and irregular and has two elevations. One is located radially and the other on the ulnar side. We propose to name these elevations, the *dorso-radial* and the *dorso-ulnar* tubercle of the trapezium according to their positions (fig. III-1a). On the volar aspect there is an elevation with a prominent tuberosity. The latter has been named the tuberculum of the trapezium (*Nomina Anatomica*, 1967). Since a more precise nomenclature is needed, we propose to add the prefix volar. We will henceforth call this tuberculum, the *volar tubercle* of the trapezium and the elevation we propose to call the *volar ridge* of the trapezium (fig. III-1b, c).
Adjacent to the volar ridge, "deeper" into the wrist, the trapezium has a groove for the tendon of the flexor carpi radialis (fig. III-1b). This groove runs along the trapezium parallel to the volar ridge. Together with the volar ridge it occupies approximately half of the volar nonarticulating surface of the trapezium. Furthermore, situated still deeper into the wrist, another depression can be seen. This depression was mainly noticable in the microscopy slides (fig. II-10) rather than on the gross specimen. This area is irregular and serves for the attachment of the deep carpal ligaments. We propose to call this depression the *volar notch* of the trapezium (fig. III-1).

Metacarpal I

The first metacarpal has a rather flat dorsal aspect and as such resembles the four other metacarpal bones. This dorsal aspect could be divided by a median plane, through the "center" of the head and the dorsal styloid process, perpendicular to the dorsum of metacarpal I in volar direction through the volar styloid process. Thus a fairly symmetrical ulnar and radial half results. A division parallel to the dorsal plane results in a rather dissimilar dorsal and volar half. For the interpretation of the X-rays in chapter IV an accurate knowledge of the first metacarpal is mandatory. Therefore a detailed description of the head, the shaft and the base will be given.

The head
Viewed from the volar aspect the head is somewhat dome shaped in its central aspect. On each side it has a small prominence, the radial and ulnar tubercle. The

ulnar tubercle is somewhat more prominent and this is partly due to the widening of the distal part of the shaft which occurs mainly in ulnar direction.
Viewed from the side the head is rather flat dorsally and this aspect appears to be a continuation of the shaft. In volar direction the head shows a sloping curve extending well beyond the width of the shaft. This accounts for a radial and an ulnar condylar process. These condyles have a "sharp" point and subsequently a recession takes place causing a curvature in the opposite direction running smoothly to the narrower shaft (fig. III-2).

The shaft
The ulnar half of the shaft is slightly curved when viewed from the volar aspect causing a "waist" at the junction of the proximal 1/3 and distal 2/3. Then the shaft flares out mainly in ulnar direction and running a fairly straight course on the radial side. Viewed from the side the dorsum is an almost straight line while the volar aspect is smoothly curved widening more suddenly at the head and somewhat less acute at the base (fig. III-2).

The base of metacarpal I
At the proximal volar aspect of the base of metacarpal I, there is a bony prominence. This prominence has no ligamentous attachements, it is actually situated intracapsularly. Since we refer to this prominence later because of its function we propose to call this prominence, the *volar styloid process* of the base of metacarpal I (fig. III-2). Slightly distal to the rim to which the volar capsule is inserted another prominence is present, referred to by *Haines* (1944) as a "bony elevation". We propose to name this elevation the *volar-ulnar* tubercle of the base of the first metacarpal (fig. III-2). Dorsally the base of metacarpal I forms a broad margin. The most proximal extremity, for reasons given above, we propose to call the *dorsal styloid process* of the base of metacarpal I. Viewed from the side the round dorsal styloid process forms a continuous line with the dorsal aspect of the shaft. The volar styloid process forms a sharp point and extends further proximal than the dorsal styloid process.

The joint surface

The proximal joint surface of metacarpal I is asymmetrical as well. The base of the first metacarpal can be considered as part of a ball surface, representing the convexity of the first carpometacarpal joint. In this surface a groove is present in radio-ulnar direction. This groove forms the concavity of the joint surface. The groove is deepest in the center and becomes shallow at the radial and ulnar extremity. In the center this groove flares out forming a widening of the joint surface in volar direction. Consequently we are left with a joint surface which is convex in dorso-volar and concave in radio-ulnar direction.

b. Soft tissues

After removal of skin, superficial fascia and deep fascia, the extensor pollicis longus and brevis on the dorsal aspect and the thenar musculature and the flexor pollicis

longus on the volar aspect were identified. In all specimen these structures were carefully removed.
For further detailed dissections, the dissecting microscope was used in all instances to avoid unnecessary damage to important structures. In the specimen 284 and 287, ligaments and jointcapsule were approached from a dorsal and a volar direction to study the relation of the ligamentous structures, tendons, arteries, thenar musculature and the dorsal interosseus muscle.

Dorsal approach: Adult R hand, specimen 284, WK. 1913 (fig. III-4, 5).
After removal of skin, superficial fascia and superficial viens, the radial nerve can be seen crossing deep to the junction of the superficial veins. Then a deeper situated artery comes into view disappearing to the palmar aspect of the index finger, originating directly proximal and underneath the extensor pollicis longus from the radial artery.
The extensor pollicis longus has an additional slip coming from the extensor indices proprius. It runs in its sheath underneath the extensor retinaculum (lateral to *Lister's* tubercle) and joins the extensor pollicis longus at the metacarpalphalangeal joint of the thumb. The radial artery continues by curving forward into the interspace between metacarpal I and metacarpal II. On its deep aspect, it is directly related to the trapezium the latter being covered by the posterior oblique ligament. In its forward course the artery follows this ligament. On its lateral aspect it borders the medial aspect of the base of metacarpal II. At this point metacarpal II gives off the first intermetacarpal ligament. The latter structure separates the artery from the base of metacarpal II. After having given off a branch to the index finger, the radial artery disappears into the superficial fascia of the first dorsal interosseus muscle. On its lateral aspect the artery is accompanied by a small vein. The lateral aspect of the base of metacarpal I and the medial aspect of the base of metacarpal II give origin to the first dorsal interosseus muscle. These two components join together just distal to the radial artery after the latter has pierced the superficial muscular fascia. Thus an arcade has been formed creating a separate compartment for the radial artery (fig. III-5).
Immediately after perforating the superficial muscular fascia the radial artery gives off a branch which runs in distal direction supplying the first dorsal interosseus muscle.
Arriving at the deep muscular fascia the radial artery gives off the princeps pollicis artery which runs in a volar direction. It curves distally to supply the thumb. The radial artery continues in a latero-volar direction to form the deep distal arterial arcade of the palm of the hand.
From this dorsal aspect the radial artery disappears out of sight. Lifting the radial artery out of its bed and carefully removing the perivascular sheath one can see the dorsal ligamentous structures on the trapezium (fig. III-5, 6).
Before we go on with our deeper dissection we will first approach the joint from the other side.

Volar approach: Adult R hand, specimen 287, WK. 2019.
The skeletal ligamentous structures as well as the neurovascular bundle are covered by the thenar musculature. Except for the adductor pollicis these muscles are carefully removed, starting at the radial aspect of the thumb, from their insertion into the first metacarpal and reflected in proximal direction. The deeper structures then come into view. We note a very complex interwoven ligamentous structure in the area of the volar aspect of the first carpometacarpal joint, and of the carpometacarpal joint area of the second ray (fig. III-8). The fibrous structure is coming from ulnar and anchores into the crest of the trapezium. This structure has been named the *radial root* of the flexor retinaculum (*Landsmeer*, 1971). From this radial root of the flexor retinaculum ligamentous fibres go out running in distal direction towards the first metacarpophalangeal joint. In their distal course they branch out to circumvent the princeps pollicis artery together with the nerve of the thumb. The princeps pollicis artery becomes volar after the bifurcation of the radial artery in the first intermetacarpal space. It then curves around the proximal border of the adductor pollicis muscle and follows its course in distal direction to supply the thumb. The ligamentous structures around the first carpometacarpal joint at this level are not as outspoken as seen on the dorsal aspect.

We now come to the deeper structures. Therefore the thenar musculature including the insertion of the adductor pollicis muscle on the volar aspect and the first dorsal interosseus muscle on the dorsal side are removed carefully from their origin without damaging the ligaments around the first carpometacarpal joint. The flexor pollicis longus tendon is also removed. The radial artery is once more closely inspected. It lies in a direct relation with the dorso-ulnar aspect of the first carpometacarpal joint. As we will see later it lies directly on top of the posterior oblique ligament and crosses the first intermetacarpal ligament. It then bifurcates in the deep palmar arch and the princeps pollicis artery. The artery is now removed. Viewing the area once more from the volar aspect, one will note that the fibrous structures which appear to originate from the radial root of the flexor retinaculum run distally to become inserted into the first metacarpal bone. This structure is of a fascia-like or membranous nature. It attaches into bone just proximal to the first metacarpophalangeal joint, at the volar aspect.

The ligaments

The attachments of the ligaments as well as the direction of their fibres around the first carpometacarpal joint are as important as the shape of the joint surfaces themselves. Although there is an individual variation of these ligaments, a general pattern can be recognized. In the literature many of these ligaments are described. However, a specific detailed analysis is not encountered. *Henle* (1856) describes a separate volar carpometacarpal ligament.
Haines (1944) has named this ligament the anterior oblique ligament. In our further discussion we prefer to adhere to the name anterior oblique ligament.

A. The anterior oblique ligament (fig. III-8, 9)
In our material used we could always identify a volar carpometacarpal ligament. This ligament originates from the volar tubercle of the trapezium and it inserts on the volar ulnar tubercle of the base of metacarpal I (fig. III-10). It is broad and strong. This ligament has probably been referred to by *Haines* as the anterior oblique ligament. The course of the fibres, running in an oblique direction from proximo-radial to disto-ulnar, can be readily seen by a slight internal rotatory twist of the metacarpal I. Sometimes these anterior oblique fibres merge with the capsular fibres, running in a "curtain" like fashion, covering the entire ulno-volar width of the joint. This may cause a misleading impression that the anterior oblique ligament is absent. Viewing the joint from an ulno-volar angle and at the same time with the metacarpal I in lateral position, the anterior oblique ligament runs straight across. Fibres of the joint capsule, of both ulnar and radial sides, appear in a V-shaped fashion. The fibres insert close to the articular cartilage of the volar aspect of the first metacarpal. The first intermetacarpal ligament inserts slightly distal to the capsule into the volar ulnar-tubercle.
In comparing both anatomical findings with our microscopy slides, we can say that the anterior oblique ligament arises in close relation to the volar jointcapsule from the volar tubercle of the trapezium. This ligament is inserted into the volar-ulnar tubercle of the base of metacarpal I.

B. The abductor pollicis longus tendon (fig. III-8)
A second important structure, which is partly volarly situated, is the tendon insertion of the abductor pollicis longus. Its tendon sheath covers the radio-volar aspect of the first carpometacarpal joint. Actually, the abductor pollicis longus tendon sheath fibres crossing the joint are not simply originating and inserting on each side of the joint. They are really coming from the infratendinous layer of the tendon sheath, from proximal and radiate into the palmar aspect of the trapezium. They pass on the radio-volar aspect of the base of the first metacarpal. Because of their close relationship to the joint, they are functioning as somekind of a "collateral" ligament. The course of the fibres of the abductor pollicis longus tendon and its sheath in this particular function are not discussed in *Henle's* work (1856). However, a drawing on page 99 gives some indication that he noted the insertion of the abductor pollicis longus to be in close relation to the joint.
Dissecting further in radial direction (specimen 287), one finds the insertion of the abductor pollicis longus tendon. After removing its covering tendinous sheath, three separate tendon bundles appear. Only the two most lateral bundles merge distally with the jointcapsule and insert into the volar aspect of the base of the first metacarpal. The third tendinous portion appears to be more adherent with the tendon sheath. After removing the tendon sheath carefully, some fibres of this strand are observed to insert into the volar aspect of the trapezium. Thus they end proximal to the first carpometacarpal joint capsule. A small portion however, which is situated laterally, crosses the first carpometacarpal joint and merges with the insertion of the jointcapsule into the volar aspect of the base of the first metacarpal. Pulling on this third part of the tendon the only motion of the metacarpal is

a slight abduction. Pulling on the two tendinous portions crossing the joint the metacarpal abducts strongly. In specimen 312 the abductor pollicis longus tendon consists of only one strong bundle. In this specimen it does not insert into the trapezium, as was noted in the other specimen. There is a strong ligament which is situated deeply, which actually is a part of the infratendinous layer of the tendon sheath, and is proximally attached to the radio-dorsal aspect of the trapezium, close to the articular cartilage. Distally it is attached to the proximo-radial aspect of the base of the first metacarpal at a little distance of the articular surface.
Thus we can say that a multiple insertion of the abductor pollicis longus is not an exception.

C. The dorso-radial ligament (fig. III-6, 11)
Approaching the first carpometacarpal joint area from a dorsal direction, a strong ligamentous structure can be separated from the joint capsule. It originates from the dorso-radial tubercle of the trapezium. It runs in a fanshaped fashion to the dorsal edge of the first metacarpal base so that the distal attachment is wider than the proximal. The ligament is situated in between the abductor pollicis longus insertion and the posterior oblique ligament, and was called the radial ligament of the first carpometacarpal joint (*Haines*, 1944). It has been referred to simply as the collateral ligament and lateral ligament. *Kaplan* agrees with *Haines*, that it is situated so much at the dorsal aspect that this fact cannot be ignored.
Furthermore this ligament was named the dorsal ligament by *Kaplan*. Combining these two terms will result in a more precise indication of its position and this in turn will prevent confusion. Therefore we propose and will henceforth call this ligament the *dorso-radial* ligament of the first carpometacarpal joint.

D. The posterior oblique ligament (fig. III-5, 7, 11)
This ligament finds its proximal attachment to the dorso-ulnar tubercle of the trapezium. It forms a rather distinct fairly long ligament which can be separated from the joint capsule. In specimen 312, the proximal attachment is rather wide. The ligament runs from radial, although it has a proximo-ulnar attachment to the trapezium, to curve forward, following the dorso-ulnar tubercle of the trapezium in an ulno-volar direction. It is further guided in its direction by the outline of the first metacarpal base, curving around it to become attached to the volar-ulnar tubercle of the base of metacarpal I.
As such it actually has a double curve: From proximal to distal around the trapezium in volar direction. This aspect has probably been the reason for some authors e.g. *Rouvière* to name it the semilunar ligament as its distal part curves around the ulnar aspect of the first metacarpal base from dorsal to volar. This gives it an oblique appearance and is therefore probably called the posterior oblique ligament by *Haines*.

E. The first intermetacarpal ligament (fig. III-6, 7, 10, 11)
This ligament is situated in the first interspace between metacarpal I and metacarpal II. It is attached to the radial aspect of the base of the second metacarpal. It arises

from the dorsal side just beyond the insertion of the extensor carpi radialis longus tendon. We propose to call this ligament the *first intermetacarpal* ligament and use this term subsequently in our further description. The first intermetacarpal ligament usually constitutes a wide flat bundle of fibres which run in radial direction. The radial 1/3 of its legth merges with the posterior oblique ligament. In this way these two ligaments become inserted into the same volar-ulnar tubercle of the base of metacarpal I. This ligament was seen in all specimen. As noted previously directly over top runs the radial artery, curving forward into the palm of the hand.

F. The "ulnar collateral" ligament (fig. III-7)
Viewing the ligamentous and capsular structures of the first carpometacarpal joint once more from the volar aspect, another ligamentous structure comes into view in the space between the first and second metacarpal. This ligamentous structure originates from the flexor retinaculum rather than from the carpal bones. Its fibres run distally in a lateral oblique direction and also become inserted into the base of the first metacarpal on its volar aspect. It becomes tight on external rotation of metacarpal I. Its deepest fibres appear to arise also from the radial root of the flexor retinaculum, however from a slightly different area crossing the first carpometacarpal joint in a more direct line on its ulnar aspect. This ligament has probably been referred to by *Bausenhardt* as the ulnar collateral ligament. It was found to be present in specimen 255. In other specimen it could not be identified as a separate ligament. Even in specimen 255 it is difficult to separate the ulnar collateral ligament from the capsular fibrous structures. It therefore can be missed easily or it can be accounted for as a part of the ulno-volar aspect of the jointcapsule.
Thus this ligamentous structure is not always present. If present it arises from the flexor retinaculum rather than from the trapezium and finally its function is no different from the function of the ulno-volar jointcapsule. Therefore it will be discussed as to its function together with the reinforcement of the ulno-volar jointcapsule.

G. The jointcapsule (fig. III-9)
A special dissection was carried out on specimen 259 in order to get a good picture of its attachments. After removal of skin, superficial fascia, tendons, the deep fascia, the thenar musculature, the first dorsal interosseus muscle and the radial artery in the usual manner with the aid of the dissecting microscope a skeletal-ligamentous specimen was obtained. The periosteum distal to the jointcapsule is removed from the first metacarpal carefully by a periosteal elevator. The insertion of the abductor pollicis longus tendon was left intact. No other tendons are retained. On inspection the abductor pollicis longus in this specimen inserts mainly into the radial aspect of the first metacarpal base, fanning out a little in volar direction. All the ligaments described above, the posterior oblique ligament, the first intermetacarpal ligament, the anterior oblique ligament and the dorso-radial ligament could be identified.

The proximal attachment

The jointcapsule was found to be attached to the first metacarpal, adjacent to the articular cartilage. With a periosteal elevator the capsule on the first metacarpal is pushed off gently in proximal direction, then metacarpal I was removed carefully (fig. III-9). In this way the full extend of the articular capsule, inclusive the abductor pollicis longus tendon was retained. We can now look inside the joint from distal to proximal. The capsular attachment on the trapezium varies from one area to another. On the radial aspect the capsular fibres are attached adjacent to the articular cartilage. Following the capsule in dorsal direction, the fibres arise at a definite distance from the articular cartilage in the dorsal area. Here we find a pouch with a fair amount of room for the dorsal styloid process of the first metacarpal. Continuing on along the ulnar margin, the capsule on the dorsal aspect is still at a marked distance from the articular cartilage. Along the ulnar border, the capsular fibres arise closer to and at the summit of the trapezium adjacent to the joint surface.

On the volar aspect the situation is rather similar. The anterior oblique ligament divides the volar jointcapsule into two parts, the ulno-volar and the radio-volar part. Following the capsule in ulnar direction, starting at the anterior oblique ligament, it arises again at a definite distance from the articular cartilage.

On the ulno-volar side the capsule is rather thick. On the radio-volar aspect the capsule is very thin. There is very little reinforcement in this area of the anterior oblique ligament. The capsule becomes thicker when we reach the radial-most extremity of the trapezium which is the area of the insertion of the abductor pollicis longus tendon. A part of the reinforcement is actually the infratendinous layer of the tendon sheath.

The distal attachment

This distal attachment is much less complicated. As noted previously the capsule is thin at the radio-volar aspect. It inserts at a definite distance distal from the articular cartilage. These characteristics on both sides distally and proximally allow for mobility of the articular facets in this area. In radial direction we arrive at the insertion of the abductor pollicis longus. The peritendinous sheath inserts immediately adjacent to the articular surface.

The capsule is stronger and thicker on the ulno-volar aspect. The fibres insert immediately beyond the articular cartilagenous edge.

Going around in dorsal direction the capsule has more space and it inserts at a distance from the articular cartilage. In the area of the dorsal styloid process of metacarpal I the capsular fibres insert close to the joint without leaving any room on the ulnar side. On the radio-dorsal aspect, between the insertion of the abductor pollicis and the dorsal styloid process of metacarpal I, the capsule is heavily reinforced by the dorso-radial ligament.

Discussion

In the past some attention has been given to the osteology of the first carpometacarpal joint specifically with regard to the joint shape. Less attention has been given to the soft tissues, specifically in relation to its biomechanical function. It soon became clear that a more detailed documentation of bones and ligaments was mandatory.

a. Osteology

With regard to the bony structures, a more detailed nomenclature was needed to facilitate the soft tissue description as well as the X-ray interpretation.

The asymmetry of the metacarpals of the four ulnar digits is well known (*Fick R.*, 1911, *Shiino*, 1925, *Landsmeer*, 1955). The features of metacarpal I regarding the prominent ulnar tubercle and the curvature of the shaft particularly of the ulnar margin are usefull in the description of the positions as seen in the X-ray projections (chapter IV). The "saddle" joint is very asymmetrical indeed, especially the joint surface of the trapezium. The curvature of the latter can change rather suddenly from one area to the other. The flat extension of the joint surface of the trapezium in volar direction and its sudden abscence on the dorsal aspect is rather remarkable.

The joint surface of the base of metacarpal I also is asymmetrical, however, much less so than the joint surface of the trapezium. The asymmetry is further demonstrated by trying to fit the metacarpal on the trapezium in reverse direction. Much has been said about the classification of the first carpometacarpal joint.

In the first half of the 19th century, it was referred to as a ball and socket joint. Later is was set apart by *A. Fick* (1854) as the saddle joint. The typical curvatures of the joint surfaces are so complex that it is impossible to simply describe its motion pattern.

It is an old concept that the motion, which takes place in a joint much depends, among other factors, on its bony shape. Trying to fit the two bony elements together one can hardly say that there is one position in which the parts fit best. That is the joint is very unstable, however sometimes, reasonable bony contact is possible. Then the surfaces are more or less each others negative. It is most difficult to define this position and no attempt will be made at this point.

Two types of jointmotion are generally recognized, sliding and rocking. In the first carpometacarpal joint rocking, although likely because of the joint composition, does not take place. It is the sliding motion that is characteristic for this joint (*Du Bois-Reymond*, 1897). If the trapezium is considered fixed, the metacarpal easily slides in volar-dorsal direction and vice versa. Sliding in a volar direction is readily stopped by the above mentioned bony ridge. Further pressure on the metacarpal in volar direction forces the joint open at its dorsal aspect. Shifting the metacarpal backwards, there is no bony block whatsoever. The bone keeps on sliding till it looses all joint contact completely. Moving the metacarpal in ulnar and radial direction, again no bony block is encountered. Bony contact however is better maintained in this direction.

b. The significance of the ligaments

In our description of the ligaments we have mainly adhered to *Haines'* (1944) nomenclature for the anterior and posterior oblique ligaments. We have added the prefix dorsal to the radial ligament for description and discussion purposes as well as for its general use.
We have only been able to find one intermetacarpal ligament in the first interspace. Since we were unable to find two intermetacarpal ligaments there was no need to use the prefix anterior or posterior in this connection. Since the ulnar collateral ligament is very inconstant we will not consider this structure as a separate entity.
The four ligaments of the carpometacarpal joint of the thumb all are of a different length and also their insertion has an asymmetrical arrangement. As for the joint capsule, the distance of attachment of the ligaments in relation to the joint determines the amount of freedom of motion as well as the direction in which motion takes place (*Huson*, 1961).
The posterior oblique ligament is long, it arises from the dorso-ulnar tubercle of the trapezium and curves around in forward direction to become attached to the base of the ulnar aspect of metacarpal I. Its course can best be described as being that of a lazy S with a twist in the centre. The name posterior oblique ligament is actually not precise enough. However since its name has been in use already we prefer to adhere to this name. On both sides, proximal and distal, it is attached at a distance from the joint margin. Therefore we can expect a fair amount of freedom of motion on account of the posterior oblique ligament.
The intermetacarpal ligament, the existence of which has been denied by *Jones* (1946), is shorter. It runs with a straight course from the base of metacarpal II and joins the posterior oblique ligament, for its distal one third.
The anterior oblique ligament is also rather short. Its proximal attachment is rather close to the proximal joint margin at the volar tubercle of the trapezium.
The dorso-radial ligament is on both sides rather closely attached to the joint margins. It is the only strong ligament on the radial aspect and it is located only dorsally.

c. The significance of the jointcapsule

Goldner (1950) stresses the prevention of soft tissue contractures and joint changes in the paralytic thumb. These contractures imply a strong capsular and ligamentous apparatus around the first carpometacarpal joint of the thumb.
As to the normal functional aspect of the jointcapsule, we can say that the joint will move more freely in the area in which the capsule is inserted at a distance from the articular cartilage (*Huson*, 1961). In the areas where there is little room left, the joint excursion is severely limited. The articular facets soon get caught into the ligamentous reinforced capsule.
At the site of attachment on the metacarpal I there are three areas in which very little or no distance is left. These are the dorsal proximal styloid process of metacarpal I, the infratendinous layer of the tendon sheath of the abductor pollicis longus and the volar ulnar capsular reinforcement.
At the site of attachment on the trapezium similar areas can be detected. These are

the ulnar volar capsular reinforcements including the joint area between trapezium and metacarpal II and the infratendinous layer of the tendon sheath of the abductor pollicis longus.

In conclusion the remarkable features of the ligamentous and capsular structures are a heavy concentration of the ligaments on the volar ulnar and the dorsal radial aspect of the metacarpal base. In the same areas the jointcapsule, both proximal and distal, is inserted close to the articular surface.

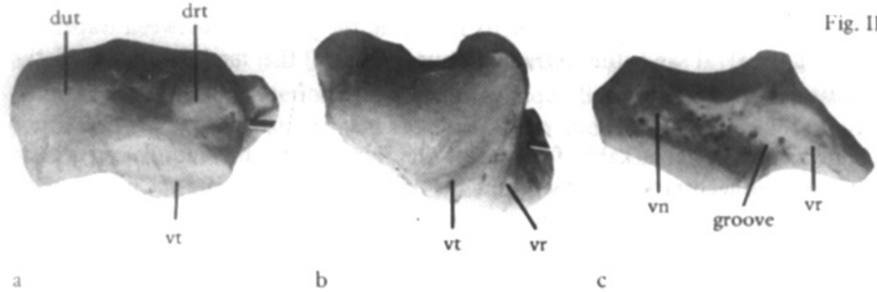


Fig. III-1

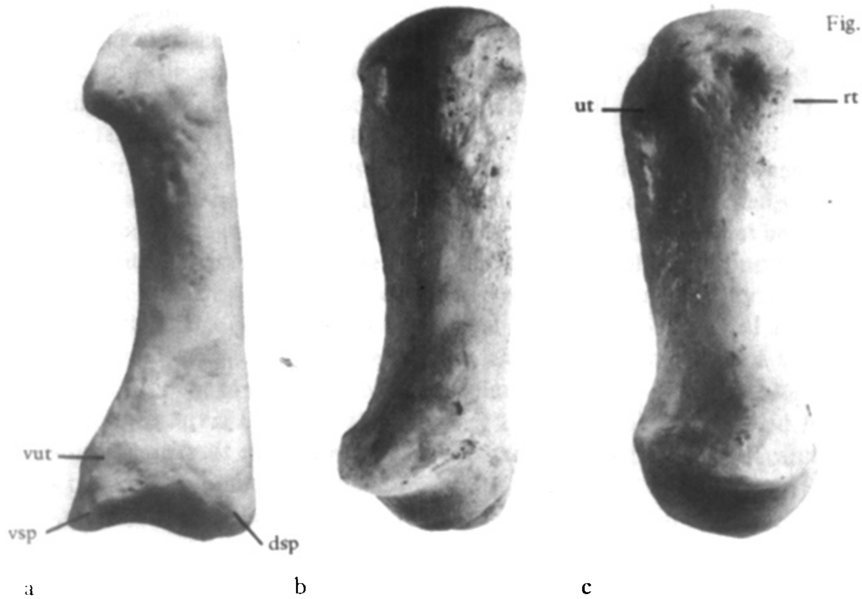


Fig. III-2

Fig. III-1.
a. (neg. no. 23740). Right trapezium distal to proximal view. The joint surface is located on the volar aspect of the trapezium. On the ulnar aspect the convex curvature is much more marked in comparison with the radial side. The bony landmarks are the volar tubercle (vt), the dorso-radial tubercle (drt) and the dorso-ulnar tubercle (dut).
b. (neg. no. 23741). The volar aspect showing the irregular volar ridge (vr) and the volar tubercle (vt).
c. (neg. no. 23742). Viewed from a volar-ulnar direction. The groove which guides the flexor carpi radialis tendon (FCR) in relation to the volar tubercle (vt), the volar ridge (vr) and the volar notch (vn).

Fig. III-2.
a. (neg. no. 23743). Right metacarpal I radial view. The volar flare of the joint surface and the concavity in dorso-volar direction. The bony prominences are the volar-ulnar tubercle (vut), the volar styloid process (vsp) and the dorsal styloid process (dsp).
b. (neg. no. 24783). Same view after a rotation of about 45 degrees. The ulnar curvature of the shaft is different as compared to the previous picture.
c. (neg. no. 24784). Volar view demonstrates the asymmetry between the ulnar (ut) and radial tubercle (rt) of the metacarpal head.

Fig. III-3

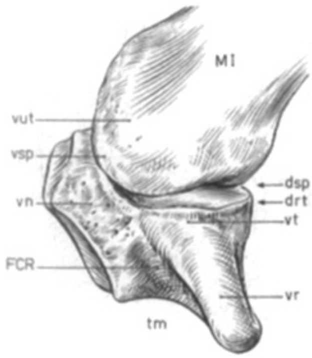


Fig. III-4

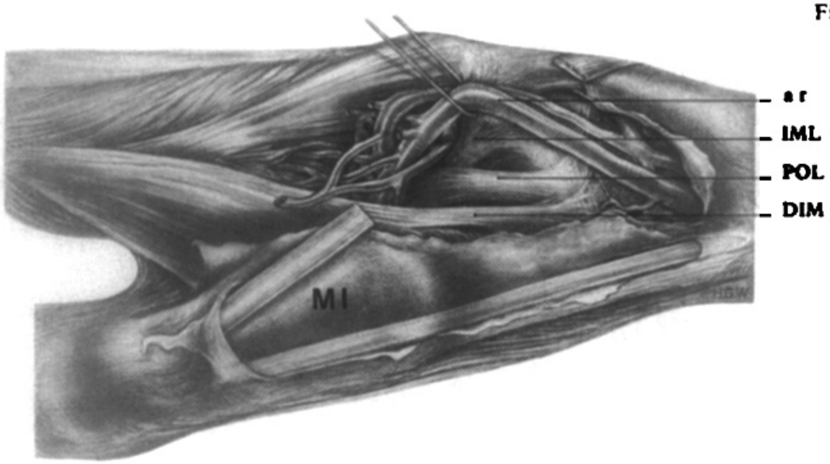


Fig. III-3. (neg. no. 24127 T 1709)
Drawing to show the relation of metacarpal I with the trapezium in volar view.

Fig. III-4. (neg. no. 23618, T 1635, WK. 1913)
Dorsal view. Drawing of carpometacarpal area of the thumb. Metacarpal I the first dorsal interosseus muscle (radial part DIM) the posterior oblique ligament (POL) and the first intermetacarpal ligament (IML).

Fig. III-5

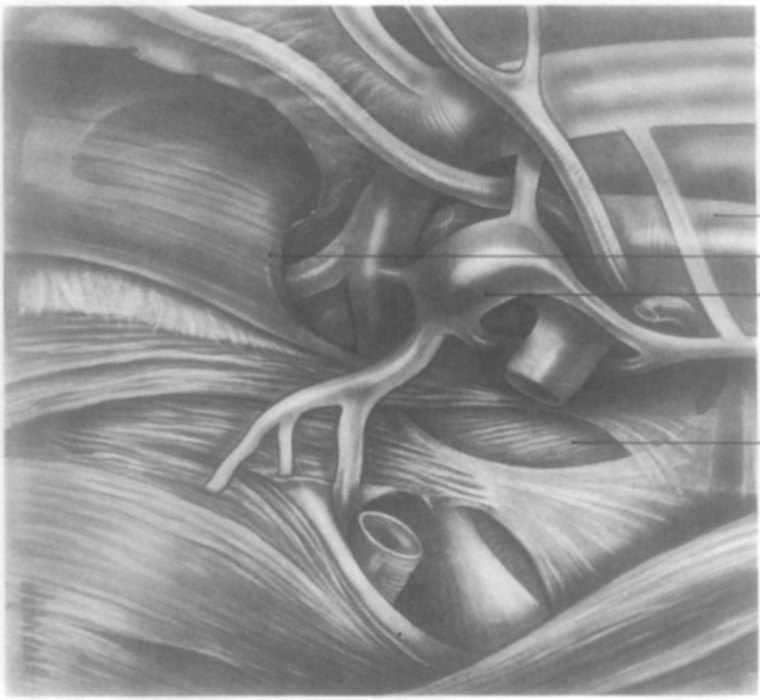


Fig. III-6

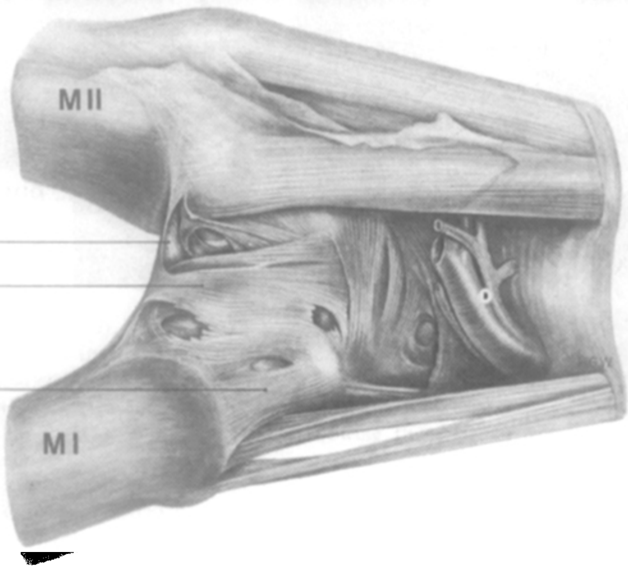


Fig. III-5. (neg. no. 24106, T 1700, W.K. 1704)
A close up view of the dorsal aspect of the anatomical snuffbox. The radial artery (ar) surrounded by a venous plexus (vp). These vessels disappear in forward direction through the arcade of the first dorsal interosseus muscle (ADI).

Fig. III-6. (neg. no. 23615, T 1638, W.K. 2019)
After removal of superficial layers and vasculature the dorso-radial ligament, the posterior oblique ligament and the first intermetacarpal ligament are visible.

Fig. III-7

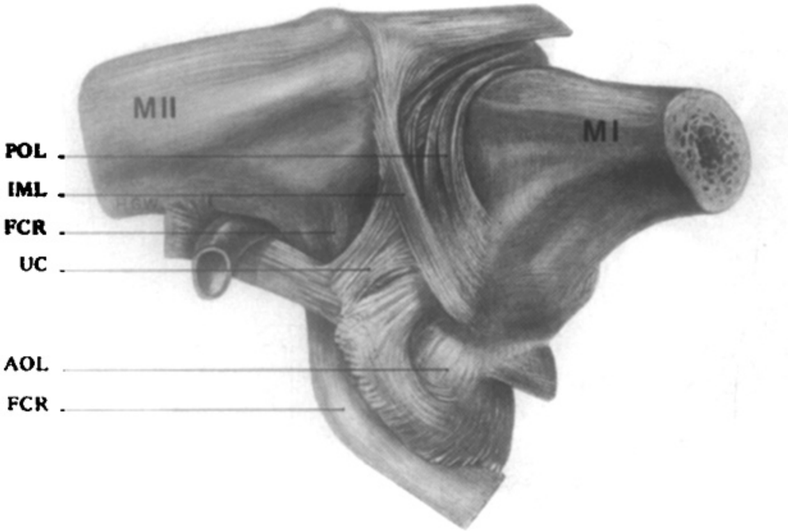


Fig. III-8

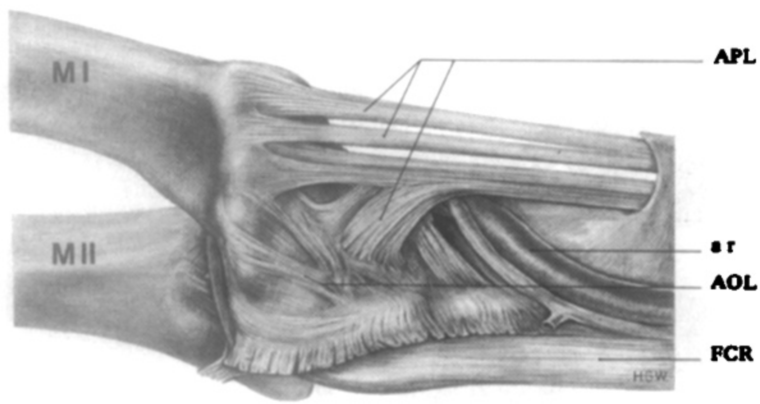


Fig. III-7. (neg. no. 24116, T 1708, W.K. 2019)
View into the cleft of the carpometacarpal area of the right thumb. Metacarpal I, pointing to the right and metacarpal II, pointing to the left with the interrelationship of the posterior oblique ligament, the intermetacarpal ligament, the anterior oblique ligament and the reinforcements of the volar capsule. Also the insertion of the flexor carpi radialis into metacarpal II (FCR) and the "ulnar collateral" (UC) are shown.

Fig. III-8. (neg. no. 23616, T. 1637, W.K. 2019)
The multiple insertion of the abductor pollicis longus tendon with its sheath into trapezium and metacarpal I is not an exception.

Fig. III-9

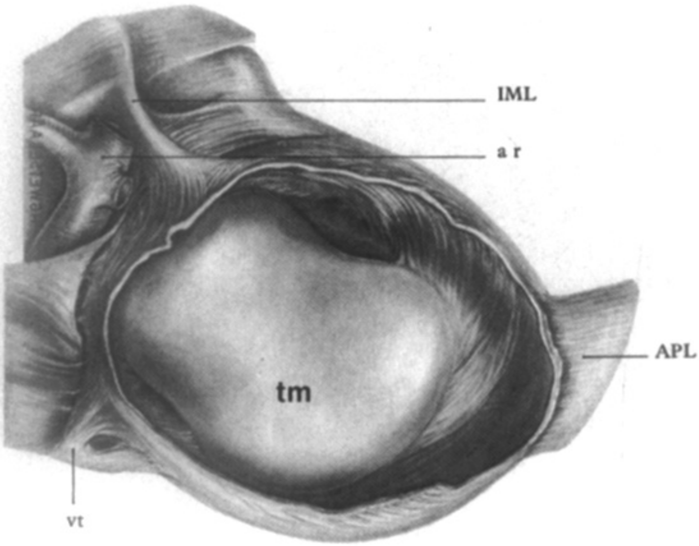


Fig. III-10

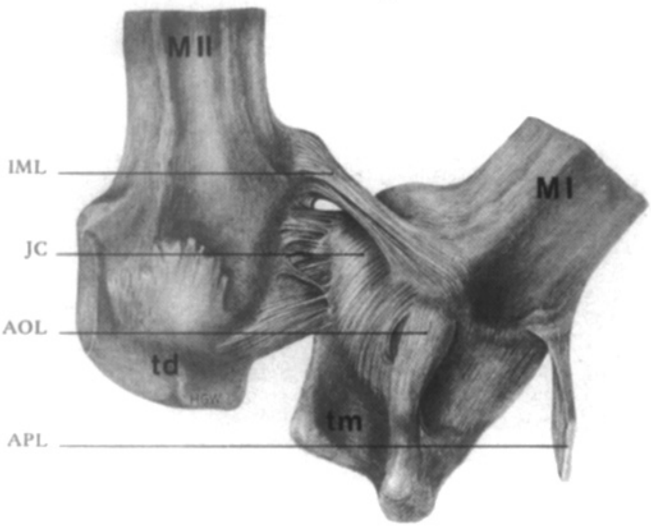


Fig. III-9. (neg. no. 23899, T 1647, W.K. 807)
The distal articular joint surface of the trapezium and capsule after removal of metacarpal I. Radial the abductor pollicis longus (APL). Dorsally the thick capsule and the dorsal pouch for the dorsal styloid process of metacarpal I (dsp). On the ulnar aspect the intermetacarpal space with the first intermetacarpal ligament (IML) merging with the thick ulno-volar capsule and volar the volar tubercle of the trapezium (vt).

Fig. III-10. (neg. no. 23900, T 1649, W.K. 3316)
Volar view of the right first carpometacarpal joint; on the left metacarpal II; on the right side the trapezium and metacarpal I.

Fig. III-11

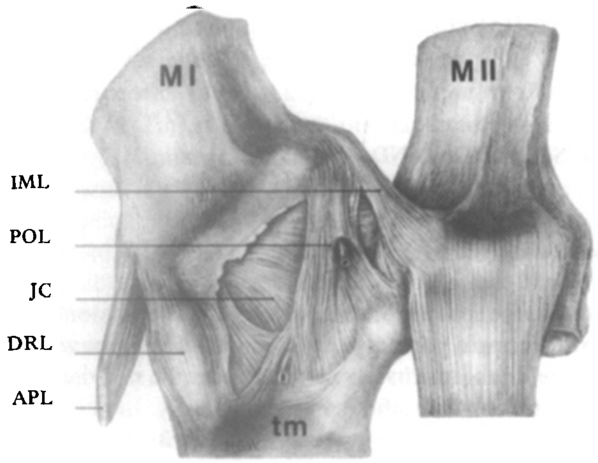


Fig. III-11. (neg. no. 23901, T. 1648, W.K. 3316)
Dorsal view of the right first carpometacarpal joint and the arrangement of the ligaments and jointcapsule (JC).

CHAPTER IV

X-RAY DESCRIPTION AND ANALYSIS

a. The first carpometacarpal joint analysed by X-ray studies

From the previous chapter we have obtained some insight in the anatomical arrangements of the first carpometacarpal joint of the thumb, and its surrounding joint capsule and ligaments. These arrangements were studied from the microscopy of the fetal hand and the gross anatomy of the adult hand.
In this chapter the ligaments and joint surfaces will be studied with the aid of X-rays of the first carpometacarpal joint.
We have the choice to fix either the distal or the proximal bone. For practical purposes it is the easiest to consider the carpus, trapezium inclusive, as the fixed part. The ligaments around the carpal bones in an anatomical specimen are so tight that for all intends and purposes no motion takes place between the carpal and metacarpal bones except for the first carpometacarpal joint. Carpal fixation can also be obtained by crosswiring the carpal bones. However, in that case some details may be obscured by shadows on X-ray pictures.
The metacarpals of the thumb and index finger, trapezium and trapezoid were held together by the ligaments between these various bones. Furthermore the posterior oblique, the intermetacarpal, the anterior oblique and the dorso-radial ligaments were wired with 5-0 stainless steel wire (fig. IV-2). We should be aware of the fact that this wire is not a spring, so that it does not in anyway indicate the tension in a ligament. It does however inform us of the position of the ligaments and in the appropriate projections on their span. The term span is used rather then length, because the real length of a ligament is constant. In reality with motion only the origin and insertion get closer together or further apart. In the latter case the span increases and eventually the ligament will be getting under tension and will exert its biomechanical function. The appropriate projection refers to the position in which the ligament is seen in its maximal length. This in fact occurs only when the plane of projection runs parallel to the ligament. These occasions are rare. Therefore we always have to be careful with the interpretation of the span of the ligaments from the projections.
The proximal and distal attachments of the joint capsule were also marked with a loop of stainless steel wire. A third loop of wire was used as a marker around the shaft of metacarpal I in order to be able to follow the rotation of this metacarpal. This wire shows a dot which is situated on the dorsal aspect of metacarpal I. It does not in anyway indicate the midline or center of metacarpal I.
We mounted the specimen with the dorsal aspect of metacarpal II against a perspex bar (fig. V-2). This surface is rather flat and was therefore considered adequate to represent a reproducable plane of reference. Then the perspex bar was mounted on

a flat perspex board together with a modified copy of a diagram used by *Ebskov* shown on the photograph (fig. IV-1 A).
The trapezoid (Td) is kept 4 cm above the laboratory reference frame. The trapezium (Tm) is fixed with the trapezoid by means of wedges. This tightens the intercarpal ligaments.
Metacarpal I (MI) is the mobile part. Attached to its head is the isotonic spring. This spring produces a pull R in any direction wanted e.g. the direction of D (this is a fixed point in one of the positions tested). The other positions are J, L, K and I. Each time the distance between M and each of these five points is kept at 14 cm. The angle α can be calculated if so desired (fig. V-2). The applied force was transmitted by a wire loop to the metacarpal head only. This wire was loosely looped around a small screw placed in the arbitrarily chosen center of the metacarpal head. An isotonic spring attached to this screw causes a force, which has a horizontal and a vertical component.
With the aid of the modified diagram used by *Ebskov* (fig. IV-1B) and the isotonic spring all the desired positions could be reproduced. For our purposes only one force is needed. We initially also used a longitudinal force, however the vertical component of R was all that was necessary to ensure adequate joint contact. Then this longitudinal force was omitted. If more forces are used the model becomes unnecessarily complicated. The X-rays are shown in figure V-2. We have chosen the five positions as described J, L, D, K and I. In these positions X-rays were taken in three directions.

In series i the X-ray plate was put parallel to the perspex bar and in series ii the X-ray plate was put at a 45° angle (fig. IV-1). The distance of the plate to the first carpometacarpal joint was in both instances equal. The applied force was transmitted by a wire loop to the metacarpal head only. To avoid enlargement and distorsion, the ray beam was kept at a distance of 2 meters, so that the beam of X-rays is for all intends and purposes parallel. These series of X-rays were obtained with the metacarpal put in the five positions mentioned above. In series iii X-rays were taken from distal to proximal along the longitudinal axis of the second metacarpal (MII).

b. X-ray observations

The observations of the X-rays will now be considered. In each of the three series metacarpal II can be seen in the same relation to the perspex bar. The metal clamp, which was used to fix the second metacarpal in place, does not interfere with any part of the joint under study. The wired ligaments are: the anterior oblique ligament (AOL) which runs from the volar tubercle of the trapezium to just beyond the volar styloid process of metacarpal I visible in the centre of the projection, best seen in J_2 (fig. V-2); the posterior oblique ligament (POL), which originates from the dorso-ulnar tubercle of the trapezium; the intermetacarpal ligament (IML), which comes from the base of metacarpal II and joins the posterior oblique ligament to reach the same distal point of attachment at the volar-ulnar tubercle of

the base of MI; the dorso-radial ligament (DRL) which arises from the dorso-radial tubercle of the trapezium and is distally inserted into the dorsal margin of the base of metacarpal I (fig. V-2).
In series iii the four wired ligaments, the anterior oblique ligament (AOL), posterior oblique ligament (POL), intermetacarpal ligament (IML) and dorso-radial ligament (DRL) can best be seen in the positions L_3 and J_3. Volarly the anterior oblique ligament and in the first interspace the posterior oblique ligament and the first intermetacarpal ligament are visible. The dorso-radial ligament is situated on the radial aspect of the trapezium.
The heavy wire around the screw, indicates the direction of the pull R on MI. If R falls outside the projection, the diagrams in chapter V and figure IV-1A should be used for orientation purposes.
In the description of the positions information was obtained from the X-rays. Additional information, e.g. for the tension of ligaments, was also obtained from direct observation of the same specimen. Furthermore, for a more precise location of joint contact, stereoscopic X-ray pictures were used.
The features of the five positions, as recorded below, should be read from left to right. Furthermore not all details can be seen in one projection only, it is therefor necessary to combine the features of the three different projections together from top to bottom.
In the description of the positions of the X-rays, our first concern lies in the joint area. In each instance we have centered the X-rays on this area. However some additional data can be obtained from the position of MI in relation to its environment. The position can be determined by some features of asymmetry of the metacarpal head and shaft (Ch. IV). It should be realised that the X-ray features of asymmetry must be most carefully interpreted. These features in itself are not an indication of a rotated position. However if subsequent positions are compared and if one considers the bony features carefully, only then we can come to certain conclusions in regard to axial rotation based on X-ray features.
One remark should be made concerning the metacarpal base. In J_1 the base is widened on the ulnar aspect and in J_2 on the opposite, the radial side. Since in reality there is no such a prominence on the radial aspect the position of MI must be rotated in such a way that the wide volar base causes this prominence in projection.
The three X-ray projections of the final position I shows the metacarpal I in its entirety.
In I_1 the ulnar tubercle of the head is more prominent than the radial one. Furthermore the curvature of the ulnar border in projection is more marked than the curvature of the ulnar border and the volar border in reality (Ch. III). This means that the volar curvature in projection can be increased by the flare of the distal part of the ulnar border in certain positions of rotation. Thus a decrease in curvature means a rotation in either direction showing the volar border or showing the ulnar border more fully (fig. III-3). In the I_2 projection the head and shaft are fairly symmetrical. In this specimen the ulnar flare of the distal part of the shaft at the ulnar border is not seen.

In the I_3 projection we are guided by the position of the volar styloid process, situated just radial to the distal attachment of the anterior oblique ligament, and the volar margins of the base of MI. The volar margin is further divided in a radial part and an ulnar part in relation to the attachment of the anterior oblique ligament. In this instance the direction of the volar ulnar part of the margin can best be judged.
Some of these just mentioned asymmetrical features are further shown in the drawings in chapter V.

c. Description of the positions in which the X-rays were taken

Position J

This position corresponds best with one of the positions of retro-flexion (fig. IV-2). We have chosen to start in position J as our first position. In each subsequent position the last position is related to the previous one. The force R runs backward and projects outside the pictures J_1 and J_3.

Metacarpal I
As outlined above some features are used to aid us in defining the position of MI in space. Although the entire MI is not shown some essential features, the ulnar tubercle of the head, the curved ulnar margin and the dot on the wire loop (located on the dorsal aspect of MI) are visible. A midline has been defined in chapter IV and this midline would correspond to an imaginary line in J_2 between the screw tip and the distal attachment of the anterior oblique ligament. Obviously the dot located in J_1 near the center of the shaft, has moved in J_2 closer to the ulnar border as a result of a change in projection.
The length of MI in J_1 approaches its real length which means that the plane of projection runs almost parallel to MI. In J_2 MI is somewhat shorter because the incidence of the X-raybeam is different.
In J_3 it can be observed that the posterior aspect of MI is situated close to the dorsal plane of MII, indicated by the interrupted line on the J_3 photograph.
Returning to the asymmetry of the metacarpal head in J_1 we note that the ulnar tubercle of the MI head is visible as a prominence. In J_1 the ulnar border is curved. These two features are far less outspoken in J_2.

The base of MI in J_1 shows the volar-ulnar tubercle as a prominence and as such adds to the smooth curvature of the ulnar margin of the shaft. In J_2 the volar-ulnar tubercle is not visible. Rather in contrast to the radial aspect a prominence is observed in this projection. Since in the study on osteology no radial tubercle is seen on the base, this prominence must be a sign of the flare of the wide volar base. It therefore gives us some impression about the position of rotation of MI.
In J_3 we would like to pay attention to the volar styloid process and to the ulnar and radial part of the volar margin of the MI base, situated on the ulnar and radial aspect of the insertion of the anterior oblique ligament respectively. The volar

styloid process is situated just radial to the insertion of the anterior oblique ligament. In the gross anatomical description we have seen that the insertion of the anterior oblique ligament reaches beyond (distally to) the volar styloid process. Thus in projection the distance of the volar styloid process and the anterior oblique ligament, can change with a change in position, that is in projection it can shift almost "underneath" the anterior oblique ligament. In our present projection the volar styloid process is seen well away from the insertion of the anterior oblique ligament. The ulnar part of the volar margin appears to run perpendicular and the radial part of the volar margin runs approximately parallel to the dorsum of MII. A line drawn through the volar styloid process and the distal attachment of the posterior oblique ligament runs at an angle with this dorsal plane. This line is easiest to follow in the subsequent projections.
Now defining the position of MI in relation to MII we must conclude that in position J MI is tilted backward corresponding to one of the positions of retroflexion. In the section on osteology we already pointed out that the absence of complete symmetry does not prevent the use of certain features of asymmetry for the interpretation of rotation in projection. These features are readily recognized both in the shaft and in the metacarpal head. Asymmetrical phenomena in these particular regions in the J_1 projection permit to accept (to conclude to) a position of MI of pronation. In this instance the plane of the dorsal surface of MI is compared with the plane of the dorsal surface of MII.

In the position J the force R runs in dorsal direction. This can only be seen and properly judged in J_3. Furthermore in J_1 MI projects at some distance from MII especially noticable at the base of the first metacarpal interspace. This interspace is also visible in J_2. In the horizontal projection, J_3, the distance corresponds to the real distance as present in the anatomical specimen.

The joint margin of the base of MI

The proximal and distal attachments of the capsule were outlined by way of a wire and their positions indicate the joint margins of the base of MI and of the trapezium respectively. In J_1 the volar margin of MI is indicated in the drawing as the dotted line. (Confirmation of its identity was further obtained from the stereoscopic pictures). Furthermore this margin is "tilted" away, that is in distal direction, from the trapezium as opposed to the dorsal margin of MI which lies in close relation to the trapezium.
In J_2 this volar margin runs slightly more horizontal then in J_1 and it can be identified in close relation with the distal attachment of the anterior oblique ligament. In this projection the volar margin is also tilted away from the trapezium. In J_3 no clear judgement can be made in this respect.

The joint gap

In J_1 a gap is visible on the ulnar aspect of the joint. In this area the metacarpal is concave. Thus the X-ray misses any bony shadows on its way. The cartilage cover sometimes gives the impression that no joint contact exists, e.g. in L_1, MI seems to float on the trapezium. One must be careful with the interpretation with regard to joint contact. Generally speaking joint contact cannot be seen on X-rays. However there are some indications from which joint contact can be deducted. Since the J_2 is a true antero-posterior projection for the joint itself, we have a better impression about the position of MI in relation to the trapezium. In J_2 MI is tilted towards MII and the ulnar half of the trapezium. At the same time there is a little gap however small on the radial aspect. In J_3 the joint gap cannot be adequately judged due to a complete overlap of bony shadows.

On the bases of the above described features: the backward position of MI, the distance between the joint margin of MI to the trapezium which is larger volarly than dorsally and the ulnar tilt, joint contact can only be expected in the ulno-dorsal quadrant. The ulno-dorsal joint contact was again confirmed in the stereoscopic X-rays as well as from direct observations of the specimen.

The ligaments

We have wired the ligaments as indicated above. In J_1 the anterior oblique and the posterior oblique ligaments are both projected on the ulnar aspect of the first metacarpal base. Only the dorso-radial ligament can be observed properly. Its distal attachment is wider than its proximal attachment. Thus it is slightly triangular in shape. Depending on the degree of rotation of metacarpal I in relation to the trapezium, it is sometimes possible that either the ulnar half or the radial half of this triangular shaped ligament is taut. At present the span of the radial half is maximal. In J_2 the anterior oblique runs in a slight oblique direction. In J_3 the proximal and distal attachments of this ligament are widely separated from each other. Although the span of this ligament cannot be judged from these X-ray projections only, we know from the stereoviews and from direct observations that the span is maximal. We will come back to this later. The posterior oblique and intermetacarpal ligament can best be followed in J_2 and J_3. In J_3 the posterior oblique runs in an almost straight line from dorsal to volar. The span of these ligaments is not maximal as compared to some of the subsequent positions.

From the information gathered we may in conclusion state, that in position J the posterior oblique, the intermetacarpal and the ulnar half of the dorso-radial ligament have no control on the joint. The anterior oblique and the radial half of the dorso-radial ligament are under maximal tension.

Position L

This position can best be compared with extension. In this position the features will be considered in relation to the previous position J. Thus it is necessary not only to compare in this new position L the three different projections but also the changes of these with the three different previous projections.

Metacarpal I

In L_1 the ulnar tubercle of the head of MI is hardly changed. The curvature of the ulnar border of the shaft is also about the same in comparison to position J_1. The wire loop about the shaft projects more as a line. The dot has the same location between the ulnar and the radial border of the shaft, but in J_1 was situated proximal and in L_1 distal to the volar part of the wire loop. The length of the projection of MI is almost the same as in position J. In the first interspace the wired ligaments cannot be adequately judged. The distance between the bases of MI and MII has increased. The entire position of MI however is more oblique. In L_2 the wire loop around the shaft projects more as a circle similar to J_2.

Both the distances between the heads of MI and MII and between the bases of MI and MII have increased. Furthermore MI has shifted radially so that the radial extremity of the MI base reaches beyond the trapezium on this side. Although the direction of the applied force in L_3 is still backward, MI is projected in a slightly more foreward position to the plane through the dorsal aspect of MII.

The MI is longer and, although not described previously in J_3, an obvious change is also seen of the volar curvature of the shaft in L_3. The volar styloid process is less prominent and has moved "toward" the distal part of the anterior oblique ligament. The ulnar volar margin appears to run more at an angle however slight, with the dorsal plane through metacarpal II and so does the radial volar margin in relation to the dorsum of MII. It is even easier in the subsequent projections to replace MI by the line taken through the volar styloid process and the distal attachment of the posterior oblique ligament. This line runs almost perpendicular to the plane through the dorsum of MII which indicates an axial rotation as compared to the J_3 position.

From the above information we may say that MI in its new position has shifted in radial direction over the surface of the trapezium and is still tilted backward. Furthermore the slight changes in the prominences of the metacarpal head and base indicate a very little axial rotation to a more pronated position as compared to position J.

The joint margin of the base of MI

We will merely limit our remarks to the altered position of the circumferential wire at the metacarpal bone. In L_1 the irregular dorsally located margin has moved away from the trapezium and more so on the ulnar than on the radial half. The volar margin projects closer to the trapezium and more so on the radial than on the ulnar side. These changes have taken place in comparison with J_1. Similar to J_2 in L_2 the dorsal joint margin still projects proximal and the volar joint margin distal to the crest of the trapezium. The crest of the trapezium is formed by the most distal margin of the joint surfaces. This crest is best seen in series ii because the plane of projection runs almost parallel with it. The distance of the volar joint margin is however more marked on the radial than on the ulnar half. Thus the ulnar distance to the trapezium has increased and the radial distance has decreased in comparison to J_2.

In L_3 we cannot interpret this feature properly. The proximity of the dorsal joint margin and the remaining volar distance to the trapezium is indicative of a volar gaping of the joint as in J_2 but at present with a tilt away from MII.

The joint gap

Due to the rotation of MI, as outlined above, we get the impression in L_1 that a joint space is present on the radial aspect. However for the same reasons given for J_2 a better observation can be obtained from L_2. In L_2 MI is tilted away from MII and from the ulnar half of the trapezium. The first interspace between the base of MI and MII has also enlarged. Furthermore the small radial gap that existed in J_2 has completely disappeared.

In L_3 the only observation about the joint "space" consists of a slight radial shift of the overlap of shadows so that this area of overlap is smaller in comparison to the overlap in J_3. From the above described features, such as the proximity of the dorsal joint margin to the trapezium, the posterior and radial tilt of MI and the loss of the joint gap radially, we conclude that in agreement with the observations on the specimen, the joint contact is located in the dorso-radial quadrant.

The ligaments

In L_1 only the dorso-radial ligament can be properly seen. Its distal attachment has shifted with MI in radial direction. Its projection has become more rectangular in shape. The distance between the proximal and distal attachment has not changed much. Both in L_1 and L_2 the distance between the proximal and distal attachment has indeed increased slightly. This increase is limited to the ulnar half. This does not contradict that the ulnar half has increased its span. That the span indeed has reached its maximum was observed in the specimen. In L_3 no additional information can be obtained.

The anterior oblique ligament is best judged in L_2. It runs possibly somewhat more parallel to the crest of the trapezium. Both in L_2 and L_3 the length in projection has not changed so that its span has remained the same.

The distance of the proximal and distal attachment of the posterior oblique ligament, best seen in L_2, has increased. So has the distance between the proximal and distal attachment of the first intermetacarpal ligament. This increase in distance for both ligaments is also seen in L_3. These distances are to be compared to the distances in J_2 and J_3 respectively. Thus the span of these two ligaments has increased. This means that these two ligaments are likely to be under tension.

In position L certain features can be summarized. The force R runs in dorso-lateral direction, the joint contact is located in the dorso-radial area. The maximal span exists in the anterior oblique ligament, in the ulnar half of the dorso-radial ligament, just as in position J and in the posterior oblique and intermetacarpal ligaments.

Position D

This position corresponds with one of the clinical positions of wide abduction.

Metacarpal I

The ulnar tubercle of the head of MI is somewhat better visible. The ulnar curvature is a bit more marked. The wire loop around the shaft has become still more circular and the dot is projected more radial in comparison to position L_1. The length of the projection is almost the same. At the base of the first interspace, the interval between MI and MII has decreased. The ligaments can be separately seen but are more accessible in D_2. In D_2 the distance between the MI head and MII as well as the intermetacarpal distance at the base has further increased. The wire loop projects more as a line while the dot has moved quite distinctly in radial direction. In D_3 it can be observed that the applied force is directed radially and slightly foreward. The MI projection is somewhat longer than in L_3, its head is projected well in front of the dorsal plane through MII and the volar curvature is somewhat "elongated". The projection of the volar styloid process coincides with the distal attachment of the anterior oblique ligament. The angle of the ulnar-volar margin with the plane through the dorsum of MII has increased. Although the projection of the radial volar margin as compared to L_3 has changed, it still appears that the angles between it and the dorsum of MII has increased. Thus MI is tilted forward and has still been shifted in a more radial position. The slight changes that have occurred, after MI has been pulled from its backward-tilted position to its forward-tilted position, are indicative that the excursions in both directions are approximately the same. A slight change has also taken place in the position of the dot on the circular marker in radial direction. For the right hand, seen from distal to proximal, it means an axial rotation in clockwise direction.

The joint margin of the base of MI

In D_1 the dorsal margin is projected well away from the trapezium mainly on the ulnar side without hardly any change on the radial aspect.

The volar joint margin has moved towards the trapezium. In D_2 the dorsal and volar margin almost project together, thus the dorsal joint margin has moved in a distal and the volar joint margin in a proximal direction. There is however an increase in the overlap of the projection of MI on the trapezium which is indicative of a motion in volar direction.

The joint gap

In D_1 a slight indication of some joint space is present radially and the ulnar space is completely obliterated. In D_2 on the ulnar side a wedge shaped joint space is visible. On the radial side no such a joint space is seen. The joint space is absent in the center. In D_3 the joint space cannot be judged. These observations, keeping the anatomical shape of the MI base in mind, do not contradict a still existing dorso-radial joint contact. With motion in volar direction together with the foreward position of MI and the displacement of the volar joint margin in volar direction, a joint contact in the radio-volar quadrant is not unlikely. Indeed from the specimen and the stereoscopic X-rays a two point contact at the above mentioned locations could be confirmed. The joint shape of the distal trapezium does not completely conform to the proximal joint surface of MI. The latter is much more curved forming an "arcade" resting with two "pillars" on the trapezium. These points of joint contact are diagrammatically shown in figure V-6A, B.

The ligaments

In D_1 the dorso-radial ligament is narrower at its distal attachment, and its span has neither increased nor decreased. The other projections D_2 and D_3 confirm this observation. The projection of this ligament has become smaller in all three projections and this does not contradict the real observations of relaxation of this ligament.

The anterior oblique ligament although visible in D_1 is again better seen in D_2. It runs in both projections in a slightly more horizontal direction. Its span has remained the same. As in position L, this ligament is under tension.

The posterior oblique and first intermetacarpal ligament in D_2 have not changed much in position. In D_1 the former runs with a slight radial convex curve in distal direction; the latter cannot be seen. In D_2 the distal attachment of both have shifted in ulnar direction and their span, as in L_3, is maximal.

In position D, the MI is tilted in a radial and a slightly foreward direction by the force R. The joint contact is located both in the radio-dorsal and the radio-volar quadrant of the joint and a maximal span of the anterior oblique, posterior oblique together with the first intermetacarpal ligament has been observed.

Position K

This position corresponds with flexion in opposition of the thumb.

Metacarpal I

In K_1 the ulnar tubercle of the head of MI is seen in closer relation to MII and its prominence neither increased nor decreased. The ulnar curvature is more or less the same. The circle of the wire is oval and the dot has not visibly shifted. The length has decreased only a little bit. The most obvious is the decrease in the distance between the bases of MI and MII.

In K_2 the circular wire is somewhat more oval as compared to D_2 but the dot is at the same distance to the ulnar border. The first interspace has decreased also in this view. The MI base still projects as far radially beyond the trapezium as in D_2.

In K_3 the applied force R runs in ulno-volar direction. The curvature of the shaft is "stronger".

The volar styloid process can be seen together with the distal attachment of the anterior oblique ligament. Because of the entire change of position of MI the projection of the MI base cannot simply be compared with the previous projections. The entire volar contour is a bit more rounded. Therefore we have in this instance taken the line connecting the insertion of the posterior oblique ligament and the volar styloid process. In the previous projections it is easier to use the joint margins. In D_3 this line forms a slight angle with the dorsal plane through metacarpal II and in K_3 this angle is much more marked giving the best indication of an axial rotation in anticlockwise direction.

Thus in position K the MI has been tilted towards MII and also in a more foreward direction, that is away from the plane through the dorsal aspect of MII. Furthermore an axial rotation has taken place and this time in anticlockwise direction.

That means that a turningpoint must be present between position D and position K. The exact point will be difficult to locate with our present methods. In figure IV-3 this rotation in clock- and anticlockwise direction has been diagrammatically drawn and will be discussed later.

The joint margin of the base of MI

In K_1 the dorsal margin is again projected away from the trapezium on the radial aspect but has become a bit closer on the ulnar side. The volar margin runs a bit more horizontal along with the crest of the trapezium as compared to D_1. Furthermore the volar margin has still moved in proximal and the dorsal margin in distal direction. K_2 confirms these features.

The joint gap

In K_1 the wedge shaped space is increased radially while on the ulnar side the overlap of shadows has been accentuated. In K_2 as compared to D_2 there is also an increase in joint space radially and a decrease on the ulnar side. These observations and foreward "supinated" position of MI, are indicative of an ulno-volar location of the joint contact. In the specimen this ulno-volar joint contact has been confirmed. At the same time the dorsal joint contact has been lost.

The ligaments

In K_1 the span of the dorso-radial ligament has reached its maximum. The same is noted in K_2.

The anterior oblique ligament in K_1 runs with a slight curve in distal direction. In K_2 it runs almost parallel to the crest of the trapezium. It has maintained its maximal span. In K_3 the distance between the proximal and distal attachments of the anterior oblique ligament is also maximal.

The span of both the posterior oblique and first intermetacarpal ligament has decreased. The same is seen in K_3.

In position K the force R runs in foreward and ulnar direction. The joint contact is situated in the ulno-volar quadrant. The span of the dorso-radial ligament and the anterior oblique ligament is maximal.

Position I

This position corresponds with flexion and adduction of the thumb.

The metacarpal I

In I_1 the ulnar tubercle of the head of MI is again seen in close relation to MII, but its prominence has decreased. The ulnar curvature is less marked. The wire loop is less "circular" and the dot has moved towards the ulnar border. The length of MI has increased and the distance between the bases of MI and MII is about the same as compared to K_1.

In I_2 the circular wire projects somewhat more horizontal. The shift of the dot in ulnar direction is more marked. The distance between the metacarpal head of MI and MII as well as the distance at the base of both bones has obviously decreased.

In I_3 the force R runs in ulnar direction and the metacarpal head has moved closer to the plane through the dorsal aspect of MII. The ulnar margin of the base again runs in a more dorso-volar direction and the angle of the line, between the insertion of the posterior oblique ligament and the volar styloid process, with the plane through the dorsum of MII has changed. The MI is tilted towards and just volar to MII.

The loss of prominence of the metacarpal head in I_1 and the change of direction of the ulnar margin of the base of MI together with the ulnar shift of the dot of the wire loop are the most obvious indications of an increased axial rotation in anticlockwise direction.

The joint margin of the base of MI

In I_1 the volar and dorsal margins are projecting together on the radial and in close proximity on the ulnar side, so that both margins are at a more or less equal distance from the trapezium. In I_2 the dorsal margin has moved towards the trapezium and the volar margin has moved in the opposite direction.

The joint gap

In I_1 the wedge shaped space radially has increased and reaches well into the ulnar half of the crest of the trapezium.

In I_2 the radial space has also increased; at the same time the ulnar space has disappeared. These features and the adducted position of MI do not contradict the location of the joint contact in the ulno-volar quadrant. In fact the joint surface of MI hugs the neck of the trapezium just at the crest on its volar aspect as is seen in the specimen and the stereoscopic X-rays.

The ligaments

In I_1 the dorso-radial ligament is still projected at its maximal span.

In I_2 the anterior oblique ligament runs completely parallel to the crest of the trapezium and its span is still maximal. The distance of the proximal and distal attachments of the posterior oblique and first intermetacarpal ligament are still well below their maximum in all three projections.

In position I the force R runs mainly in ulnar direction. The joint contact is located at the "neck" of the trapezium. The dorso-radial and anterior oblique ligaments show their maximal span.

Finally our last position is equal with the first which is position J. In this position, which has already been described, we note that the ulnar tubercle of the radial head has become smaller. The length of MI has decreased and the dot of the wire loop around MI has moved closer to the ulnar border of the shaft.

Thus the axial rotation in anticlockwise direction has seemingly progressed to its maximum or actually just past this stage as drawn in figure V-9A. Therefore somewhere close to position J there must be a second turning point for the axial rotation back to a clockwise direction for the right thumb. With this last step we have closed our "circle" of the MI movement through its extreme positions.

Discussion

From the above described data, as summarised in table IV-1, we have gained information with respect to the position of function of the ligaments and the joint contact in five positions. The relation that exists will be further analysed in the next chapter.

The diagram

For the purpose of reproducible investigations on the cyclic motions of the thumb, *Ebskov* (1970) used a simple diagram. This diagram has been explained by drawings of the hand (p. 81). The positions as indicated may apply to the position which the distal phalanx can reach with mobility of the first metacarpal, the metacarpophalangeal and the interphalangeal joint.

However during his investigations *Ebskov* fixed the interphalangeal joint with a splint so that these various points could not be reached by the distal phalanx. This matters only little because the positions on the diagram still indicate the direction in which the thumb has been put. In every reproducable position the posture of the metacarpal and both phalanges is the same. This applies to the entire thumb, but also to the metacarpals and the phalanges individually. We were able to use some of the positions of MI only and therefore like to use the same letters. Thus the letters of the first metacarpal as indicated in figure IV-1A, B correspond to the position the distal tip of the second phalanx of the thumb can reach in the average living hand.

The position of MI

The position can be interpreted from the X-rays only if we pay due attention to the anatomy of MI. The foreward and backward positions were interpreted with the aid of the length and the relation to the plane through the dorsum of MII. The wire along the joint margin of the MI base was helpfull confirming flexion, extension, abduction and adduction. The axial rotation was followed by a change of the ulnar curvature, the tubercle of the head and the asymmetry of the base of metacarpal I in series i and ii.

In series iii we have followed the axial rotation of the base and head of MI in projection. At the base it was easiest to follow the line connecting the volar styloid process and the distal attachment of the posterior oblique ligament in relation to the plane through the dorsum of MII. The angular change could be followed in each instance (fig. IV-3) into two directions. These two directions are clock- and anticlockwise.

From J via L to D MI rotates in a clockwise direction (pronation). Between D and K changes take place in anticlockwise direction (supination) via I back to J.

These excursions at the head (fig. V-9A) are obtained by the average angular changes seen at the base and at the head. The main purpose has been to demonstrate the occurrence of axial roation of MI rather than to measure the degree of rotation of MI. That the excursions at the head are greater than at the base is only due to the different projection of the head and base. In reality the excursion is of course the same. The axial rotation is in agreement with a mechanical saddle shaped surface. The actual measurement of axial rotation may be possible. It is a rather technical and difficult problem which falls beyond the context of this investigation. Axial rotation indeed occurs into two directions. For the right thumb, viewed from distal to proximal, when moved in a clockwise direction, starting in J, the initial axial rotation occurs also in a clockwise direction. Between position D and K we find a turning point. This means that when MI is moved further in clockwise direction axial rotation in the opposite, that is in anticlockwise direction takes place. A similar turning point is situated close to the starting position J.

A clock and an anticlockwise rotation was also noted by *MacConnaill* (1946). However his statements as to when we will find an anticlock- and when a clockwise rotation and in which thumb, right or left, is not clear.

The area of joint contact

With each motion into the five extreme positions joint contact is seen in the area in which the metacarpal has been pulled by the force R. The result is that in position J the contact is located in the direction of J. Similarly joint contact is located in the direction of L when MI is pulled towards L. In position D joint contact is seen at two areas but both areas are also located in the direction of D. These two areas are further characterized by the fact that this is not a line contact. This allows metacarpal I to slide forward on the trapezium when proceeding from position D to position K without being blocked by the crest of the trapezium or the dorso-radial ligament. This subject touches on the problem of the degrees of freedom of motion of a joint. This problem needs further investigation which we were unable to finish as yet. Except for position D, other positions tested did not show more than one area of joint contact.

In the literature we have not encountered any description relating the position of the thumb with the area of joint contact. *Bausenhardt* (1949) implies that with a position, that can be compared with our position D, the thumb swings about the neck of the trapezium. The joint contact should probably be expected in the ulnar half of the first carpometacarpal joint, that is opposite to the direction of the applied force in contrast to our findings. In position K the joint contact is located in the ulno-volar quadrant and in position I in the ulnar joint compartment (tabel IV-1). These areas are depicted in figure V-9B.

We have used the term "area" of joint contact rather than "point" contact. This implies that we adhere to the classical concept of compressibility of the joint cartilage. Again this is a problem for discussion. This compressibility will be difficult to measure. From our preliminary investigations on the degrees of freedom that do exist in any joint, the adaptibility (compressibility) of cartilage may be completely unnecessary. Furthermore from the clinical observations in a normal joint the cartilage is quite "firm" and it is hard to believe that the cartilage shows a great deal of adaptability.

MacConnaill (1969) has proposed a close packed position (CPP) for the thumb in extreme opposition. This clinical position of opposition would correspond best to our position K. From our description and observations in position K joint contact is only located in the ulno-volar quadrant with a loss of contact of the remainder of the joint. In fact in any other extreme position tested the joint contact is located in only one area, except for position D. This is in complete contradiction to *MacConnaill's* theory of a close packed position for the thumb.

Thus the two authors who imply (*Bausenhardt*, 1949) or mention (*MacConnaill*, 1969) joint contact in other areas as just mentioned, have neglected to observe the real anatomical situation.

The ligaments

As mentioned earlier a ligament only functions when it is tight. The function then is twofold. Generally speaking it has an inhibiting function. Furthermore it has a specific role which depends on the course of its fibres and its points of attachment. If the joint is moved through its five extreme positions from J via L, D, K, I through to J again, MI is guided without failure through a complex pathway sliding sideways, foreward and finally backward at the same time rotating in clock- and anticlockwise direction.

We have used in our description the term span. The span of the ligaments can only be judged in the appropriate projections. If such a projection, in the positions described, was not encountered the actual specimen in the same position was studied. Only if the span is maximal the ligament excerts its function. Thus in the positions described the ligaments with a maximal span imply functioning ligaments. These functioning ligaments in the extreme positions counteract the applied force R and balance MI against the area of joint contact. This balance will be more fully explained in the next chapter.

In the literature the function of ligaments has been mainly described in relation to the gross anatomical observations (*Rouvière*, 1924; *Haines*, 1944; *Kaplan*, 1965) and the clinical positions of the thumb. The ligaments are generally considered to be an inhibiting factor, preventing luxations of the joint. Sometimes if the joint motion cannot be explained by its shape only then the ligaments should be taken into account (*Bausenhardt*, 1949). This statement has not been further substantiated with an analysis of the "teamwork" of joint shape and ligaments.

With our method we have been able to approach the first carpometacarpal joint much more exact, so that in each position studied each functioning ligament could be found. These functioning ligaments are conveniently listed in table IV-1.

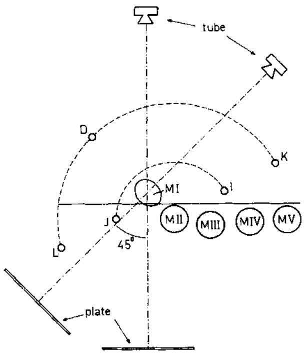


Fig. IV-1A

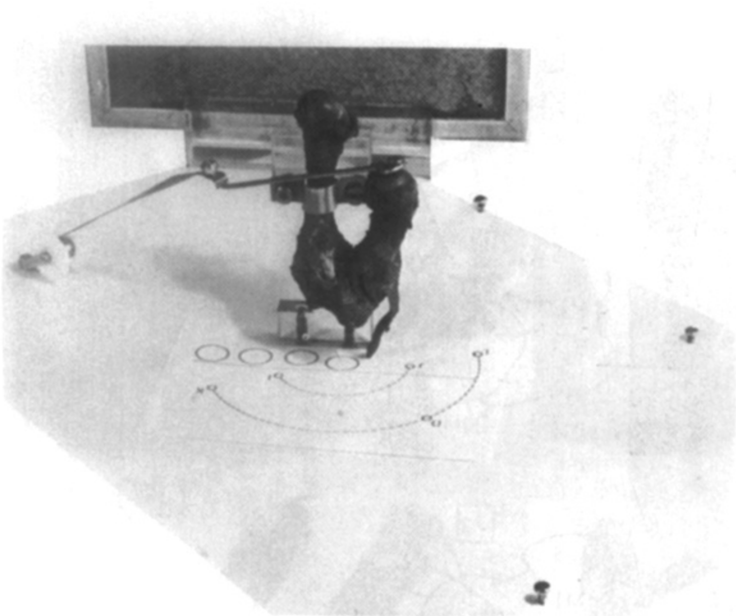


Fig. IV-1B

Fig. IV-1A
Diagrammatic representation of the method of investigation by X-rays. For the basic set up the diagram Ebskov used, has been modified. The metacarpals MII, MIII, MIV and MV represent the position of the hand. MI is situated at an angle of 45° to the rest of the hand. The tube was centred at the first carpometacarpal joint. In series i the plate was put parallel and in series ii at an angle of 45° to the dorsum of the hand.

Fig. IV-1B (neg. no. 24503)
The specimen in the experimental set up. The X-ray plate is seen in the back. The force R is exerted by the isotonic spring.

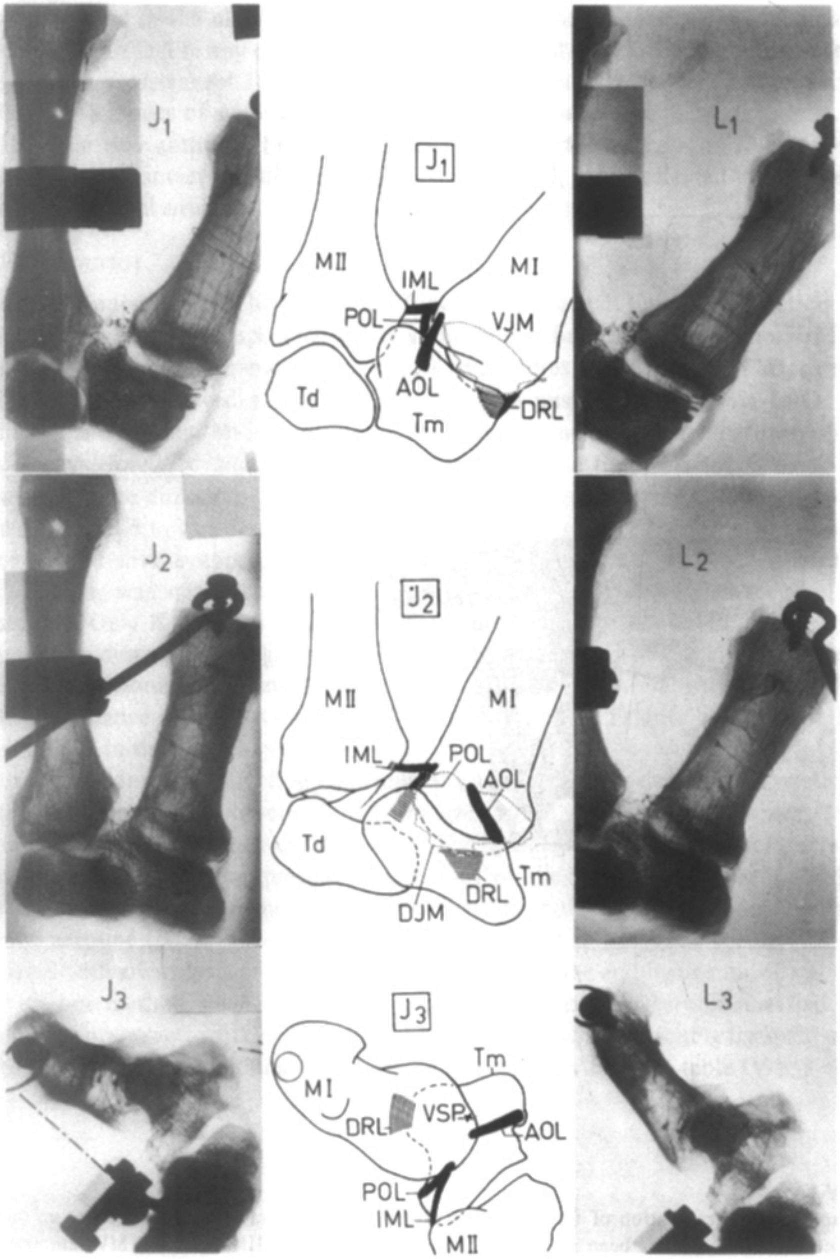
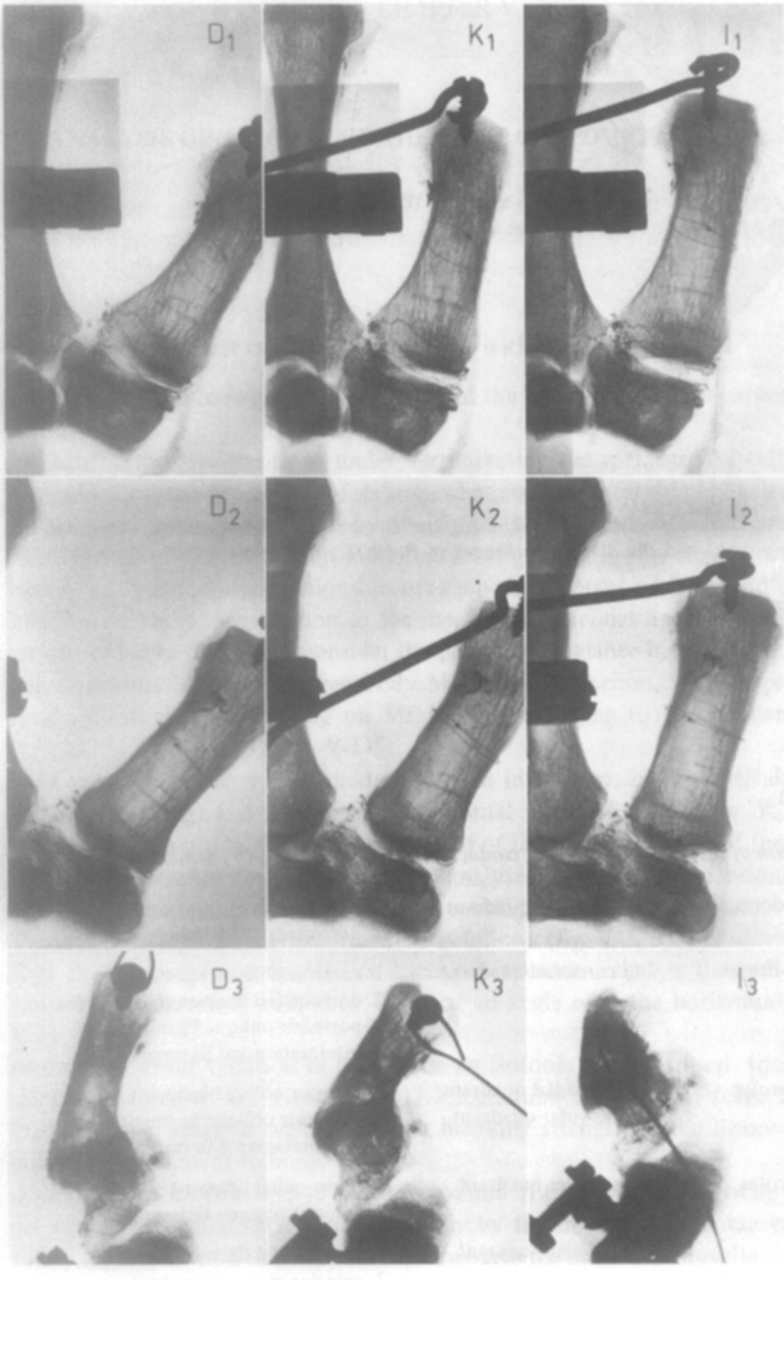


Fig. IV-2
For description see text.


D1
K1
I1
D2
K2
I2
D3
K3
I3

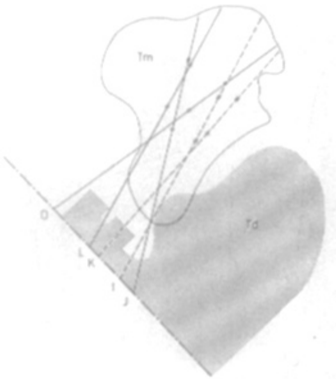


Fig. IV-3
The axial rotation analysed by superimposing the change of position of the connecting line between the vsp (x) and the distal attachment of the POL (o) in relation to the dorsum of MII from series iii.

TABLE IV-1

	position of MI	*area of joint contact*	*maximal span of ligaments*
J	ulno-dorsal	ulno-dorsal quadrant	1. anterior oblique ligament 2. dorso-radial ligament (radial half)
L	radio-dorsal	dorso-radial quadrant	1. anterior oblique ligament 2. dorso-radial ligament (ulnar half) 3. posterior oblique ligament 4. intermetacarpal ligament
D	radio-volar	dorso-radial quadrant radio-volar quadrant	1. anterior oblique ligament 2. posterior oblique ligament 3. intermetacarpal ligament
K	ulno-volar	ulno-volar quadrant	1. dorso-radial ligament 2. anterior oblique ligament
I	ulnar	ulno-volar quadrant	1. dorso-radial ligament 2. anterior oblique ligament

CHAPTER V

ANALYSIS OF A MODEL OF THE FIRST CARPOMETACARPAL JOINT

'If we are in error, the quarrel is with the observation and its interpretation and not with the law itself'
STEINDLER

a. Analysis of the first carpometacarpal joint with the aid of a model

In chapter IV we have given a description of the X-rays of the first carpometacarpal joint.

In each of the five positions under consideration the metacarpal I (MI) could be recognized by the projection of its somewhat asymmetrical shape. Each position of MI was maintained in balance by the force R, the ligaments under tension and reacting force N at the area of joint contact (fig. V-2). In this chapter we will more closely analyse the interrelationship between these forces with the aid of a model. Therefore a short introduction to the mechanical priciples appliable will be necessary in order to be able to consider the position of balance in the above mentioned five positions. Because the free body MI is in equilibrium, in each position, the resultant of all forces acting on MI is zero according to the mathematical law $R_v = O, R_h = O, M_o = O$ (fig. V-1).

This equation applies to our model, which is in balance, in the vertical plane (the plane of drawing) and also for the horizontal plane of projection. R_v = vertical force, R_h = horizontal force, M_o = moment of forces at any point of the free body. Since the moments can not be further analysed in a three dimensional way, we must be certain that the object MI under consideration does not rotate.

The forces acting on MI are represented as follows (fig. V-2, 3):

R is the applied force on MI, its direction is known, that is the pull is directed toward the laboratory reference frame at an angle with the horizontal plane (fig. V-2).

In order to avoid variation in magnitude an isotonic spring is used, which exerts a calculated force of 0.7 Newton (0.07 kilogramme force). This force results in a loading force which is well below the breaking strength of the ligaments at their points of attachment to bone.

Anderson and Ekström (1940) already pointed at the great variety of applied forces on any object when carried out manually by the investigator. These variations of forces are a source of error and furthermore give irreproducible results.

The reacting force N goes through the perpendicular of the tangent at the point of contact (fig. V-3A). This tangent belongs both to MI and Tm, which coincides at the point of contact. The coëfficient of friction is so little, that it will not be considered. The vectors of the forces R and N meet in S. Since equilibrium exists the vector of L is going through S as well. If either N or L are unknown they can be found. From the closed figure of forces the relative magnitude of each of the forces in relation to R can be deducted if so desired.

Therefore the direction of the third resultant force (L) can be found. It has to go through S and also through the point of distal attachment of the ligament if the ligament is under tension. This ligament may be one or it may be the combination of two or more ligaments. In the latter case the direction found is the resultant of the forces acting in the chosen plane of the free body MI. If all forces are taken together in sequence, in e.g. clockwise direction, the resultant triangular or polygonal figure of R, N and L must be closed (fig. V-1). The sequence in which the forces are put together, clockwise or anticlockwise, is unimportant (*Hartog*, 1961; *Timoshenko and Young*, 1956).

The composition of the forces is always considered acting in one plane, that is the plane of the direction of the force R. If we view the model from "above" or rather from a distal to proximal direction, axial rotation comes into play. Mathematically, forces and moments in balance are considered in a plane perpendicular to the longitudinal axis of the specimen under study. If the balance of *forces* is lost in one plane, the freebody MI in that plane under consideration will translate. If the balance of *moments* is lost in a certain plane, the free body MI will rotate. (In each plane rotations can take place; if this plane is perpendicular to the longitudinal axis of the freebody it is called an axial rotation).

In priciple the consideration of balance of forces and moments is the same. However, it is more difficult with our present methods to obtain the proper information of all separate components of the forces of moments of the ligaments and the points of joint contact as to be able to apply our model.

The complexity of the composition of several forces is demonstrated in position D (fig. V-6), which will be described below. We have had to use the horizontal plane of projection. This became a necessity because while analysing the forces in the vertical plane not all factors could be used and/or explained in this one vertical plane only. This became clear when we were dealing with the anterior oblique ligament which was at one point acting solely in a horizontal plane. The second occasion occurred when the dorso-radial ligament was twisted so much in a horizontal direction that no vertical component could be found. At the same time the horizontal component of N became zero that is, this force acts perpendicular to the horizontal plane.

Furthermore as mentioned before, the horizontal projection demonstrates axial rotation by direct observation. In first instance any three points in space define a plane. In figure V-4A such a plane was taken through the three attachment points of the forces acting on MI; the point of attachment R, the point of attachment of the ligament L and the point of joint contact N. The direction of the force R_v is known. Its magnitude in the original drawing is arbitrarily taken. The dorso-radial ligament under tension runs in a straight line and meets R_v in S_v. The only point of contact lies volarly. The perpendicular on the conjoint tangent of the curvatures of joint surfaces at the point of contact also has to go through S_v. This point can therefore be found exactly at N_v. If it is easier to establish the point of joint contact and if the shape of the joint surfaces is known, then the force through the ligaments can be found. Such a situation is seen e.g. in position L (compare fig. V-2B and fig. V-5A). L_V is an almost true projection of the cut surface of the plane in which all the vertical forces act. The X-ray plate is almost parallel to the horizontal axis through the trapezium in ulnar to radial direction. Because the plane of projection equals the cut surface we can simply trace the contours. The drawing can be completed by adding the force R_V. The joint contact occurs in N. At this point the perpendicular N_V is erected and meets R_V in S_V. The tension of the ligaments exerts a force on MI and must by definition be going through S_V as well. A slight lengthening of such ligaments, due to their elasticity may take place. However, the elasticity factor only will act before the equilibrium is reached. Other forces of larger or lesser magnitude cause an increased or decreased elastic force and therefore a different excursion. This does not alter however the analytical principle of the object in equilibrium. This force generated in the ligaments is represented by L_V. L_V is the resultant of the forces of each ligament which takes part in the stabilization of MI.

b. The method

In our analysis we have approached the first carpometacarpal joint in two ways using a "vertical" and a horizontal plane. This vertical plane is taken as opposed to horizontal. In the vertical plane an attempt has been made to draw a plane from the actual specimen through the point of the applied force, the area of joint contact and the probable resultant force exerted by the ligaments. Each vertical plane therefore is taken at a different angle in each of the five positions considered.
While carrying out our investigations in this way, it was realized that in principle the same diagram of forces as well as the closed polygonal figure of forces could be obtained from the projections of these forces. In this way we are only using the components of the real forces in the plane of projection under consideration.
It is possible to approach the free body in equilibrium in all three planes of the three spatial coordinates using the same principles. We initially used the vertical plane only and thus approached the real situation as closely as possible. It soon became clear that not all features could be explained. Although the position of balance each time could be found, some functioning ligaments or parts of it seemed useless. Then the necessity of the horizontal (h) approach was born. Indeed all factors could then be accounted for. In this horizontal plane the components of the forces were analysed in the same five positions. The magnitude of the same forces may vary from one diagram to another in order to keep the drawing in the available space. Furthermore it must be said that we have used a mechanical approach to an anatomical situation. This is not new. However in the past such approaches resulted in symmetrical mechanical models which were far from the real situation and many aspects had to be ignored. The features which could not be explained were then accounted for by those aspects which were omitted in first instance (*Fick, A.*, 1856; *Bausenhardt*, 1949). Therefore the conclusions often ended with a remark that other factors also have to be taken into account and play a role.
That mechanical principles can be applied to anatomical specimen has been amply proven among others by *Huson* (1961) and *Snijders* (1971).

c. Description of the position of balance in sequence

In position J, in the vertical plane (v) as we have noted in chapter IV, the equilibrium is maintained by the forces R_v, the dorso-ulnar joint contact N_v and the anterior oblique ligament L_v. These forces are depicted in figure V-4A. The forces all go through S_v. They form, as separately shown, a closed triangle. In the horizontal plane two ligamentous components, a part of the dorso-radial ligament L_1 and the horizontal component of the anterior oblique ligament L_2, result in L_h. N_h is created in the point of joint contact. L_h, N_h and R_h meet in S_h. The closed triangle of forces is again shown separately (fig. V-4B).

In position L this vertical plane corresponds almost completely to the X-ray tracing. R lies in the plane of projection. Its direction is known and is drawn in this diagram. The joint contact lies in the dorso-radial compartment. The perpendicular N_v meets the vector of R_v in S_v (fig. V-5A). The ligamentous counterforce must be going through S_v as well. The tension is generated by the posterior oblique ligament L_1 and the anterior oblique ligament L_2. The resultant tension force L_v can be found by adding their two components together as is done in the ulno-volar view (inset). Since there is equilibrium, the forces can be put together forming a closed triangle shown separately (b). It can readily be seen that a relative small force R, which is arbitrarily taken, can create rather large reacting forces at the point of joint contact and tension forces in the ligaments. In this horizontal projection the equilibrium is also maintained by the applied horizontal component R_h. However the tangent of joint contact is parallel to the field of projection and therefore no horizontal component of N can be found. The dorso-radial ligament appears to balance MI, preventing sliding away. It has a horizontal component only, meeting R_h in S_h. The three other ligaments the anterior oblique ligament L_2, the posterior oblique ligament and the intermetacarpal ligament L_1 together (and the ulnar joint capsule) create a resultant third force going through S_h. Thus in this projection the equilibrium of MI solely depends on the ligamentous arrangement around the joint (fig. V-5B).

The position D has been the most complex and difficult one. Not only did more then one ligament take part in the position of balance, but also there was more than one area of joint contact. In the vertical plane it was not possible to find a satisfactory explanation.

Therefore it was decided to attack the horizontal projection first. In the horizontal projection the direction of R was known. The point S_h must be on this line. The next step was to decide by approximation the direction of L_h. L_h was found by approaching the direction of the individual functioning ligaments. The direction of the latter (the AOL, IML and POL) was taken to be the direction in which the wire shadows were running. First L_1, the average possible direction between the intermetacarpal ligament and posterior oblique ligament, was composed. Then the meeting point between L_1 and L_2 was taken. The resulting L_h has to go through this point and the direction of L_h must be somewhere between L_1 and L_2. Again the average was taken so that a preliminary point S could be determined. Without defenitely deciding on point S_h, the areas of joint contact were approached. These

points were determined in the previous chapter and marked in the drawing. Subsequently the possible directions of N_1 and N_2 in space acting on MI were considered. From this information the horizontal components were deducted. Each component could only be running in a limited field. By carefully trying to compose these two components and furthermore by trying to combine L_h and N_h in a simultaneous meeting point S_h the drawing figure V-6B resulted. The data obtained were again by trial and error transferred to the vertical drawing (fig. V-6A).
In reality the direction of forces may vary slightly but cannot be far from the truth, because the triangles of forces which resulted in both instances are closed.
For easy reading purposes we followed the pattern of systematic description below by considering first the vertical and then the horizontal plane. The following description of position D can be considered as a summary of the above.
In position D the complexity of an analysis, when more ligaments and more points of joint contact are partaking in balancing MI, is clearly shown and drawn in figure V-6A. In chapter IV we have seen that the force R runs in radial and slightly forward direction. The joint contact is located in two areas and the functioning ligaments are the anterior oblique, the posterior oblique and the first intermetacarpal ligament.
In the vertical plane this position of balance is shown in figure V-6A. The vertical force R_v is balanced by the composition of forces in the above mentioned ligaments resulting in L_v and the two areas of joint contact N_1 in the radio-dorsal and N_2 in the ulno-volar quadrant. The composition of N_1 and N_2 results in N_v. Because MI is in equilibrium R_v, L_v and N_v form a closed triangle shown separately. In the horizontal plane the applied force R_h creates tension in the intermetacarpal ligament and the posterior oblique ligament. These two components together result in L_1 (fig. V-6B).
Once more it is stressed that only the direction of the force vectors are used. The force vector drawn does not necessarily start at the point of joint contact.
The anterior oblique ligament causes the force L_2. L_1 and L_2 together cause L_h, the resulting force of all ligaments together. The points of joint contact are located in the dorso-radial and in the volar-radial joint compartment. At these points the force N_1 and N_2 are acting and their probable directions are drawn. Of importance is only the resulting force N_h. All these forces R_h, L_h and N_h meet in S_h. The triangle of forces is separately shown as a closed figure. Our main concern is to show the *direction* of the forces and their components.
In position K in the vertical plane the forces R_v, the dorso-radial ligament L_v and the perpendicular N_v in the volar joint compartment are meeting in S_v. (Note that there is no joint contact in the posterior joint compartment). The closed triangle is again shown separately (fig. V-7A).
In the horizontal projection L_h is composed of the anterior oblique ligament L_1 and the dorso-radial ligament L_2. The volar joint contact creates a component N_h. All three R_h, N_h and L_h meet in S_h. Their closed triangle of forces is shown separately (fig. V-7B).
In position I, in the vertical plane, the forces R_v, L_v from the dorso-radial ligament and the perpendicular N_v at the point of joint contact are shown (fig. V-8A).

In the horizontal projection the forces R_h the anterior oblique ligament L_h and the horizontal component of N are in equilibrium. They meet in S_h and their closed triangle of forces is shown separately (fig. V-8B).

Discussion

Our aim was to establish the relation between the joint shape and the ligaments surrounding the first carpometacarpal joint. For this purpose in last instance we have used a vector analysis. This vector analysis was used in our specimen only in the extreme positions. In the five positions in our model a situation of equilibrium had been established by means of a loading force, which was applied from the outside.

We have stressed the importance of the direction of the forces rather then the magnitude. In a simple example e.g. position J in the vertical plane this poses no problem.

If however more than one ligament is participating (e.g. in J_h) it is only possible to find the resultant force L_h when R_h and N_h are known. L_h however has no "point of attachment" so that its direction is still a guess. In this instance we have to approach the analysis with the most probable direction of the vectors in projection of all the ligaments that participate. Then their directions L_1 and L_2 are an indication for the most likely parallelogram of forces (fig. V-6A, 6B). If in position D the magnitude of L_1 and L_2 are known this parallelogram of forces could be more exactly drawn. We have been unable however to measure the magnitude of forces created in each ligament.

Furthermore the vertical and horizontal planes were checked against each other in regards to the area of joint contact and the functioning ligaments.

We consider that the error of obtaining the paralllelogram of forces is very slight, because if a functioning ligament (with the direction of the projection of this ligament) was omitted no satisfactory explanation could be obtained.

Furthermore a closed triangular figure of forces did not occur. The mechanical principle used has been discussed with the staff of the department of mechanical engineering of the Eindhoven University of Technology. This principle was then applied to our model.

In figure V-9 we have superimposed the horizontal projections of the five positions used.

The pathway of MI

The metacarpal head follows a closed curve which can be divided into two parts: the outer or *radial curve* and the inner or *ulnar curve*. The radial curvature is stronger than the ulnar curvature. This pathway is quite dissimilar to the symmetrical ball surface *Bausenhardt* (1949) obtained in his mechanical model. He admits that the anatomical specimen does not completely follow this theoretical model. However, even the observations of motion on the anatomical specimen does not at all show such a simple relation in the motion pattern pictured in this model. It has been just this very lack of correlation between a theoretical model and the anatomical structure that has stimulated us to investigate the typical nature of this joint. It is realised that our representation is only a horizontal projection of the actual excursion of the metacarpal head. However it is sufficient to contradict *Bausenhardt's* mechanical model. Furthermore the ulnar curve is *curved* rather than linear (*Caffinière*, 1970).

Axial rotation

In figure V-9 the axial rotation has been determined by the angular changes of the metacarpal condyles volarly and the ulnar and radial border of the volar aspect of the base of MI as represented in the horizontal projection. The resulting angular change, in reality the same, is also in projection almost similar.

Furthermore we do not agree that rotation is only taking place in the extremes of flexion and extension (*Haines*, 1944). Axial rotation is a *must* in all motions throughout the entire spectrum of extreme positions.

During clockwise motion of the right hand metacarpal I throughout the radial curve, from dorsal to volar, axial rotation also occurs in the same direction, that is clockwise, till just before position K, viewed from distal to proximal. By continuing motion throughout the ulnar curve from volar to dorsal, from position K via I back to J that is still in clockwise direction for MI, axial rotation occurs in the opposite way, that is in anticlockwise-direction.

Although *Gray* (1901) denies axial rotation we had already gained evidence of such axial rotation and with the aid of the drawing in figure V-9 there is no doubt that axial rotation indeed takes place.

The terms medial and lateral rotation (*Napier*, 1955) we would like to avoid because they are confusing and can be used in specific occasions only. As we have seen, axial rotation takes place in the opposite direction during adduction.

Furthermore *Napier* is influenced by *MacConnaill* using the term conjunct rotation as well. *Napier's* main aim is to clarify two routes of motion: an indirect and a direct route. Since he cannot explain rotation *Napier* jumps to the opponens pollicis muscle. This would then be the rotator of the thumb causing a so-called adjunct rotation. His theories are demonstrated with a living hand which picks up small and large objects.

It clearly sounds contradictory, when *Napier* later discusses movements, that during the direct motion the congruent joint surface with the posterior oblique ligament requires no rotator muscle and during the indirect motion the opponens pollicis does all the axial rotation without mentioning an antagonist rotator to recover from this rotated position. He ignores the function of all the other ligaments.

MacConnaill (1946) also noted a clockwise rotation of the thumb without saying in which hand, left or right. He states that a clockwise displacement upon a sellar surface is accompanied by an anticlockwise conjunct rotation of the displaced body. We did not find this true for the first carpometacarpal joint.

Area of joint contact

A third feature, which also was noted during analysis in the vertical plane, was the place of joint contact during motion. During motion throughout the radial curve, joint contact occurred in the perophery, that is radially. During motion throughout the ulnar curve joint contact occurred medially, that is in the ulnar half of the joint compartment. This is in direct contrast to *Bausenhardt's* finding. He states that the trapezium must be considered a modified curve cone surface, this is taken to be the ulnar part of the trapezium, about which the metacarpal I swings. In figure V-9B we have depicted the areas of joint contact on the trapezium. In the positions L and D the contact lies radially and in the positions K, I and J the contact lies on the ulnar side.

Conclusions

In conclusion we may say that:

1. The arrangement of the ligaments and their function as such follow mechanical priciples. By combining the mechanical characteristics of ligaments and area of joint contact a model can be built.
2. The MI follows a closed curved pathway which can be divided into a *radial curve* and an *ulnar curve*.
3. Axial rotation is a must in all motions throughout the entire spectrum of extreme positions. It occurs in clockwise direction in the radial curve and in anticlockwise direction in the ulnar curve, when moved from dorsal to volar and viewed from distal to proximal for the right thumb.
4. The area of joint contact can be found in the direction in which the loading force R is applied.
5. A small loading force R can and sometimes does create large reacting forces in the ligaments and the area of joint contact.

Although we do not completely agree with the term saddle joint, it seems impossible and furthermore not usefull to eradicate the saddlejoint concept. It is hoped that it does not really matter as long as its mechanism is clearly understood.

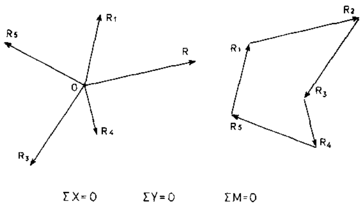


Fig. V-1

Fig. V-2

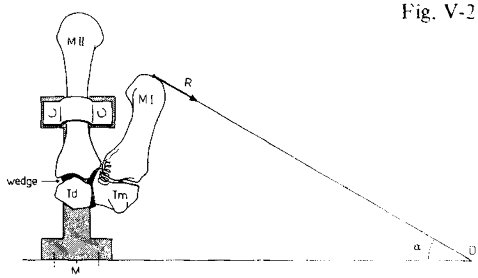


Fig. V-3

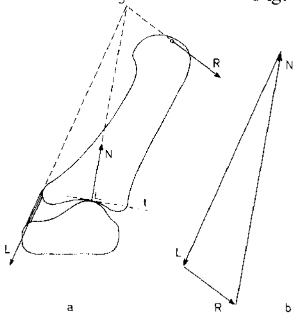


Fig. V-1
If equilibrium of the forces R_1, R_2, R_3, R_4, and R_5 exists then the equations X = 0, Y = 0 and M = 0 are valid. The polygonal resulting from the composition of forces is closed.

Fig. V-2
MII is mounted on a perspex bar. Its longitudinal axis is perpendicular to the horizontal plane. The trapezoid and trapezium are firmly connected with MII. This rigidity was augmented by forcing wooden wedges between the joints to ensure maximal tension on all ligaments. MI is mobile. The force R is variable in direction. Its magnitude is constant and is kept within reasonable limits preventing pulling the specimen apart. Its direction is determined by the points J, L, D, K and I. R runs at an angle with the horizontal plane which varies a few degrees in the different positions. This variation is not important for our analysis. R can be resolved into a horizontal and a vertical component. The latter ensuring joint contact in all positions.

Fig. V-3
The model diagram which was used in the five positions of equilibrium J, L, D, K and I. R is the applied force by means of the isotonic spring. N is the perpendicular force on MI erected at the conjoint tangent (t) of the articular surfaces of the distal trapezium and the proximal metacarpal I. L is the force of the ligament exerted on MI. In this situation of equilibrium, as shown, all three forces must go through S. (a). The forces R, L and N are singled out parallel to their directions and are put together in one figure. The magnitude of R is arbitrarily chosen. If its length would be an indication of the magnitude of the forces N and L, it can readily be seen that a small force R creates large forces N and L at the first carpometacarpal (b).

Fig. V-4A

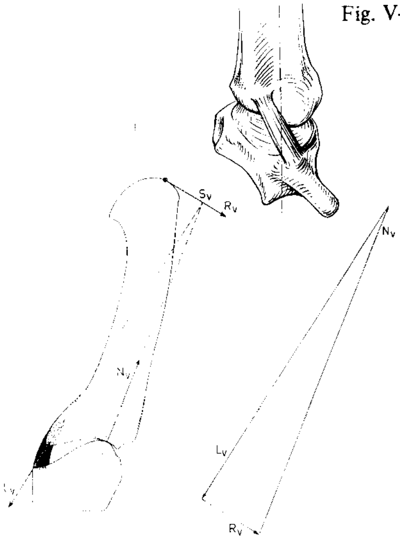


Fig. V-4B

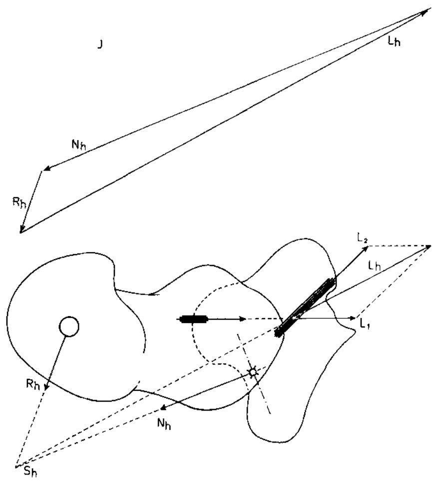


Fig. V-5A

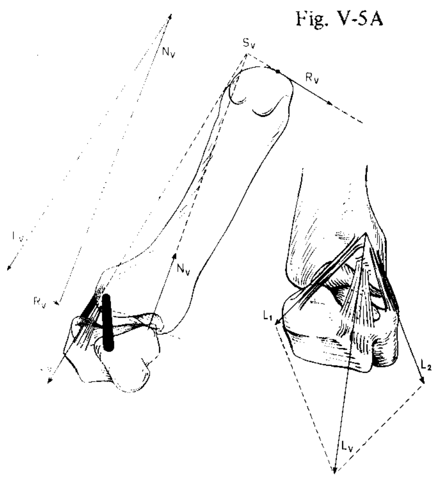


Fig. V-5B

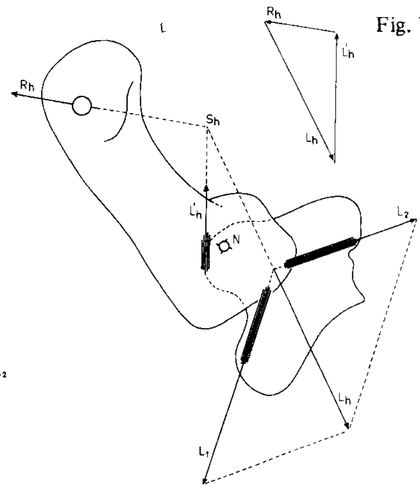


Fig. V-4A
The vertical vector diagram of position J showing the applied force R_V and the reacting forces L_V and N_V at the point of attachment of the ligament and joint contact respectively (a). The vector L_V coincides with the projection of the anterior oblique ligament (inset top). The composition of forces results in a closed triangle (b).

Fig. V-4B
The horizontal vector diagram of position J (a) and the closed triangle of the composition of forces (b).

Fig. V-5A
The vertical vector diagram of position L showing the forces R_V, N_V and L_V (a) and the composition of forces resulting in the closed triangle (b). L_V consists of the resultant force obtained from the POL with the IML and the AOL (inset right).

Fig. V-5B
Horizontal vector diagram of position L showing the forces R_h, N_h and L_h. Note that in this projection the component of force N at joint contact is zero because N runs perpendicular to the plane of projection.

Fig. V-6A

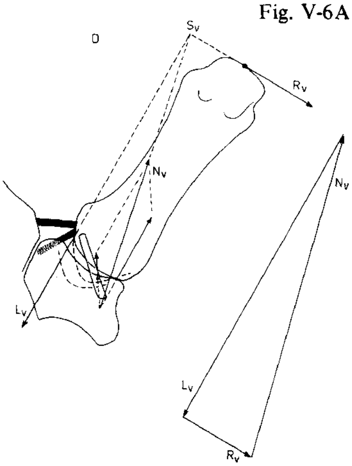


Fig. V-6B

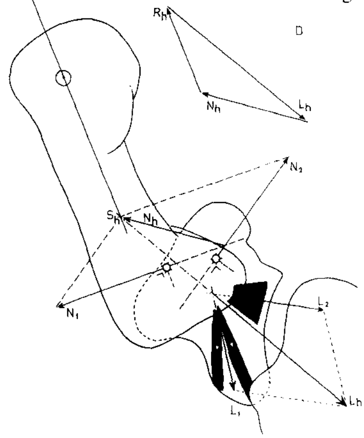


Fig. V-7A

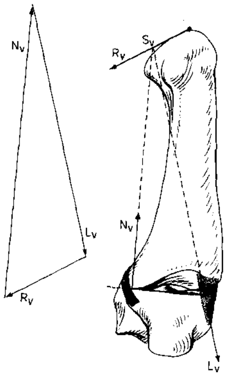


Fig. V-7B

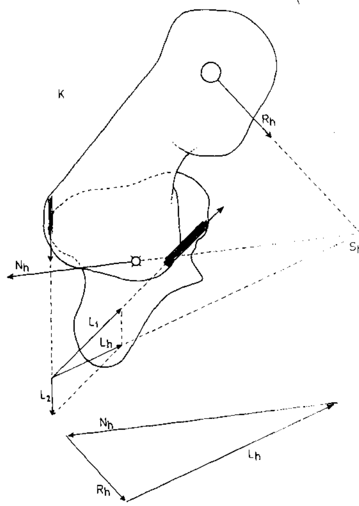


Fig. V-6A
The vertical vector diagram of position D showing the force R_v, N_v and L_v. Because there are two areas of joint contact, N_v has to be composed of the vertical components of N_1 and N_2 (a). The composition of forces results in a closed triangle (b).

Fig. V-6B
The horizontal vector diagram demonstrates the complexity of the composition of the forces acting on MI in case of two areas of joint contact. The L_h has been composed of three ligaments.

Fig. V-7A
The vertical vector diagram of position K. The equilibrium is being maintained by the applied force R_v, the tension of the dorso-radial ligament L_v and the point of joint contact N_v in the volar joint compartment. Note that there is *no* joint contact in the dorsal joint compartment (a). The closed triangle resulting from the composition of forces (b).

Fig. V-7B
The horizontal vector diagram of position K is maintained by R_h, the horizontal component of the dorso-radial ligament L_2 and the horizontally running anterior oblique ligament L_1. The joint contact is located in the volar joint compartment (a). The closed triangle resulting from the composition of forces (b).

Fig. V-8A

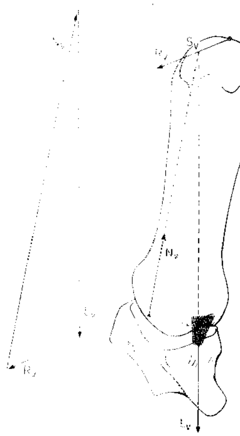


Fig. V-8B

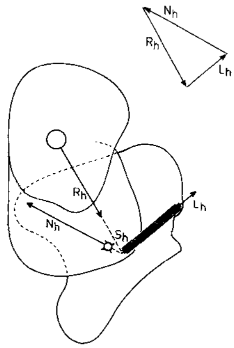


Fig. V-9A

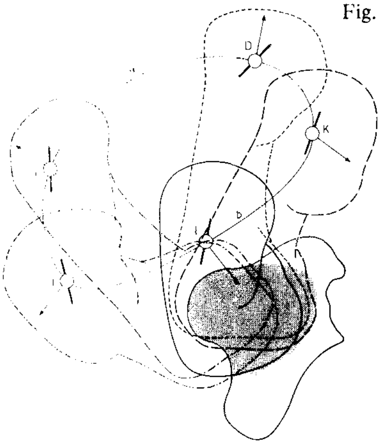


Fig. V-9B

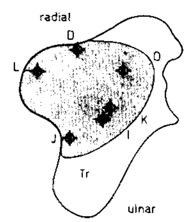


Fig. V-8A
The vertical vector diagram of position I showing the forces R_v, N_v and L_v (a) and the closed triangle of the composition of forces (b).

Fig. V-8B
The horizontal vector diagram of position I showing R_h, N_h and L_h (a) and the composition of forces resulting in the closed triangle (b).

Fig. V-9A
Drawing showing a composition of overprojections in a horizontal plane of all five positions. Each time the arrow indicates the direction of the applied force. The pathway of the metacarpal head is divided into the outer or *radial curve* (a) and the inner *ulnar curve* (b). The direction of the axial rotation is indicated by the marker on the metacarpal head.

Fig. V-9B
The points of joint contact in the positions J, L, D, K and I are put together in one picture. This demonstrates clearly that in the ulnar curve the joint contact lies about the "neck" of the trapezium and in the radial curve the joint contact lies radially.

SUMMARY

An insight in the kinesiology regarding the relationship between joint shape and ligaments of the first carpometacarpal joint has been our aim.
The included detailed microscopic and macroscopic study resulted in a modification of some existing and an introduction of some new names of the bones and ligaments concerned. With complementary X-ray studies, in which the ligaments were wired, a relation between the areas of joint contact and the functioning anterior oblique (AOL), posterior oblique (POL), intermetacarpal (IML) and dorsoradial ligament (DRL) could be established.
In conclusion we can say that the joint behaviour based on the "solids of revolution" theory has not been satisfactory. Instead we attempted to explain joint properties in the light of a free body in equilibrium. This resulted in a confirmation of axial rotation, a new concept of the pathway of metacarpal I and the area of joint contact.
In figure V-9 we have superimposed the horizontal X-ray projections of the five positions used.
MI follows a closed oval pathway which can be divided into two parts: the outer or *radial curve* and the inner or *ulnar curve*. This oval curve differs from *Bausenhardt's* (1949) concept.
The center of MI shows an axial rotation throughout the entire motion spectrum of extreme positions rather than in flexion and extension only (*Haines*, 1944). During motion in the radial curve MI rotates in a clockwise direction and in the ulnar curve axial rotation occurs in an anticlockwise direction in the right hand, viewed from distal to proximal. This finding differs from *MacConnaill's* (1946) concept of clockwise and anticlockwise rotations. The area of joint contact in the radial curve is noted in the periphery, that is radially. In the ulnar curve this contact is present in the ulnar joint compartment in contrast to *Bausenhardt's* (1949) findings.

SAMENVATTING

Het was ons doel een inzicht te krijgen in de kinesiologie betreffende de relatie tussen de ligamenten en de vorm van het eerste carpometacarpale gewricht.
Het noodzakelijk gedetailleerd mikroskopisch en makroskopisch onderzoek leidde tot een modifikatie van enkele bestaande en een introduktie van enkele nieuwe namen van de betrokken botjes en ligamenten. Met aanvullende rö-foto's, waarbij de ligamenten met draadjes waren omwikkeld kon een relatie worden aangetoond tussen de punten van gewrichtskontakt en de funktionerende anterior oblique (AOL), posterior oblique (POL), intermetacarpale (IML) en dorso-radiale ligamenten (DRL).
De konklusies leidden ertoe dat het gewrichtsgedrag, gebaseerd op de theorie van de omwentelingslichamen niet bevredigend is. We hebben in plaats hiervan geprobeerd de gewrichtseigenschappen te benaderen vanuit een vrij lichaam in evenwicht. Dit resulteerde in de bevestiging van een axiale rotatie van MI, een nieuw inzicht in het bewegingspatroon van MI, en verder het gebied van gewrichtskontakt.
In figuur V-9 hebben we de horizontale rö-projekties van de vijf onderzochte posities samengesteld. MI volgt een gesloten ovale baan die kan worden verdeeld in twee delen: de buitenste of *radiale kurvatuur* en de binnenste of *ulnaire kurvatuur*. Deze ovale baan verschilt van *Bausenhardt's* (1949) opvatting. Het centrum van MI maakte een axiale rotatie door tijdens de *gehele* beweging van extreme posities in plaats van alleen in flexie en extentie (*Haines*, 1944). Gedurende de beweging in de radiale kurvatuur roteert MI in dezelfde richting en in de ulnaire kurvatuur vindt axiale rotatie plaats in tegengestelde richting van de wijzers van de klok voor de R. hand gezien van de distaal naar proximaal. Deze bevinding verschilt van *MacConaill's* (1946) opvatting van klok en anti-klok rotaties. Het gewrichtskontakt in de radiale kurvatuur ligt in de periferie, dat is radiaal. In de ulnaire kurvatuur ligt het kontakt in de ulnaire helft van het gewricht in tegenstelling tot *Bausenhardt's* (1949) bevindingen.

LIST OF ABBREVIATIONS

DIM	first dorsal interosseus muscle
FCR	flexor carpi radialis
AOL	anterior oblique ligament
IML	first intermetacarpal ligament
POL	posterior oblique ligament
FR	flexor retinaculum of carpal tunnel
PIM	palmar interosseus muscle
CT	carpal tunnel with contents
EDC	extensor digitorum communis
EPB	extensor pollicis brevis
APL	abductor pollicis longus
ECR	extensor carpi radialis longus and brevis
ThM	thenar musculature
LT	Lister's tubercle
FPL	flexor pollicis longus
RR	radial root flexor retinaculum
EPL	extensor pollicis longus tendon
M	metacarpal
JC	jointcapsule
VJM	volar joint margin
DJM	dorsal joint margin
ADI	arcade first dorsal interosseus muscle
DRL	dorso-radial ligament

tm / Tm	trapezium
td / Td	trapezoid

vut	volar-ulnar tubercle of the base of metacarpal I
dut	dorso-ulnar tubercle of the trapezium
drt	dorso-radial tubercle of the trapezium
vr	volar ridge
vn	volar notch of the trapezium
vsp	volar styloid process metacarpal I
cmc	first carpometacarpal joint
dsp	dorsal styloid process of metacarpal I
r	radius
u	ulna
l	lunate
t	triquetrum
p	pisiforme
s	scaphoid
c	capitate
h	hamate
ar	arteria radialis
dn	dorsal notch trapezium
app	arteria princeps pollicis
rpp	radial proximal pole MII

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