THE FORM AND FUNCTION OF THE CARPO-METACARPAL JOINT OF THE THUMB

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Although this joint has been extensively studied by many workers including Fick, L. (1854), Fick, R. (1911), Du Bois Reymond (1895, 1896), and more recently by Haines (1944), certain aspects of its motion in relation to the function of the thumb, and in particular to the part played by the joint in the complex movement of opposition, would seem to merit further investigation in the light of MacConaill's (1946 *a–d*) studies of the fundamental mechanics of synovial joints.

The exact status of the term opposition is in itself a problem that cannot be solved by turning to the standard books of reference. Opposition is used here in a functional sense and is defined as that movement which results in the pulp surface of the thumb becoming diametrically opposed to the pulp surface of one or other of the remaining digits for the purposes of prehension.

The observations made are based upon examination of the joint in forty-two cadavers during the course of a previous investigation (Napier, 1952) and upon six dissections recently carried out.

OBSERVATIONS AND DISCUSSION

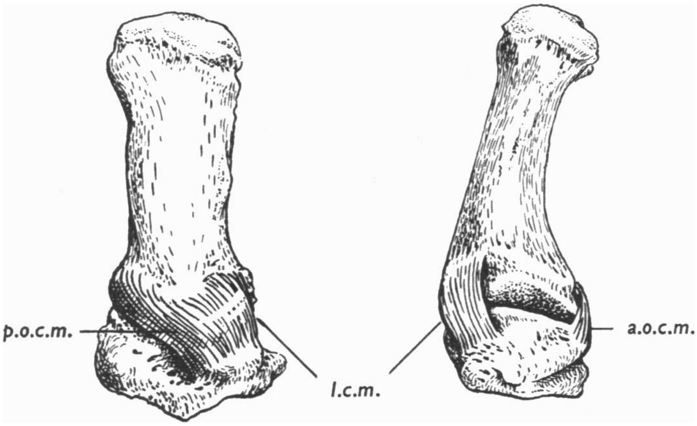
The form of the articular surfaces

The carpo-metacarpal joint of the thumb is composed of two articulating surfaces which are concave in one principal section and convex in the other. The joint differs in one important respect from other saddle-shaped joints. Sections made of the ankle joint, for example, in the planes of its two principal curvatures demonstrate a relative congruity between the articulating surfaces when the joint is in the neutral position. Corresponding sections through the first carpo-metacarpal joint held in the neutral position reveal quite a different state of affairs. In the radio-ulnar section virtual congruity is apparent, but in the dorsi-palmar section a wide disparity is seen between the two bones (Text-fig. 4). The curvature of the metacarpal base is considerably greater than that of the distal surface of the trapezium, so that there exists between them a wedge-shaped interval that, in life, is filled partly by synovial fluid and partly by fibro-fatty synovial folds (Haines, 1944). It is upon this incongruity, together with the relaxed condition of the ligaments, that the well-known passive mobility of the joint in its mid-position depends (Fick, R., 1911). Attempts to rotate the thumb passively in a fully abducted or adducted position, on the other hand, meet with the resistance of congruous surfaces and tense ligaments.

Arrangement of ligaments

Haines (1944) has given a comprehensive account of the ligaments of the first carpo-metacarpal joint and his observations have been, in the main, confirmed in the present series of dissections. Special mention, however, should be made of the lateral carpo-metacarpal ligament which consists of vertical fibres attached to the postero-lateral aspect of the metacarpal and to the posterior tubercle of the trapezium (Text-fig. 1); and of the posterior oblique carpo-metacarpal ligament whose fibres reach their distal attachment to a tubercle on the medial side of the metacarpal after an oblique course.

Haines (1944) suggests that these two ligaments are discrete, but in the six dissections of the present series their fibres were found to merge at their edges.



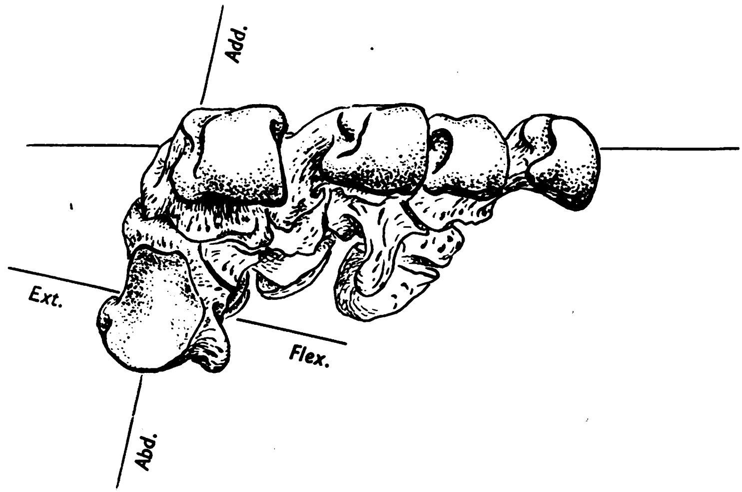
Text-fig. 1. Dissection showing the position and attachments of the three main ligaments of the carpo-metacarpal joint of the left side: (*a*) posterior view, (*b*) lateral view. *p.o.c.m.*, posterior oblique carpo-metacarpal ligament; *l.m.c.*, lateral carpo-metacarpal ligament; *a.o.c.m.*, anterior oblique carpo-metacarpal ligament.

Motion in the joint

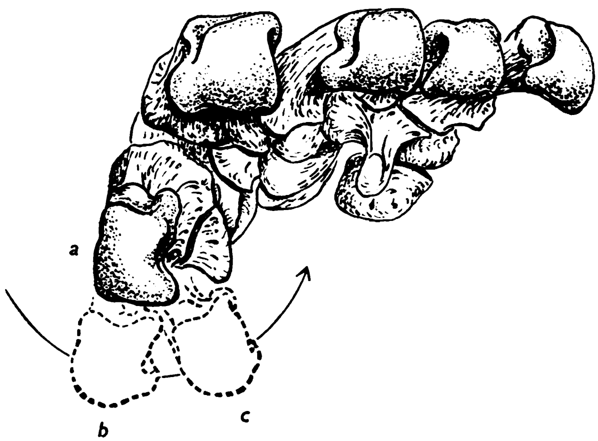
The neutral position of the thumb metacarpal is taken as the starting-point for a description of the movements; this not only simplifies description, as Haines (1944) has observed, but is an entirely logical starting-point since it corresponds to the position of rest of the thumb in the living hand. In the account which follows, the movements of the metacarpal are defined in terms of the axes of the distal articular surface of the trapezium rather than directly in terms of the plane of the palm. The trapezium is set in the carpus in such a manner that the long axis of its distal articular surface makes an angle of 80° with the plane of the palm (Text-fig. 2).

Thus, in the angular movement of abduction the metacarpal moves away from the index finger in a somewhat antero-lateral direction, making an angle of 80° to the plane of the palm. During flexion, which takes place in the plane of greatest convexity of the trapezium, the thumb passes medially and 10° forwards of the plane of the palm. The movements of flexion and extension are sliding movements of the metacarpal on the trapezium with a somewhat limited range. For present purposes it is sufficient to consider both these movements as uniform translations along a chord, and they are, therefore, by definition, movements free from any associated rotation. This can be shown to be true in an osteo-ligamentous preparation providing abduction is prevented.

The movements of abduction and adduction take place in a plane which corresponds to the greatest concavity of the trapezium which is at right angles to the plane of flexion-extension. Abduction-adduction movements are brought about mainly by a sliding of the metacarpal on the trapezium and they, too, can be regarded



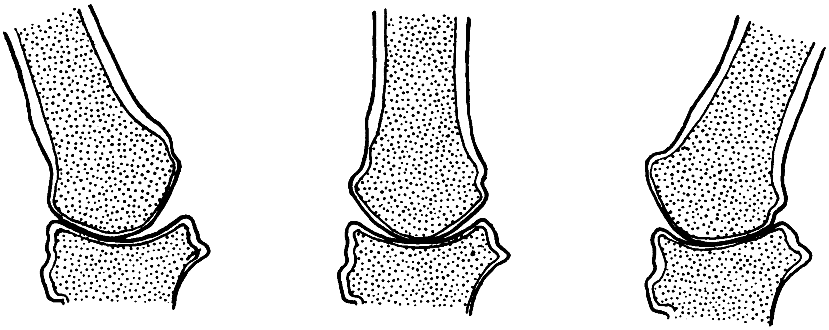
Text-fig. 2. The carpal and metacarpal bones of the left hand seen in vertical view. The 1st metacarpal has been omitted to expose the distal articular surface of the trapezium. The planes of flexion-extension (*Flex.-Ext.*) and abduction-adduction (*Abd.-Add.*) are indicated.



Text-fig. 3. The view is the same as in Text-fig. 2, but in this case the 1st metacarpal is in place. *a*, metacarpal head in neutral position; *b*, in abduction; *c*, in full medial rotation.

as uniform translations, for they are unassociated with any rotation when flexion or extension are prevented. The axes round which these angular movements occur are illustrated by Toldt (1901) in fig. 389 of his Atlas.

As the metacarpal is abducted, the lower end of the bone is displaced in a dorsal direction towards the index metacarpal until a relative congruity of the surfaces is established (Text-fig. 4). Similarly, the opposite displacement of the base of the first metacarpal, that is to say in a direction away from the index metacarpal, occurs during adduction (Text-fig. 4). During this movement in the living hand an obvious prominence appears on the radial border of the hand (Pl. 1, fig. 1) and disappears when the thumb is returned to the neutral position. This gross displacement of the metacarpal base reflects the extent of the sliding movement which converts what is virtually a point contact into the state of relative congruity that obtains in abduction. When the thumb is fully abducted, it may be freely circumducted* in either an ulnar or a radial direction: movement in an ulnar direction is associated with medial rotation of the metacarpal, and movement in a radial direction with lateral rotation.



Text-fig. 4. Diagrams of a longitudinal section of the 1st left carpo-metacarpal joint made in the abduction-adduction plane. Note the incongruity apparent in the mid-position.

During each of these movements the metacarpal traverses, in effect, a quadrant of the total pathway of circumduction. The pathway traversed by the head of the metacarpal consequent upon an abduction followed by a circumduction displacement of the base can be regarded as a movement starting from the centre of a circle, passing along the radius to the circumference and then along the circumference itself. The second part of its course necessarily involves a change in direction of the head. This two-part movement is an example of a *diadochal* movement (Text-fig. 3, *a–b–c*). MacConaill (1946*b*) has shown mathematically that a diadochal movement at any joint is necessarily accompanied by a degree of axial rotation at the articular surface, that, in terms of the generalized geometry of curved surfaces, is known as a *conjunct* rotation. Thus, in the carpo-metacarpal joint of the thumb, medial rotation of the metacarpal is a conjunct rotation and is the *inevitable accompaniment of abduction followed by circumduction in an ulnar direction.*

The serial photographs in Pl. 1, figs. 2–5, illustrate, in a functional manner, this movement of circumduction in a living hand. In Pl. 1, fig. 2, the thumb is shown fully abducted at the carpometacarpal joint, but, although it is functionally opposing

* Circumduction is here used to describe that form of motion that takes place between the head of a bone and its articular cavity when the bone is made to circumscribe a conical space (*Gray's Anatomy*, 1954 edition). It is not used in the theoretically general sense in which MacConaill (1946*b*) employs it.

the 5th digit, it has not yet undergone any measureable medial rotation at this joint; the rotation of the thumb apparent in this photograph is taking place at the meta-carpo-phalangeal joint and not at the carpo-metacarpal joint. In Pl. 1, fig. 5, the thumb is shown in opposition to the index finger, its metacarpal now being both fully abducted and fully medially rotated. The thumb can attain this terminal posture by traversing the circumduction pathway through the series of stages illustrated, but it can also achieve it by following an alternative and more direct pathway which might be described as a short cut. Starting from a position of rest (the mid-position of the joint) the thumb may move *by a direct route* to a posture where it is in opposition to the index finger (Text-fig. 3, *a–c*) without having traversed the intermediate stages. This latter movement may be visualized by sliding the thumb distally from its position of rest opposite the terminal interphalangeal joint of the index finger until the tip of the finger is reached. This movement, which is in fact the habitual one in the normal hand when objects of small size are handled, consists of a movement of medial rotation combined with flexion and abduction.

The behaviour of the ligaments of the carpo-metacarpal joint of the thumb in an osteo-ligamentous preparation provides evidence in support of the reality of these two alternative pathways. In the neutral position all ligaments of the joint are relaxed. As the thumb metacarpal is moved through the first leg of the diadochal pathway (Text-fig. 3, *a–b*), that is to say when it is abducted, the posterior oblique ligament becomes tense, and the lateral ligament becomes further relaxed. During the second leg of the movement (Text-fig. 3, *b*, *c*)—the circumduction component—axial rotation of the bone occurs inevitably with the application of a *flexing* force. The posterior oblique ligament remains tense throughout this phase. During the short-cut movement, on the other hand, medial rotation is not inevitable and requires the application of a *rotatory* force to bring it about. During this movement the posterior oblique ligament remains lax until the rotation is nearly complete, at which time tension develops. This tension does not, however, develop as a direct result of medial rotation or again of flexion, as Haines (1944) has suggested, but as a result of the abduction component of the short-cut movement which effects a separation of the bones on the side nearest the index finger and, therefore, a separation of the extremities of the ligament. In fact, throughout simple flexion the posterior oblique ligament remains relaxed.

Thus, in an osteo-ligamentous preparation, full medial rotation can be brought about by movement of the metacarpal through two different pathways to reach the same end-point: (1) an *indirect* movement consisting of abduction followed by circumduction and accompanied by medial rotation; (2) a *direct* movement of medial rotation, accompanied by flexion and abduction. During the indirect movement the ligaments of the joint manifestly contribute to the rotation while in the direct movement they remain relaxed until the movement is virtually complete.

Thus it would appear that the rotation of the metacarpal, which occurs during the direct movement, must depend largely upon the existence of a special rotator muscle. The opponens pollicis would seem to be admirably situated in this respect. Such a movement is termed an *adjunct* rotation (MacConaill, 1946*b*), and is made possible in this instance by the incongruity of the articular components of the joint, discussed above. At the extreme of the direct movement, however, when congruity is finally established, it is probable that an element of conjunct rotation is present, but its effect is insignificant in the presence of the well-marked adjunct rotation.

Fick, R. (1911) points out that in spite of the saddle-form of the articular surfaces longitudinal rotations are not impossible, owing to the loose composition of the joint. He does not make it clear, however, that such rotations are only possible when the joint is in its mid-position. Theoretically, the direct or short cut movement, which is essentially a longitudinal rotation, can only occur in the mid-position when the laxity of the joint and the incongruity of the articular surfaces favour such a movement.

The following case history of a patient who has been under personal observation for 10 years provides some evidence in support of these anatomical observations by demonstrating that paralysis of the opponens pollicis does not abolish the mechanism of medial rotation of the metacarpal:

G. F. C., age 39, male. Gunshot wound. R. arm, resulting in a median nerve paralysis. Nerve exploration revealed 8 cm. gap in median nerve. Suture was not attempted. When examined 7 years after injury the abductor pollicis brevis and opponens pollicis were completely paralysed but the flexor pollicis brevis was acting strongly (Pl. 1, fig. 6). The functional opposition of the thumb was not perfect (Pl. 1, fig. 7) owing to the loss of abduction and rotation of the proximal phalanx, but the metacarpal could be fully abducted and medially rotated by the combined action of the abductor pollicis longus and flexor pollicis brevis.

The patient is only able to achieve opposition by the indirect movement. Abduction is achieved by the contraction of abductor pollicis longus, while the flexor pollicis brevis provides the angular force necessary to circumduct the metacarpal in an ulnar direction. The medial rotation accompanying the circumduction movement is clearly quite independent of the opponens pollicis muscle which, in this case, was paralysed.

Functional considerations

Duchenne (1856) records that on electrical stimulation of the abductor and flexor pollicis brevis, the movement which preceded opposition depended on the posture of the thumb at the time of stimulation. When the thumb was stimulated in its 'natural position' (*sic*) the movement followed the shortest course, but when the thumb was initially abducted, opposition was preceded by a sweeping movement of the thumb which he describes as 'a sort of circumduction'. It is clear from this description that although Duchenne recognized the existence of two alternative pathways he was not, apparently, aware of their functional significance.

The characteristic requirement of prehensile movements of the hand is that of stability. In respect of the thumb this stability is achieved by full abduction or full adduction at the carpo-metacarpal joint; either action renders the articular surfaces congruent. In movements in which the demands of precision are paramount and the need for power is of secondary importance, the thumb is fully abducted at the carpo-metacarpal joint. If, on the other hand, the need for power is paramount the thumb is fully adducted at this joint (Napier, 1953). During precision movements, the thumb provides the requisite stability to the grip by opposing one or other of the digits. This state of opposition can be achieved, in respect of the metacarpal, by movement along either of two pathways. In following the *indirect* pathway the thumb undergoes, first, abduction at the carpo-metacarpal joint, followed by circumduction in an ulnar direction, a movement which has the effect of increasing the degree of axial rotation of the first metacarpal and, at the same time, reducing the span of the hand. Clearly there is a need, therefore, for a precise correlation between circumduction and axial rotation throughout the whole range of movement, so that the hand may accommodate itself to objects of different sizes without losing opposition and, thereby, sacrificing stability. Such perfect integration does not depend upon the function of opposing groups of rotatory muscles, as would be the case were the joint of the ball-and-socket variety, but upon the reciprocal congruence of the articular surfaces and a suitable arrangement of ligaments. Once the first metacarpal is abducted it is guided into the requisite degree of medial rotation as ineluctably as a child is conducted down the spiral way of a helter-skelter.

Alternatively, opposition of the thumb may be achieved by moving the first metacarpal through the *direct* pathway. The axial rotation in this case is not attributable to the possession of congruent articular surfaces and a tense posterior oblique ligament, but to incongruent surfaces and a complete laxity of all ligaments. The movement, it is suggested, is effected by a special rotator muscle—the opponens pollicis. This direct movement is habitually employed when objects small enough to be stabilized between finger and thumb are handled. The wide excursion of the metacarpal through the indirect pathway (Pl. 1, figs. 2–5) is necessarily employed when picking up an object too large to be held conveniently between finger and thumb.

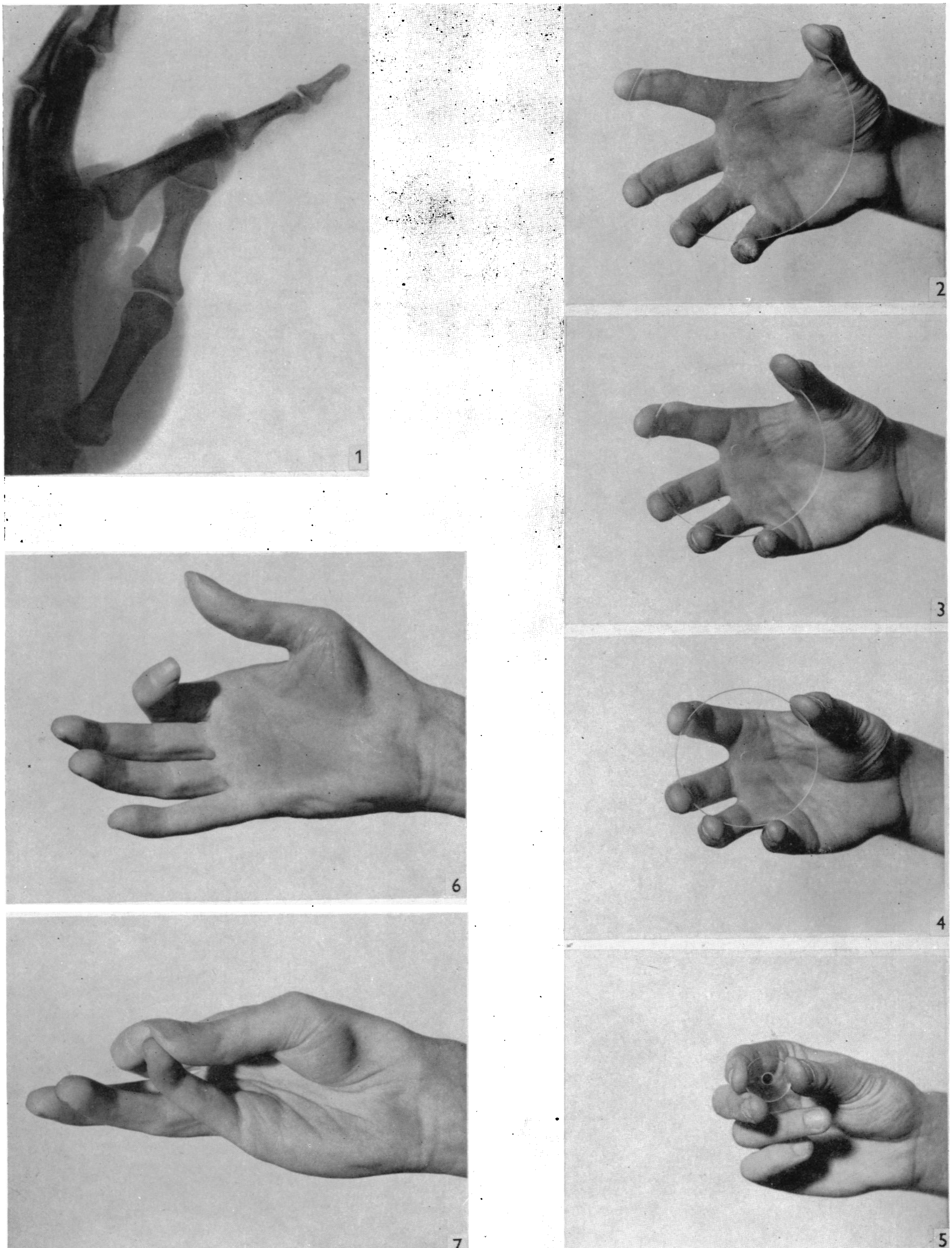
SUMMARY

1. The observations are based on the examination and dissection of the first carpo-metacarpal joint in forty-eight dissecting room and post-mortem subjects.

2. An account is given of the contours of the joint's surfaces and the arrangement of ligaments. In the mid-position of the joint the articular surfaces are markedly incongruent and the ligaments are relaxed, conditions which favour the well-known passive mobility of the joint in this position. Attempts to rotate the thumb passively in a fully abducted or adducted position, on the other hand, meet with the resistance of congruous surfaces and tense ligaments.

3. Motion in the joint is described, particularly the movements of the metacarpal which result in medial (axial) rotation of the bone. The significance of these movements is discussed in the light of MacConaill's (1946 *a–d*) studies on the fundamental mechanics of synovial joints. It is suggested that there are two alternative pathways—here termed *direct* and *indirect*—by which the metacarpal may move into its fully rotated position, the former being dependent upon the loose composition of the joint in its mid-position, and the latter upon the state of congruity that exists between the articular surfaces when the joint is abducted.

4. The functional significance of these alternative pathways are discussed in terms of the function of the hand as a whole. It is suggested that the selection of the appropriate movement in the normal living hand is dependent mainly upon the dimensions of the object to be handled.



NAPIER—Form and function of the carpo-metacarpal joint of the thumb

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EXPLANATION OF PLATE

Fig. 1 Radiograph of normal hand taken in the A.P. plane of first metacarpal which is fully adducted. Note the extent of the lateral displacement of the base of the bone.

Figs. 2–5. The photographs illustrate in a living hand the movement of circumduction of the thumb in an ulnar direction taking place at the carpo-metacarpal joint. The thumb is in opposition with one or other of the digits throughout the series.

Fig. 6. Photograph of the right hand of a patient (G. F. C.) with a high division of the median nerve. Abductor pollicis brevis and opponens pollicis are paralysed but flexor pollicis brevis is active.

Fig. 7. The same patient performing thumb to little finger opposition. Abduction and rotation of the proximal phalanx of the thumb is not complete, however, owing to the paralysis of the abductor pollicis brevis.