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Studies on the hand in ulnar nerve paralysis

*A clinical-experimental investigation
in normal and anomalous innervation*

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Introduction

With the increasing interest in reconstructive hand surgery knowledge of the nerves and muscles of the hand is of fundamental importance. Considerable contributions in this respect have been made by Foerster (1929), Saikku (1947), Bunnell (1956), Landsmeer (1955, 1963), Moberg (1958, 1962, 1964) and Stack (1962).

Despite these contributions surgeons less experienced in operations on the hand are apt occasionally to miss injuries of the ulnar and median nerves. Injuries of the radial nerve, on the other hand, are more readily recognised.

The reasons why these nerve injuries are apt to remain concealed are *firstly* the lack of adequate methods for estimating loss of strength of muscles with nerve injury, and *secondly* inadequate knowledge of the functions and muscular movements of the hand.

Of the three aforementioned nerves, it was the radial nerve that was most commonly damaged in the first world war (Pollock 1919, Foerster 1929). To-day, however, it is the ulnar nerve which is more frequently injured than the other two nerves in members of the armed forces on active service and in the civilian population (af Björkesten 1947, Woodhall 1947, Zachary 1954, Zachary and Roaf 1954, Nicholson and Seddon 1957, Bateman 1962, Mumenthaler and Schliack 1965).

Though the literature on lesions of the ulnar nerve is voluminous (Mumenthaler (1961) gives more than 350 references) the investigations on record are based on various types of injury such as pareses and paralyses. They are classified according to level, and to the patients' ages and occupations. The interval between the injury and the examinations also varies widely, the interval sometimes being sufficient for contractures to develop or for the patients to learn trick movements, *i.e.*, various manipulations to compensate the loss of strength of certain muscles (Braithwaite, Channel, Moore and Whillis 1948). Lesions of the ulnar nerve are also sometimes complicated by local simultaneous fractures and often by lesions of tendons.

In such heterogeneous series it is difficult to estimate functional losses after injuries of the ulnar nerve.

In the present investigation it was therefore decided to study the effect of induced paralysis of the ulnar nerve on the function of the hand in as homogeneous a series as possible.

Plan of the investigation

As mentioned above, no simple, adequate method was available to measure the strength of hand muscles supplied by the ulnar nerve. A suitable method was therefore devised. Under standardised conditions the strength of these muscles was estimated with the subject's lower arm and hand placed in a testing bridge. The actual measurement was done with a specially constructed dynamometer (Mannerfelt 1961).

The method was first tried on 100 controls (50 males and 50 females) all university students, aged 18 to 29 years.

The strengths of following hand functions and movements governed by the ulnar nerve were studied.

1. Pinching grip.
2. Palmar adduction of the thumb.
3. Radial abduction of the index finger.
4. Adduction in the second and fourth interspaces.
5. Ulnar abduction of the little finger.

It is known that muscle function is sometimes impaired in certain positions of the joints and that actively and passively insufficient muscles are distinguished (Hjortsjö 1959). Therefore, it cannot be excluded that different positions of the wrist in its radio-ulnar axis can affect also the functions studied in the present investigation. It is, of course, not the position of the joint *per se* that decides such weakening, but the consequent position of the muscles and tendons. It is known that certain grips are stronger with the wrist extended slightly dorsally (Bunnell 1956). Tests 1, 2 and 3 were therefore done with the wrist at different angles. Tests 4 and 5, with the wrist in mid-position between dorsal extension and volar flexion, were performed with the MP joints in two different angles.

Two functions of the hands were included in the investigation, a picking-up test (Moberg 1958) on time and a more specialised picking-up test, where the examinee was instructed to pierce a piece of paper a certain number of times with a needle, and the time required was noted. Finally the strength of the hand was measured with Collin's dynamometer. Each subject was examined twice, once on day 1 and again on day 13.

The next link in the investigation was examination of the effect of ulnar paralysis on the function of the hand. A series with clinical ulnar lesions

would be less suitable for this purpose because of the above-mentioned complicating and varying factors. In order to secure as homogeneous a series as possible it was decided to study the clinic of paralysis of the ulnar nerve in 40 healthy volunteers (university students) and to block the ulnar nerve by intraneural injection of a local anesthetic, Carbocain®, 1 % without adrenalin. The author was included in this material, where the age range was otherwise the same as that of the control series.

Proper evaluation of muscular weakness because of nerve injury as after nerve blocks in lower arm and hand requires knowledge of the variants of innervation. Such variants in the lower arm have long been known. An anastomosis of the nerve distally to the actual level of nerve injury may lead to underdiagnosis of paresis or paralysis. The possible occurrence of anomalous innervation was therefore given particular attention in the present investigation. Interest was thus focused on the so-called Martin-Gruber anastomosis between the median and ulnar nerves in the lower arm, an anastomosis first described by the Swedish anatomist Martin in 1763.

It was therefore motivated to place the intraneural block of the ulnar nerve at a level proximal to the sulcus nervi ulnaris, thus at the level of the elbow. This level was also chosen for the following reasons:

1. It is a common level of clinical injury.
2. Block affects the nerve before it has given off any motor branches.
3. The nerve is readily accessible for block and electric stimulation.
4. Clinical experience suggests that such a blockade is not injurious.

With a special electrophysiological technique (Hodes, Larrabee and German, 1948) it was checked that the block was complete.

Under standardised conditions and with the same tests as the control group, the persons in the blocked group were examined 4 times. They were examined on day 1 and day 7 before and after the block, which was induced on day 7, and finally on day 13. The blocked group included a small subgroup, which was examined daily for 13 days and the block was likewise induced on the 7th day.

As a final step in the examination measurements were made on a small number of patients with clinical ulnar motor lesions and cared for at the Department of Orthopaedic Surgery, University Hospital, Lund, between the years 1962—1964. The measurements were, as a rule, made in the test bridge with the special dynamometer.

Adduction of the thumb appears to be brought about by long extensors and long flexors of the thumb in ulnar nerve paralysis. Fick (1845) and Duchenne (1867) believed that the extensor pollicis longus is a main adductor substitute in paralysis of the ulnar nerve. Other authors (Villiger-Ludwig 1946, Wartenberg 1953, v. Lanz-Wachsmuth 1959) claim that the

flexor pollicis longus is the main substitute for the adductor. Opinions thus differ on this point and it was considered justified to ascertain which of the two muscles, the extensor pollicis longus or flexor pollicis longus, is the true substitute for the adductor of the thumb on palmar adduction after the induction of total ulnar paralysis of the hand.

Problems

An attempt was made to find answers to the following questions:

1. Does the strength of the pinching grip, palmar adduction of the thumb and radial abduction of the index finger normally vary with the angulation of the wrist in the radio-ulnar axis.
2. To what extent is the strength of palmar adduction of the thumb, radial abduction of the index finger, ulnar abduction of the little finger and adduction in the 2nd and 4th interspaces decreased after total ulnar block if the radio-ulnar axis of the wrist is in midposition between volar flexion and dorsal extension and to what extent is the strength of the pinching grip decreased when the wrist is extended dorsally 30° ?
3. Does the strength of the pinching grip, the palmar adduction of the thumb and the radial abduction of the index finger after total ulnar block vary with movement of the wrist about the radioulnar axis?
4. Can any anomalous innervation of Martin-Gruber type be demonstrated after total ulnar block?
5. Can Fick's (1845) and Duchenne's (1867) conception be verified that the extensor pollicis longus can act as an adductor substitute and if so, how strong is its effect in acute paralysis of the ulnar nerve and to what extent does it vary with the angle of the wrist?
6. Has the flexor pollicis longus any adducent effect on the thumb in acute paralysis of the ulnar nerve?
7. Does intraneural block with 1 % Carbocain® without adrenalin cause any sequelae with consequent loss of strength or sensibility of the hand?

Definitions

ANGLE OF THE WRIST

Dorsal extension about the radio-ulnar axis of the wrist is marked +, volar flexion —. The midposition between dorsal extension and volar flexion is designed $\pm 0^\circ$. At $\pm 0^\circ$ position the metacarpal plane II—V is in an

extension of the lower arm, which according to the experimental conditions used is in midposition between pronation and supination. The elbow joint is then flexed 90°.

POSITIONS IN MP-JOINTS II—V

MP 180° designates extended MP-joints; MP 120°, 60° volar flexion.

PINCHING GRIP

According to Bunnell (1956), the pinching grip represents a round 0, where the thumb with its distal volar ulnar aspect is in contact with the distal volar radial aspect of the index finger to form a grip (tip pinch).

PALMAR ADDUCTION MOVEMENT OF THE THUMB

In the final phase of palmar adduction the ulnar aspect of the extended thumb is in contact with the volar proximal surface of the extended index finger. In the examination bridge the elbow is flexed 90° and the forearm is horizontal and locked in midposition between pronation and supination, so that the nail of the thumb in the last phase of movement of palmar adduction is also horizontal. At the beginning of palmar adduction, when the thumb is abducted, it is pronated about 30°. Palmar adduction movement can therefore be described as an adduction-supination movement.

RADIAL ABDUCTION OF INDEX FINGER

MP-joint, PIP- and DIP-joints II are extended and the only movement that occurs is about a dorso-volar axis in the MP-joint II, from adduction to full abduction in radial direction.

ADDUCTION IN SECOND AND FOURTH INTERSPACES

With MP-, PIP- and DIP-joints extended the index finger is adducted towards the middle finger and the little finger towards the ring finger. Movement occurs about the respective dorso-volar axes of the MP-joints.

ULNAR ABDUCTION OF THE LITTLE FINGER

In principle this movement is like the radial abduction of the index finger, with the difference that abduction occurs ulnarly about the dorso-volar axis of the extended MP-joint V.

Abbreviations

ABD V	M. Abductor digiti quinti	FCU	M. Flexor carpi ulnaris
ADD POLL	M. Adductor pollicis	FDP II—V	M. Flexor digitorum profundus II—V
APB	M. Abductor pollicis brevis	FDS II—V	M. Flexor digitorum sublimis II—V
APL	M. Abductor pollicis longus	FPB	M. Flexor pollicis brevis
ECRB	M. Extensor carpi radialis brevis	FPL	M. Flexor pollicis longus
ECRL	M. Extensor carpi radialis longus	IOD I—IV	M. Interosseus dorsalis I—IV
ECU	M. Extensor carpi ulnaris	IOV I—III	M. Interosseus volaris I—III
EDC II—V	M. Extensor digitorum communis II—V	LI I—IV	M. Lumbricalis I—IV
ED V P	M. Extensor digiti quinti proprius	OPP POLL	M. Opponens pollicis
EIP	M. Extensor indicis proprius	OPP V	M. Opponens digiti quinti
EPB	M. Extensor pollicis brevis	PB	M. Palmaris brevis
EPL	M. Extensor pollicis longus	RA	Ramus articularis
FD V B	M. Flexor digiti quinti brevis	MP joint	Metacarpo-phalangeal joint
FCR	M. Flexor carpi radialis	CMC joint	Carpometacarpal joint
		PIP joint	Proximal interphalangeal joint
		DIP joint	Distal interphalangeal joint
		IP joint	Interphalangeal joint

ABBREVIATIONS IN TABLES

ABD II	Radial abduction of index finger	ADD II i	Adduction in second interspace
ABD V	Ulnar abduction of little finger	ADD IV i	Adduction in fourth interspace
ADD POLL	Palmar adduction of thumb	PINCH	Pinching grip

Part II Anatomy

Chapter I Normal and anomalous pattern of innervation of the ulnar nerve

The hand is supplied mainly by 3 nerves: the radial, the median, and the ulnar nerves. The radial nerve originates from the fasciculus dorsalis (C5—ThI). The median nerve: radix lateralis from fasciculus lateralis (C5—C7) and radix medialis from fasciculus medialis (C8—ThI). The ulnar nerve also stems from the fasciculus medialis (C7—ThI). According to Linell (1921) and Foerster (1929), the flexor carpi ulnaris muscle is innervated to a certain extent by fibres from segment C7.

For practical reasons 4 zones of the ulnar nerve were distinguished in this investigation (Fig. 1 and Table 1). The *first zone* comprises the proximal part of the ulnar nerve extending from the brachial plexus to the first branch of the nerve inclusive viz the ramus articularis to the elbow. The *second zone* extends from this level to the level just distal to the origin of the ramus dorsalis manus of the ulnar nerve in the distal part of the lower arm. The *third zone* extends from this point to the level of the hamular process to and including the origin of the ramus profundus with branches to the 3 hypothenar muscles: abductor digiti quinti, opponens digiti quinti and flexor brevis digiti quinti. The *fourth zone* comprises the end of the ulnar nerve.

ZONE I. NORMAL PATTERN OF INNERVATION

The ulnar nerve is situated in the caudal part of the fasciculus medialis in the infra-clavicular part of the brachial plexus. This segment of the nerve runs on the ulnar side of the axillary artery. At this level the nerve lies close to the nervi cutanei brachii et antebrachii ulnares and radix medialis of the median nerve. Dorsal to the septum intermusculare brachii the nerve runs in distal direction, without sending off any branches, down towards the sulcus nervi ulnaris on the dorsal aspect of the elbow. Here the nerve follows the arteria collateralis ulnaris proximalis. Somewhat proximal to this level the ulnar nerve gives off its first branches, namely the rami articulares to the elbow, see Table 1.

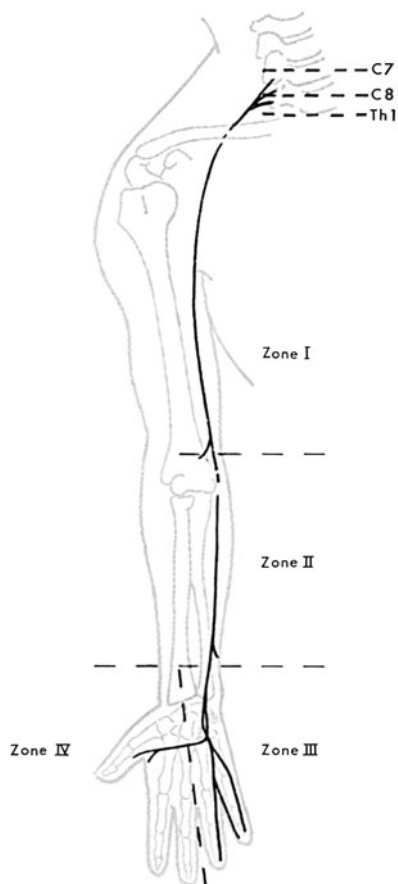


Fig. 1. Zones of right ulnar nerve.

ZONE I. ANOMALOUS PATTERN OF INNERVATION

According to Linell (1921) the ulnar nerve rarely gives off any branch above the elbow. However, in a series of 20 dissected ulnar nerves Sunderland & Hughes (1946) found a branch to the flexor carpi ulnaris, which originated at the level of the epicondyle in one case and in another a branch that ran to the aforementioned muscle 4 cm proximal to the epicondyle. The level of the origin of the rami articulares also varies, but according to Sunderland (1945), it never arises at a level more than 7 mm above the epicondylus ulnaris humeri.

Table 1. Right ulnar nerve — zones and branches

Zone	No.	Musc. branches	Sens. branches	Other branches
Zone I	1		RA elbow joint	
Zone II	2		RA elbow joint	
	3	FCU		
	4		RA elbow joint	
	5	FCU		
	6	FDP IV and V		
	7	FDP IV and V		
	8	FCU		
	9			Nerve of <i>Henle</i>
	10		R. palmaris	
	11		R. dors. manus	
Zone III	12			Nerve of <i>Henle</i>
	13		R. Superfic. from Dig. 1/2 IV and V	
	14	PB		
	15	R. Profundus		
	16	ABD V		
	17	FD V B		
	18	OPP V		
Zone IV	19			Nerve of <i>Henle</i>
	20	L IV		
	21	IOV+D 4th space		
	22	IOV+D 3rd space		
	23	L III		
	24		RA carpal joints	
	25	IOV+D 2d space		
	26	ADD POLL oblique portion		
	27	ADD POLL transv. portion		
	28	IOD I		
	29	FPB deep portion		
	30			(<i>Riche-Cannieu</i> anastomosis)

ZONE II. NORMAL PATTERN OF INNERVATION

In zone I the nerve is relatively superficial and shiftable, but in zone II it dips into the sulcus nervi ulnaris and further distally between the two heads of origin of the flexor carpi ulnaris and here down as in an osseofibrous tunnel. The floor of the tunnel consists of the medial collateral ligament of the elbow joint; its roof, of fibrous tissue forming an aponeurosis filling the triangular gap between the two heads of origin of the flexor carpi ulnaris. This tunnel has been called the cubital tunnel (Feindel and Stratford

1958). Here the ulnar nerve sends off its first motor branch, the one innervating the flexor carpi ulnaris. According to Sunderland and Hughes (1946), the origin of the motor branches to the flexor carpi ulnaris varies widely. As mentioned, in a study on 20 cadavers the present writers found the branch to the flexor carpi ulnaris to originate at the level of the epicondyle in one case, and 4 cm proximal to the epicondyle in another. In both cases branches ran to the flexor carpi ulnaris also distally. No branches to the flexor carpi ulnaris were seen at or above the epicondyle in any of the remaining 18 cases. This is in agreement with Linell's (1921) observation that the ulnar nerve rarely gives off branches to muscles above the elbow. As a rule, the branches running to the flexor carpi ulnaris and flexor digitorum profundus IV—V originate at separate levels of the ulnar nerve, but sometimes they are given off in the form of a single branch, which then divides to supply these muscles (Sunderland and Hughes 1946). According to these authors, the first motor branch often supplies the musculus flexor carpi ulnaris, but in their material (20 cadavers) they sometimes also found a first branch supplying the flexor digitorum profundus IV—V muscle. They found the last motor branch in the lower arm to supply the musculus flexor carpi ulnaris in 9 cases, the flexor digitorum profundus in 6, and as a bifurcated branch in the remaining 5. In 19 of their 20 cases they found multiple branches to leave the nerve and to supply the musculus flexor carpi ulnaris.

In the distal part of the lower arm the arteria ulnaris is on the radial side of the nerve. There the ulnar nerve gives off fine branches to this artery. Kaplan (1965) calls this nerve Henle's nerve. Henle (1868) described these nerves as chiefly vasomotor. Sometimes in association with one of these small Henle nerves, sometimes as an independent branch, a fine nerve is sent off from the ulnar nerve at a level somewhat proximal to the middle of the forearm, namely the ramus palmaris, which supplies the skin in the ulnar part of the proximal carpus and the palm of the hand. The ulnar nerve so far sandwiched between the musculature of the flexor carpi ulnaris and digitorum profundus IV—V then runs distally along and beneath the tendon of the flexor carpi ulnaris and gives off its last branch in zone II, namely the ramus dorsalis manus. This branch originates at the transition between the middle and distal third of the forearm and then runs between the ulna and the tendon of the flexor carpi ulnaris in distal-dorsal direction. This sensory branch runs somewhat proximal to the caput ulnae, through the fascia and then divides subcutaneously into its end branches supplying, with certain variations, the ulnar-distal parts of the dorsal part of the hand and the dorsal parts of the 5th and 4th fingers and the ulnar part of the 3rd finger (Villiger-Ludwig 1946, von Lantz-Wachsmuth 1959).

Turner (1874) described an isolated branch arising at roughly the middle level in the forearm from the trunk of the ulnar nerve and running as a fine nerve on the volar side of the volar carpal ligament out to the ulnar part of the 4th finger. The ramus dorsalis manus sometimes originates at different levels of the lower arm. The variation in the innervation of the flexor carpi ulnaris and the flexor profundus IV—V has been described (*vide supra*) by Sunderland and Hughes (1946).

The main anomaly in zone II is, however, the occasional anastomosis between the median and ulnar nerves. This anomaly was apparently first described by the Swedish anatomist R. Martin who (1763) in his *Tal om Nervers allmänna Egenskaper i Människans kropp*, where he wrote (paragraph 179 on the median nerve) that "en gren, som stundom går under pronator teres att anastomosera med cubiteo. N. B. är denna stor fins ofta ej någon Nervus anastomoticus i vola manus, som gör arcum volarem." Cubiteo was the term used at that time to designate the ulnar nerve. In paragraph 181 is to be read on "Nervus cubitalis s. ulnaris . . . 4:0 ofta en anastomose gren med mediano, dock ej beständigt".

According to Gruber (1870), the anatomical literature from Vesalius and Vieussens (1690) to Monro (1763) does not mention anything about an anastomosis between the median and the ulnar nerve in the forearm. With reference to Martin (1763), Gruber then dissected 125 cadavers and thereby found an anastomosis in 38 of 250 arms (15.2 %). The anastomosis was bilaterally in 10 cases (8 males and 2 females). It was thus unilateral in 18 and was right-sided in 4 (males) and left-sided in the remaining 14 (12 males and 2 females).

Hirasawa (1931) of Japan found the anastomosis in 10.5 % of a similar material consisting of 124 arms. As in Gruber's series, the anastomosis was more common on the left side.

According to Hirasawa (1931), Ssokolow (1925) demonstrated this anastomosis in 44 % of 55 arms in Russians and Curtis (1886) in 30.7 % (19 of 62 arms) in a French series.

Borchhardt and Wjasmenski (1917) found the anastomosis in 2 of 4 cases in which the median nerve was dissected and slit up.

It might be convenient at this stage to give a brief description of the phylogenesis of this Martin-Gruber anastomosis, to facilitate the understanding of the character of the anastomosis.

A thorough analysis of the phylogenesis of the hand has been published by Bunnell (1956). Bunnell shows that the intrinsic muscles of the hand can be traced back through the animal series to the early fish, when there was no arm but only a pectoral fin, from which the hand later developed.

Thus, phylogenetically, the hand preceded the arm, which developed later and from higher cervical segments. (The intrinsic muscles of the hand are thus primordial.) The intrinsic muscles in *Homo* are still supplied by the two lowest nerves in the brachial plexus and this applies to both the ulnar and median nerves (Wood Jones 1949).

This is not in agreement with Rauber-Kopsch (1940) and Villiger-Ludwig (1946) who state that *inter alia* opponens pollicis is innervated by C6—C7. In further support of the intrinsic muscles of the hand being supplied by the two lower segments of the brachial plexus, reference may be made to the clinical picture of Klumpke's paralysis, which affects the lower part of the brachial plexus. The small muscles of the hand there are paralysed, both those innervated by the ulnar nerve and those innervated by the median nerve.

It is also interesting to note that in the early stages of evolution (in amphibiae, reptiles, birds, see Foerster 1929) the three flexor group nerves, *i.e.* musculocutaneous, the median and the ulnar nerve were originally united in a common ventral trunk. Moreover, in several types of monkeys the anastomosis between the median nerve and the ulnar nerve is an invariable phenomenon (Hepburn 1892).

Ranschburg (1917) wonders whether this anastomosis is motor, sensory or mixed. He refers to Curtis (1886), who describes 3 forms of this anastomosis, namely the straight one, which was said to be of purely sensory nature, the looped one, with its convexity distally and giving off muscular branches and finally the mixed one, which is regarded as a combination between the first two forms and which also gives off motor branches. Ranschburg dissected 12 forearms and found an anastomosis between the median and ulnar nerves in four, 2 on the right and 2 on the left. These 4 cases were said to represent two essentially different morphologic types. As the first type Ranschburg found a simple anastomosis between the ulnar and median nerves and according to him it carried sensory fibres from the ulnar to the median nerve. The second type was fan-shaped or Y-shaped and was a true motor anastomosis from the median to the ulnar nerve and thus formed part of the deep ulnar nerve. Borchhardt and Wjasmanski (1917), who split up 2 preparations of the median nerve, found an anastomosis with the ulnar nerve, and in their opinion this anastomosis went down to the motor branch of the ulnar nerve.

All of the above-mentioned authors demonstrated the anastomosis in cadavers. The clinical literature contains only scanty reports on the occurrence of this anastomosis. Thus Remak (1874) described a case of ulnar nerve injury in the upper arm with paralysis of the flexor carpi ulnaris but without substantial impairment of function of the other muscles normally innervated by fibers of the ulnar nerve. Electrical stimulation of the

ulnar nerve above the injury produced no response of the flexor carpi ulnaris muscle, but stimulation below the injury produced a response of those muscles normally innervated by the ulnar nerve. More recent clinical literature contains only single references to this Martin-Gruber anastomosis (Goldman 1906, Clifton 1948, Rowntree 1949, Brash 1955). In *Surgery of the Hand* (Bunnell 1956) only little space is given to anastomoses between the median and the ulnar nerve.

Thus, each author reports only a few cases *i.e.*, numbers too small to permit statistical analysis of the frequency of the anomaly.

Recently Goldner and Jones (1966) in a series of 25 patients with nerve injuries' showed some cases with a true Martin-Gruber anastomosis.

ZONE III. NORMAL PATTERN OF INNERVATION

The level of the origin of the opponens digiti quinti and flexor brevis digiti quinti, *i.e.*, after the nerve had passed hamulus ossis hamati, was chosen as the lower limit of zone III. All hypothenar muscles thus are innervated by the nerve in this zone. The reason for this level was also to incorporate the so-called Guyon's loge (Guyon 1861) in this zone. In the proximal part of this zone III the ulnar nerve divides into the ramus superficialis and the ramus profundus. The ramus superficialis lies more superficial and on the radial side of the ramus profundus. The nerve extends with its two branches volar to the ligamentum carpi transversum and there the pisiform bone lies on the ulnar side. There the 2 branches of the nerve are covered by the palmaris brevis muscle and a thin layer of fascia, the volar carpal ligament. The nerve lies in Guyon's loge (which Barthold (1960) calls the "ulnar canalis carpi") on a floor formed by ligamentum piso-hamatum. The ramus superficialis gives off a motor branch (branches) to the palmaris brevis, which may, however, be innervated by branches from the ramus profundus. After first running radially to the deep branch the superficial branch courses in a distal direction and then divides into the nervus digitalis ulnaris V, the nervus digitalis volaris radialis V and the ulnaris IV. It also probably invariably gives off a branch to the nervus digitalis volaris communis dig. III from the median nerve. The superficial branch thus supplies the entire volar surface of the 5th finger and the ulnar-volar part of the 4th finger. Branches sometimes extend up to the dorsal surface of the distal phalanx of the 5th finger and ulnar half of the intermediate and distal phalanx of the 4th finger (Villiger-Ludwig (1946).

According to Sunderland and Hughes (1946) the pattern of the motoric innervation of the deep ulnar branch here sometimes varies in that a common branch divides to form future branches of the flexor brevis, opponens dig. V and to both volar and dorsal interossei to the 4th interspace. As a

rule, however, branches to the abductor brevis V are given off before those branches supplying the flexor brevis V and opponens V.

After the nerve has given off motor branches to these 3 hypothenar muscles it dips and "loops around the ulnar aspect of the hook of the hamate" (Boyes 1964) in radial-distal direction and passes into zone IV. There the nerve is covered by the origin of opponens digiti quinti and flexor brevis digiti quinti.

ZONE III. ANOMALOUS PATTERN OF INNERVATION

In 1963 Kaplan described a variation of the ramus dorsalis manus with an unusual distribution enclosing the pisiform bone. A similar variant, called an auto-anastomosis, was described in 1938 by Hirschclaff-Hjortsjö.

ZONE IV. NORMAL PATTERN OF INNERVATION

After the deep motor branch of the ulnar nerve has left the tunnel limited by the distal part of the hamatum and the origin of the opponens V and flexor brevis V, the nerve continues in radial direction, where it lies deep under the long flexor tendons in the hand. It gives off motor branches to the 4th lumbrical and sometimes also a Henle's nerve to the deep palmar branch of the ulnar artery, which it accompanies on its path radial wards. This arterial branch belongs to the arcus volaris profundus. In the order given motor branches then extends to interossei in the 4th and 3rd interspaces and to the 3rd lumbrical, after which it receives some articular branches from the carpo-metacarpal, inter-metacarpal and metacarpophalangeal joints, more or less radially in the hand (v. Lanz-Wachsmuth 1959). The interossei in the 2nd interspace are then supplied by the nerve, which then divides into branches running to oblique and transverse parts of the adductor pollicis and to branches of the interosseus in the first interspace. Before this the ramus profundus of the ulnar nerve runs through a small arcade which is situated in the transition between the transverse and oblique head of the adductor pollicis. The nerve supplies the adductor muscles with fibers entering the dorsal side of this muscle. The nerves to the interosseous dorsalis I enter this muscle from the volar aspect. The nerve is thereby "sandwiched" between the adductor pollicis and interosseus dorsalis I. Sunderland and Hughes (1946) found the adductor pollicis to be supplied before the 1st dorsal interosseus in 10 of 20 preparations, at the same distance in 7 of 20 preparations and distal to the first dorsal interosseus in 1 case. The 1st dorsal interosseus might, according to these authors, thereby be the last of the muscles innervated by the ulnar nerve. They did not, however, extend their investigation to include innervation

of the deep head of the flexor pollicis brevis. The deep part of the flexor pollicis brevis is innervated not only by the median nerve but also by the ulnar nerve in varying frequency (Brooks 1886, Spourgitis 1895, Cannieu 1896, 1897, Riche 1897, Foerster 1929, Highet 1943, Murphey, Kirklin and Finlayson 1946, Wood-Jones 1949).

ZONE IV. ANOMALOUS PATTERN OF INNERVATION

The anatomical and clinical literature dealing with the anomalous pattern of innervation of this zone is fairly abundant and contradictory. The anomalies fall largely into 5 different types.

1. Double innervation of interosseus dorsalis I.
2. Double innervation of lumbricals.
3. Thenar muscles innervated entirely or partly by the ulnar nerve.
4. Anastomosis between deep ulnar branches and motor branches of the median nerve in the radial part of the palm of the hand.
5. Hypothenar muscles innervated entirely or partly by the median nerve.

Some authors studied these patterns in cadavers, other by careful analysis of muscle function after complete or partial nerve injury.

Double innervation of interosseus dorsalis I

Double innervation of the interosseus dorsalis I was demonstrated by Murphey, Kirklin and Finlayson (1946) in 4 out of 698 patients with ulnar injury. In these 4 cases then the interosseus dorsalis I was either innervated only by the median nerve or by both the median nerve and the ulnar nerve. In his investigation of 124 patients with ulnar injuries Rowntree (1949) found double innervation of the interosseus dorsalis I in 2 and possibly in 4. Double innervation of interosseus dorsalis I therefore appears to be relatively rare.

Double innervation of lumbricals

Brooks (1887) described double innervation of lumbricals. Double innervation of lumbricalis I by both the median nerve and the ulnar nerve could not be demonstrated in any of his 21 cases, but such double innervation of the 2nd lumbrical was found in 1 case, of the 3rd lumbrical in 2 and of the 4th lumbrical in 1 of his 21 cases. Riche (1897) also found double innervation of certain lumbricals by the median and ulnar nerves.

Thenar muscles entirely or partly innervated by the ulnar nerve

It would appear that Brooks (1886) was one of the first to demonstrate double innervation of the flexor pollicis brevis muscle by both the ulnar and

the median nerves. According to Rowntree (1949), the flexor pollicis brevis is innervated by more than one nerve in more than 50 % of cases of injury to the ulnar and median nerve.

Foerster (1929) reported cases in which the ulnar nerve had innervated all thenar muscles in a case of median injury, but he made no attempt to ascertain whether the muscles were innervated by both the median and the ulnar nerves. Clifton (1948) studied 250 ulnar injuries and 150 median injuries and found the function of the opponens pollicis, flexor pollicis and abductor pollicis brevis to be preserved in only 1 case of complete median injury. In this case these muscles were innervated by the ulnar nerve.

That the opponens pollicis can be innervated by the ulnar nerve is known. But it is surely rare and Murphey, Kirklin and Finlayson (1946), who studied 551 injuries of the median nerve, found that the opponens pollicis was innervated by the ulnar nerve in only 1 case.

Anastomosis between ramus profundus of the ulnar nerve and motor branch of median nerve in the palm of the hand

Such anastomoses have been demonstrated by several authors, who have wondered whether the anastomoses between the ramus profundus of the ulnar nerve and motor branch of the median nerve are sensory, motor or mixed. Turner (1874) believed that the communication in the hand passed from the ulnar to the median nerve. Foerster (1929) who founded his opinion on a large number of war injuries believed the anastomosis to be of motor type. Gehwolf (1921) assumed the anastomosis to be of sensory type. Cannieu (1897) found the anastomosis in 3 out of 23 cadavers. Ranschburg (1917) found no such anastomosis in 12 cadavers studied. Riche (1897) reported 3 types of anastomosis between the ramus profundus of the ulnar nerve and motor branches of the median nerve. The first was a connection across the tendon of the flexor pollicis longus between the motor median nerve branch that run to the superficial head of the flexor pollicis brevis and the ulnar branch running to the deep head of the flexor pollicis brevis. Another type is the anastomosis between the median nerve and the deep branch of the ulnar nerve across the first lumbrical. The last type was discovered by Riche (1897), and is a branch from the median nerve extending to the ulnar nerve and piercing the substance of the adductor pollicis and anastomosing in that muscle with the motor branch given off thereby the ramus profundus.

Judging from the literature then this anastomosis in the hand is not uncommon. In the literature it has been called the Riche-Cannieu anastomosis. Opinions differ on the nature of the anastomosis; some regard its nature as obscure, some think it to be of motor type while others believe

it to be of sensory type. A search of the literature failed to reveal any systematic investigation of the nature of the anastomosis.

Hypothenar muscles entirely or partly innervated by the median nerve

According to the literature, the hypothenar muscles are rarely innervated by branches of the median nerve. One case has been published by Murphey, Kirklin and Finlayson (1946) and a few by Gassel (1964) and Marinacci (1964).

S U M M A R Y

The normal anatomy of the ulnar nerve is reviewed. For practical reasons 4 zones of the nerve were distinguished. Various forms of anomalous innervation are presented. The most important ones—the Martin-Gruber and Riche-Cannieu anastomoses—are described in detail.

Chapter II Author's dissection of the ulnar nerve

To form an opinion of the anatomy of the ulnar nerve and muscles governed by the nerve 15 fresh post mortem specimens (right hand) and one amputated (left hand) were studied. The specimens are numbered 1—16. In 9 of them interest was focused particularly on the nerve. The dissection comprised zones II, III and IV.

In zone II (Fig. 2) well defined Henle's nerves to the ulnar artery were seen (Henle 1868, Kaplan 1965). Multiple branches to the flexor carpi ulnaris described previously by Sunderland (1946), for example, were also found. In one preparation (No. 13) two branches were seen to supply the flexor digitorum profundus IV—V.

In zones III and IV the findings were those largely expected from the standard anatomic literature. Some Henle's nerves could be demonstrated in zone III (Fig. 3). In 2 of 3 specially prepared specimens (Nos. 14 and 15, see Fig. 3) the palmaris brevis musculature was innervated by the superficial ulnar branch; in the 3rd preparation (No. 2) this muscle was innervated by the deep ulnar branch. Superficial sensible anastomosis with the median-innervated digital nerve to the 3rd interspace could be demonstrated in all the cases studied. The deep ulnar nerve in 1 (No. 2) of the 3 specially examined preparations sent a branch to the interosseus dorsalis I earlier, and to adductor pollicis later, and the last muscle innervated by the ulnaris in that preparation was the deep head of the flexor pollicis brevis. In preparation No. 3 double innervation of the adductor pollicis was strongly suspected because the nerve fibres to that muscle came from both the deep ulnar nerve and the motor branch of the median nerve. This resembles the third type of anastomosis described by Riche (1897). In preparation No. 8 the interosseus dorsalis I was the last muscle innervated by the deep ulnar branch. In preparations 7, 8 and 9 a search was made for anastomoses between the deep ulnar nerve and the motor branch of the median nerve. Such anastomoses were found in all 3 consecutive cases studied (Figs. 3 and 4). These dissections thus verified what most other authors have found, namely an ansa or anastomosis between the deep ulnar nerve in the palm and motor branch of the median nerve (Turner 1874, Riche 1897, Cannieu 1897, Frohse and Fränkel 1908, Ranschburg 1917,

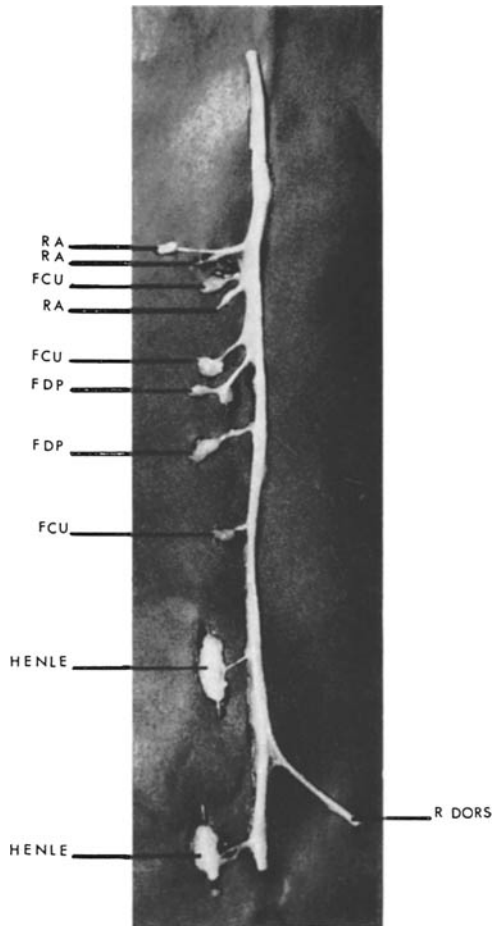


Fig. 2. Right ulnar nerve, zone II: Preparation number 13 in present series.

Gehwolf 1921, Foerster 1929). It is this anastomosis that is known in the literature as the Riche-Cannieu anastomosis. The question whether this connection is rather constant must for the time being be left unanswered because the material was too small.

In 1 case (No. 15 Fig. 3) the deep ulnar branch was found to innervate lumbricalis II, a finding made by Brooks (1887) in 1 of his 21 dissected hands. Whether the lumbricalis II in this case was doubly innervated also by the median nerve was not investigated further.



Fig. 3. Right ulnar nerve, zone III—IV. Reproduction composed of two preparations (Nos. 15 and 9).

Key to symbols.

- | | |
|---|--|
| 1. N. Ulnaris. | a. PB. |
| 2. R. Superficialis N. Ulnaris. | b. ABD V. |
| 3. R. Profundus N. Ulnaris. | c. OPP V. |
| 4. Digital nerve from ulnar side of little finger. | d. FD V B. |
| 5. Digital nerve from radial side of little finger. | e. IOV II. |
| 6. Digital nerve from ulnar side of ring finger. | f. IOD III and L III. |
| 7. A <i>Henle's</i> nerve to a digital artery in the palm. | g. L II. |
| 8. R. communicans to median nerve in the palm. | h. IOV I. |
| 9. Digital nerve from radial side of ring finger from median nerve. | i. IOD I. |
| 10. Riche-Cannieu anastomosis between deep ulnar nerve and motor branch of the median nerve, see also fig. 4. | j. ADD POLL. |
| 11. N. Medianus. | k. FPB. |
| | x. Borderline between two preparations, Nos. 15 and 9. |
| | z. Borderline between zone III and IV. |

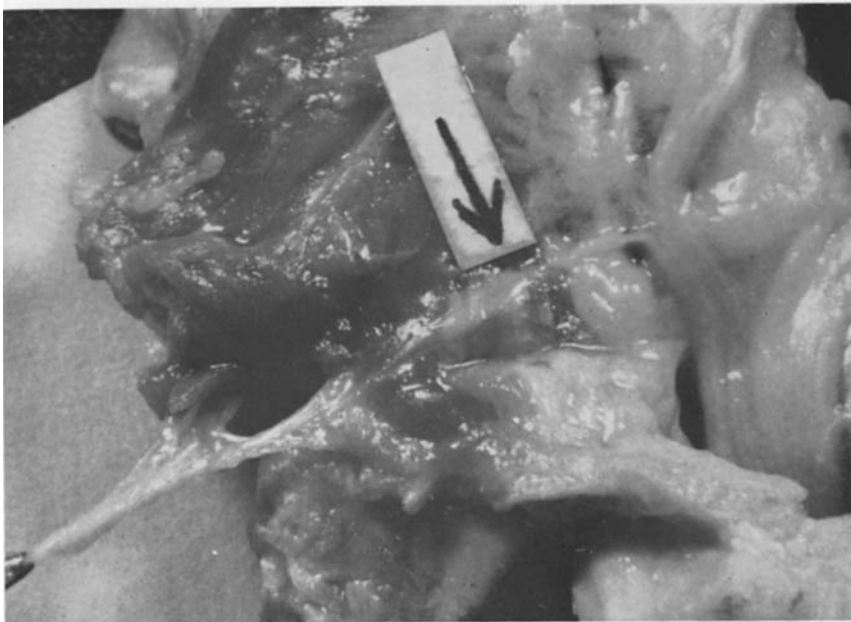


Fig. 4. Riche-Cannieu anastomosis. Preparation number 9. Deep ulnar nerve to the left, median nerve to the right.

S U M M A R Y

The ulnar nerve was dissected in nine specimens within zones II—IV. The findings were those largely expected from the standard anatomic literature. In three preparations the so-called Riche-Cannieu anastomosis was found. In one case the deep ulnar branch was found to innervate the second lumbrical muscle.

Chapter III On muscles and tendons of the thumb, index finger and little finger

In the investigation of the function of a muscle it is necessary to consider not only its origin, insertion, amplitude and innervation pattern, but also the course of the muscle and its tendons relative to the axes of pertinent joints (Landsmeer 1955, 1963, Hjortsjö 1959, 1964).

The muscles acting upon the hand fall into 2 groups, extrinsic and intrinsic. An intrinsic muscle has both its origin and insertion in the hand, while an extrinsic muscle is one which, although it acts upon the hand, has its origin in the arm. This classification of the muscles is less satisfactory from a functional point of view because practically every movement of the hand is the result of an intricate interplay between extrinsic and intrinsic muscles. From a descriptive point of view, however, it is useful.

INTRINSIC MUSCLES OF THE THUMB

The thenar group consists of the abductor pollicis brevis, opponens pollicis, flexor pollicis brevis and adductor pollicis.

Abductor pollicis brevis

This muscle is the most dorsoradial and most superficial of the muscles representing the thenar profile. The muscle which is well defined, originates mainly from the ligamentum carpi transversum and from the eminentia carpi radialis. The tendon of the muscle is inserted on a tuberosity on the radial side of the base of the proximal phalanx of the thumb. According to v. Lanz-Wachsmuth (1959), the muscle is also inserted on the radial sesamoid bone, an assertion denied by Stener (1962). As a rule, fibres from the superficial part of the muscle continue up through a superficial aponeurosis to the dorsum of the 1st phalanx of the thumb, where the aponeurosis unites with the tendon of the extensor pollicis longus as an insertion on the radial side of the terminal phalanx. This aponeurosis may be called the abductor-aponeurosis, in analogy with the adductor-aponeurosis radiating from the ulnar side (Mondry 1940, Stener 1962). Sometimes an extra tendon from the abductor pollicis longus enters the abductor pollicis

brevis muscle and this tendon may also lie superficially on the abductor pollicis brevis and unite with the superficial abductor-aponeurosis.

Opponens pollicis

The origin of this muscle is situated immediately beneath the origin of the abductor pollicis brevis. The muscle originates from the ligamentum carpi transversum, from eminentia carpi radialis and from the joint capsule in the carpo-metacarpal joint I. The muscle runs obliquely in distoradial direction and is fixed osseously along the lateral border of the first metacarpal and therefore represents the only thenar muscle that is attached to this bone. The other 3 thenar muscles are attached distally to the first metacarpal.

Flexor pollicis brevis

Opinions differ on this muscle. According to Wood Jones (1949), the flexor pollicis brevis has not two heads but four.

1. The superficial head gaining origin from the ligamentum carpi transversum is attached to the radial sesamoid bone. The muscle runs on the volar and radial side of the tendon of the flexor pollicis longus. According to Flemming (1887), this is the only head that deserves the name "flexor pollicis brevis".
2. The deep head takes origin from the multangulum majus and capitulum. The belly of the muscle runs on the dorsal side of the tendon of the flexor pollicis longus, and this part of the muscle is inserted also on the radial sesamoid bone.
- 3, 4. Wood Jones mentions 2 other muscle bundles attached to the ulnar sesamoid bone. One of them runs along the ulnar border of the first metacarpal and likewise originates proximally and ulnarly from this bone. According to Wood Jones (1949), this is what most British anatomists call the inner deep head of the flexor pollicis brevis. Other anatomists call this muscle the first palmar interosseus. Wood Jones refers to this muscle as Henle's interosseus primus volaris.

Kaplan (1965) found that the flexor pollicis brevis was inserted on the radial sesamoid bone and on the fibrocartilago volaris, and partly on a radial tuberosity on the base of the basal phalanx of the thumb and finally with an expansion up in the long extensor tendon of the thumb. In a special study of the flexor pollicis brevis Day and Napier (1961) found the deep head to be missing in 3 of 65 hands dissected.

However, this difference in conception of the flexor pollicis brevis can be cleared up if it be assumed that the muscles inserted on the radial

sesamoid bone are called flexor pollicis brevis, and those inserted on the ulnar sesamoid bone adductor pollicis (Frohse-Fränkell 1908, Wood Jones 1949 and Stener 1962).

Adductor pollicis

This muscle consists of at least 2 well defined muscle bellies called the adductor pollicis transversus and the adductor pollicis obliquus. The transverse belly springs from the major part of the 3rd metacarpal, roughly from the midline of its volar surface. This transverse belly runs radialwards covering the 2nd metacarpal, the 1st volar and the 1st dorsal interosseus to terminate in 3 insertions on the ulnar side of the thumb. The oblique belly arises from the carpus in the region of capitatum and multangulum minus, and from the base of the 3rd metacarpal. Between the transverse and the oblique parts there is a small arcade, through which run the deep branch of the ulnar nerve and the arcus volaris profundus (ramus volaris profundus of the arteria radialis and the arteria ulnaris). The oblique portion is inserted on the ulnar sesamoid bone. According to some authors, parts of the adductor pollicis are inserted on the radial sesamoid of the thumb (Wood Jones 1949). Provided, however, that the muscle bundles inserted on the radial sesamoid are called flexor pollicis brevis and those inserted on the ulnar sesamoid adductor pollicis, there need no longer be any confusion (Frohse-Fränkell 1908, Wood Jones 1949 and Stener 1962). According to Rauber-Kopsch (1940) and v. Lanz-Wachsmuth (1959), the adductor pollicis is inserted only on the ulnar sesamoid of the thumb; according to others (Wood Jones 1949), on the ulnar sesamoid and the base of the first phalanx of the thumb. Several authors have demonstrated the aponeurosis, which extends from the adductor pollicis to the tendon of the extensor pollicis longus (Mondry 1940, Strandell 1959, Stener 1962 and others). As early as 1867 Duchenne pointed out that fibres extend to the tendon of the extensor pollicis longus. This was also mentioned by Foerster (1937). The adductor muscle inserts on a tuberosity on the first phalanx of the thumb. According to Frohse-Fränkell (1908), this is the tuberosity which Poiriér called tubérosité interne et supérieure de la première phalange du pouce.

EXTRINSIC MUSCLES OF THE THUMB

These muscles consists of the extensor pollicis longus, extensor pollicis brevis, abductor pollicis longus and flexor pollicis longus.

Extensor pollicis longus

The extensor pollicis longus gains origin from the extensor surface of the ulna immediately proximal to the origin of the extensor indicis proprius. It

also originates partly from the membrana interossea. The muscle is bipennate and merges in a tendon on the dorsal side of the muscle, somewhat proximal to the radio-carpal joint. It is Lister's tuberosity on the dorsal side of the distal radius which then causes the tendon to assume a radial direction. The extensor pollicis longus runs in the 3rd compartment of the ligamentum carpi dorsale in distal direction towards the thumb, where it obliquely crosses the tendons to the extensor carpi radialis longus and brevis, and then courses to the ulnar side of the dorsal surface of the thumb, finally to be inserted on the base of the terminal phalanx of the thumb. The extensor pollicis longus lies in the 3rd compartment firmly anchored but relatively movable from side to side from the level of the multangulum majus right up to the point where the tendon meets fibers from the adductor aponeurosis (Stener 1962) and the "abductor aponeurosis" at the level of the 1st metacarpo-phalangeal joint. But, even at this level, the tendon can be displaced to a certain extent laterally. The adductor aponeurosis and "abductor aponeurosis", together also called the hood, can be moved a few millimetres in distal-proximal direction (Bunnell 1956). On its radial side the extensor pollicis longus tendon is accompanied for a short distance by the extensor pollicis brevis tendon.

Extensor pollicis brevis

This muscle originates from the membrana interossea and from the extensor aspect of radius below the middle of the latter and lies beneath the muscle bundles of the extensor pollicis longus and abductor pollicis longus. Its tendon forms at the level of the distal part of the radius and runs together though sometimes separated by a sheath, with the abductor pollicis longus in the first compartment of ligamentum carpi dorsale. The tendon runs along the dorsal aspect of the 1st metacarpal and is usually inserted on the base of the first phalanx of the thumb. Variations have been described in the literature. Thus, Stein (1951), for example, reported a double extensor pollicis brevis tendon in 4 % of 84 dissected hands when the extensor ran in the same sheath as the abductor pollicis longus. The extensor pollicis brevis tendon rarely appears to be in contact with the "abductor aponeurosis" but to pass beneath the aponeurosis on its way to its insertion on the first phalanx. In one case Kaplan (1965) found that the tendon of the extensor pollicis brevis continued along the extensor pollicis longus tendon on both the first phalanx and the distal phalanx of the thumb, where it was inserted together with, but radially to, the extensor pollicis longus tendon. Strandell (1955) found that the tendon of the extensor pollicis brevis ran along the *radial* part of the 1st metacarpal. The first compartment, in which the extensor pollicis brevis runs, serves also as an

annular ligament of the abductor pollicis longus tendon — tendons. This compartment, which in Quervain's disease (de Quervain 1912, Wiberg 1941) is to be separated longitudinally, is sometimes divided into 2 compartments. Lipscomb (1951) stresses the necessity of unroofing both compartments in such cases.

Abductor pollicis longus

The abductor pollicis longus originates from the extensor surface of the ulna proximally to the origin of the extensor pollicis longus and distally to the insertion of the supinator. The muscle gains origin also from the membrana interossea and from part of the radius. The belly of the muscle then runs disto-radially and its tendon courses, together with the tendon of the extensor pollicis brevis, through the 1st compartment of the ligamentum carpi dorsale (see above). The tendon or tendons of abductor pollicis longus have often more than one insertion. In most cases the tendon is inserted on the base of the 1st metacarpal. Thus, Fenton and Lapidus (1953), who dissected 54 wrists, arrived at the conclusion that at least one tendon of the abductor pollicis longus was always inserted on the base of the 1st metacarpal. In the variant forms, *i.e.* with extra tendons, the latter were sometimes inserted on the soft tissue, sometimes on bony structures of the wrist. Of 84 dissected hands, Stein (1951) found that in 68 % the abductor pollicis longus tendon was double when it passed into the same sheath as the extensor pollicis brevis, as it most often did. Occasionally a tendon of the abductor pollicis longus blended with the muscle and the fascia of the abductor pollicis brevis and passed out through its tendon distally.

Flexor pollicis longus

This muscle springs partly from the volar surface of the radius distal to the insertion of the supinator, and partly from neighbouring parts of membrana interossea. The muscle, which is unipennate, merges into a tendon on the ulnar-distal side of the muscle belly. After the tendon has passed through the canalis carpi, it lies between the superficial and deep head of the flexor pollicis brevis and after it has passed through a relatively narrow tendon sheath it is inserted on the base of the volar surface of the terminal phalanx of the thumb. This tendon, unlike that of the extensor pollicis longus, can thereby move only to a small extent laterally. The flexor pollicis longus is the only muscle that can flex the terminal phalanx of the thumb, while most of the intrinsic muscles of the thumb (adductor pollicis, flexor pollicis brevis and abductor pollicis brevis) flex the basal phalanx of the thumb in the metacarpo-phalangeal joint.

INTRINSIC MUSCLES OF THE INDEX FINGER

The index finger has 3 intrinsic muscles; the interosseus dorsalis I, interosseus volaris I and the 1st lumbrical. Landsmeer (1955 and 1963) focused special attention on the anatomy and function of these muscles. He thought that Albinus (1734) should be regarded as the first to have demonstrated the differences between the dorsal and volar interossei, and that he should also be regarded as one of the earliest to report the observation that the first dorsal interosseus is inserted osseously on the radial part of the base of the index finger. Albinus therefore called this muscle the abductor indicis. The 1st dorsal interosseus originates from both the 1st and 2nd metacarpal and must be regarded as the strongest of all the 7 interossei of the hand. Its tendon runs on the volar side of the radio-ulnar axis of movement in the 2nd metacarpo-phalangeal joint (Landsmeer 1955). The 1st dorsal interosseus consists of two parts. The dorsal component is attached, according to Landsmeer (1955), osseously to a tuberosity on the radial aspect of the first phalanx. The volar component runs a more varying course in distal direction. He found that fibers from the first dorsal interosseus were always fixed osseously and that only few extended up into the dorsal aponeurosis or into the hood.

The other muscle of the index finger that extends up into the radial hood is the 1st lumbrical. This muscle arises from the radial aspect of the tendon of the flexor profundus of the index finger and, separated from the adductor, it runs distally out along the radial side of the index finger. Its tendon is attached to the dorsal aponeurosis.

The 1st volar interosseus belongs to the homogeneous group of 3 muscles, none of which show any osseous attachment (Landsmeer 1955). Its tendon thus runs in dorsal direction up as the ulnar wing of the dorsal aponeurosis. The major part of the tendon runs on the volar side of the radio-ulnar axis of movement of the metacarpo-phalangeal joint (Landsmeer 1955).

EXTRINSIC MUSCLES OF THE INDEX FINGER

These muscles consist of 2 extensors and 2 flexors: the extensor indicis proprius, extensor digitorum communis II, flexor digitorum sublimis and flexor digitorum profundus II.

Extensor indicis proprius

This muscle originates from the extensor surface of the ulna and from the membrana interossea. The muscle, which belongs to the deeper layer of the extensors, merges with its tendon at the level of the wrist and runs in the 4th compartment of the ligamentum carpi dorsale to reach the index finger

on the ulnar side of the extensor digitorum communis with whose terminal tendons it unites. In this way it reaches the terminal phalanx of the index finger and here merges with the extensor digitorum communis II (see below). The action of the extensor indicis proprius is fairly independent (Wood Jones 1949), while in ulnar paralysis the index finger can still be adducted against the third finger with the help of this tendon. This therefore indicates that the extensor indicis proprius tendon lies on the ulnar side of the dorso-volar axis in the 2nd metacarpo-phalangeal joint.

Extensor digitorum communis II

This muscle, together with other extensors of the superficial group arises from the radial epicondyle of the humerus. In the common extensor (digitorum communis II—V) mass a relatively distinct muscle can be recognized for the index finger, the extensor digitorum communis II. The muscle passes into the tendon somewhat proximally to the radiocarpal joint and runs in the 4th compartment of the ligamentum carpi dorsale. When the tendon reaches the 2nd metacarpo-phalangeal joint it spreads in both directions to form the "hood", with transverse fibres running in volar direction. This hood can be displaced a few millimetres in proximal-distal direction (Bunnell 1956). Oblique fibres extend up into the extensor aponeurosis distally to the metacarpo-phalangeal joint; on the radial side, the 1st lumbrical and the 1st dorsal interosseus, on the ulnar side the 1st volar interosseus.

A deeper part of the extensor tendon is inserted on the base of the dorsal side of the first phalanx. The tendon then becomes broader and divides into 3 portions. The middle portion (the central or medial band), is inserted proximal-dorsally on the middle phalanx, while the other two—extensor lateral bands—continue along this central tendon and finally unite to be inserted on the distal phalanx proximal-dorsally. The lumbrical tendon from the radial side and the 1st volar interosseus from the ulnar join these 2 lateral portions (Tubiana and Valentin 1964).

According to Duchenne (1867) and Wood Jones (1949), the extensor digitorum communis II can abduct the index finger radially. This would mean that this tendon lies radially to the dorso-volar axis of the metacarpo-phalangeal joint.

Flexor digitorum sublimis II

This muscle arises from the ulnar epicondyle of the humerus, from the ulna and from the radius. A fibrous arcade extends between the ulna and the radius and covers the median nerve at this level. Its tendon lies in the carpal tunnel deeper than do the tendons of sublimis III and IV. The muscles of the index finger therefore lie deeper and fairly isolated. The

sublimis tendon later divides to allow the passage of the tendon of the profundus muscle and is inserted on the volar-lateral aspect of the middle phalanx. In the finger and in the distal part of the palm the tendon is enclosed in a relatively narrow sheath.

Flexor digitorum profundus II

This muscle has a broad origin on the volar aspect of the ulna and the interosseus membrane. It seems to be a relatively well isolated muscle. It is separated from the common flexor mass. It runs through the above-mentioned perforation of the sublimis to be inserted on the proximal-volar aspect of the distal phalanx. In the finger and the distal part of the hand the tendon is enclosed in a fairly narrow sheath.

INTRINSIC AND EXTRINSIC MUSCLES OF THE LITTLE FINGER

The little finger is acted upon by 5 intrinsic muscles and 4 extrinsic muscles.

INTRINSIC MUSCLES

The hypothenar muscles that act upon the little finger are the abductor, flexor brevis and opponens digiti quinti.

The abductor digiti quinti is a long thin muscle that takes origin from the pisiform and surrounding ligaments. This establishes continuity between the flexor carpi ulnaris and the abductor digiti quinti via the pisiform bone. The muscle is inserted on the ulnar aspect of the base of the little finger and spreads up into an aponeurosis in the extensor aponeurosis. In this respect the muscle resembles the short abductor of the thumb.

The flexor digiti quinti brevis arises more radially in the hand, and above all from the hamulus ossis hamati. The tendon of the muscle runs in distal direction on the radial side of the tendon of the abductor muscle and is inserted on the ulnar aspect of the basal phalanx of the little finger.

The opponens digiti quinti also takes origin from the hamulus ossis hamati and surrounding ligaments and is inserted on the major part of the ulnar facette of the 5th metacarpal. Of the three hypothenar muscles, this one lies deepest.

The little finger is also acted upon by 2 other intrinsic muscles, *the 3rd volar interosseus* and *the 4th lumbrical*. According to Landsmeer (1955),

this volar interosseus is never inserted osseously on the little finger. Both this volar interosseus and the 4th lumbrical extend (fan-like) up into the extensor aponeurosis. Landsmeer found that the direction of pull of these 2 muscles was always situated on the volar side of the radio-ulnar axis in the metacarpophalangeal joint. The 3rd volar interosseus must be regarded as an antagonist to the abductor digiti quinti in that it acts and effects radial abduction of the little finger and thereby contributes to adduction in the 4th interspace towards the ring finger.

EXTRINSIC MUSCLES

Extensor digiti quinti proprius and extensor communis V

These 2 muscles belong to the superficial extensors. The extensor digitorum communis V, like the extensor digiti quinti proprius originates from the radial epicondyle of the humerus. The tendon of the extensor digitorum communis V runs in the 4th compartment of the ligamentum carpi dorsale, while the tendon of the extensor digiti quinti proprius extends in a separate compartment, namely, the 5th. It is known (e.g. Wood Jones 1949) that the extensor digitorum communis does not always send a tendon to the little finger, and then there can be a connection between the extensor tendon (juncturae tendineum) of the ring finger and the extensor digiti quinti proprius.

The tendon of the extensor digiti quinti proprius fairly often divides into 2 tendons in the back of the hand. The course of the distal segment of the tendon of this muscle and of that of the extensor communis V resembles that of the extensors of the index finger.

The extensor digiti quinti proprius runs on the ulnar side of the dorso-volar axis in the 5th metacarpo-phalangeal joint and can thereby abduct the little finger (Duchenne 1867, Wood Jones 1949).

Flexor digitorum profundus and sublimis V

The 2 flexors of the little finger essentially resembles that of the deep and superficial flexors of the index finger.

SUMMARY

A brief review of the normal anatomy of muscles and tendons of the thumb, index finger and little finger is presented with special reference to the intrinsic muscles of the thumb.

Chapter IV Author's dissection of muscles, tendons, joints and ligaments around the thumb

Opinions in the literature differ concerning the intrinsic musculature of the hand. In order to form a personal opinion of the muscle anatomy of the thumb the present writer therefore studied these parts in 13 fresh autopsy (right hand) not embalmed, specimens and in one amputated specimen (left hand). Interest was focused mainly on the muscles and tendons presumably taking part in the palmar adduction of the thumb and the various possibilities of insertion of the adductor pollicis on the first ray.

The specimens were so fresh that tendons and joints could still be moved. The function of the muscles could therefore be partly studied by pulling them in the specimen.

ATTACHMENT OF ADDUCTOR MUSCLES ON THE FIRST RAY

Six groups of adductor attachments were found (Table 2).

Insertion No. 1, called the adductor aponeurosis (Mondry 1940, Stener 1962). The most dorsal superficial parts of the adductor musculature are attached partly across the extensor aponeurosis (the hood), and partly obliquely in the extensor aponeurosis. The last portion of the adductor muscles consists of a delicate "tendon" extending up into the distal extensor pollicis longus tendon (Fig. 5).

Insertion No. 2. With strong muscle and likewise strong tendon the deeper part of the adductor musculature is attached to a small tuberosity proximal- ulnar and volar on the basal phalanx of the thumb. In all of the specimens it was possible to demonstrate the "tubérosité interne et supérieure de la première phalange du pouce" (Poirier as quoted by Frohse-Fränkell (1908) (Fig. 6).

Insertion No. 3. No further attachment of the adductor musculature on the dorsal aspect was demonstrable, the rest of this musculature being attached to the volar aspect of the thumb. Intermediate slips of the adductor mus-

Table 2. Attachment of adductor musculature to first ray according to author's dissections

No.	Name	Insertion
1 a	Adductor aponeurosis (<i>Mondry</i> 1940, <i>Stener</i> 1962)	Transversally into the hood
1 b		Obliquely into the hood
1 c		As a tendon out to distal EPL
2	Tubérosité interne etc. Poirier as quoted by <i>Frohse-Fränkell</i> 1908	Tuberosity on ulnar-volar aspect of basal phalanx
3		Volar capsule of MP joint
4		Ulnar sesamoid bone
5 a	Superficial radial fan	Distal, volar, radial on first metacarpal bone
5 b		Strands running distally and osseously inserted on volar, radial part of basal phalanx. Strands running distally and osseously inserted on volar, radial part of distal phalanx (prep. No. 2)
5 c		
6	Deep radial fan	Along and strengthening fibrocartilago volaris and more distally

culature are attached on the volar and ulnar surface of the joint capsule at the level of the first metacarpophalangeal joint.

Insertion No. 4. A 4th attachment is that which, according to conventional conception, is the most known, namely that of the adductor insertion on the ulnar sesamoid bone (Fig. 7).

Insertion No. 5. The 5th possibility of insertion of the deep part of the adductor musculature proved to consist of superficial (volar) tendons extending fan-like (radially) from the adductor musculature, past the ulnar sesamoid bone and merging with the volar aspect of the tendon sheath of flexor pollicis longus. This superficial fan-like arrangement in radial direction divided into three groups in the specimens: a) some fibres crossed the tendon to the flexor pollicis longus on its volar side and were attached

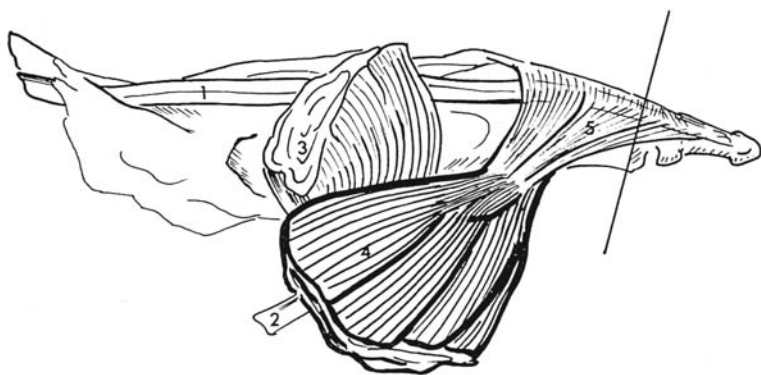


Fig. 5. 1. EPL. 2. FPL. 3. Reflected IOD I. 4. ADD POLL. 5. Adductor aponeurosis.

on the volar-radial-distal part of metacarpale I. b) Relatively strong strands of fibres which were found in all of the dissected specimens and which run in distal-radial direction to be attached on the proximal-volar-radial aspect of the basal phalanx of the thumb (Fig. 7). c) In one preparation (No. 2) some strands also ran distally and radially and were attached to the radial-volar-proximal aspect of the distal phalanx osseously.

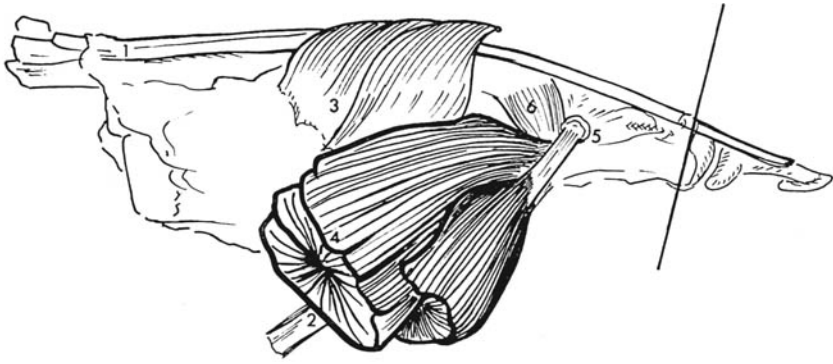


Fig. 6. 1. EPL. 2. FPL. 3. Reflected IOD I. 4. ADD POLL. 5. Tubérosité interne et supérieure de la première phalange du pouce (Poirier). 6. Ulnar collatéral ligament.

Insertion No. 6 could be demonstrated after the tendon sheath of the flexor pollicis longus had been divided and the tendon was retracted. A well defined insertion of the adductor continued with strong strands reinforcing the fibrocartilago volaris (Fig. 8). These bundles continued between the ulnar and radial sesamoid bone, partly further distally-radially finally to be attached osseously on the volar proximal radial aspect of the basal

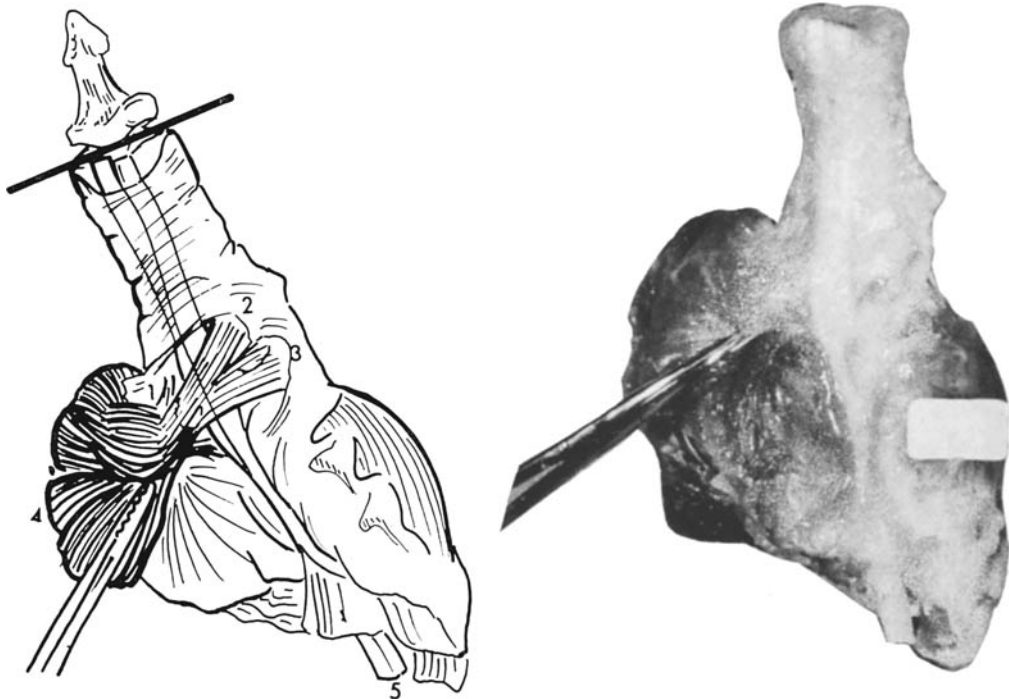


Fig. 7. 1. Ulnar sesamoid bone. 2. Radial sesamoid bone. 3. Attachment of ADD POLL to distal part of metacarpal I. 4. ADD POLL. 5. FPL.

phalanx. Strands from the adductor thus ran both volarly and dorsally to the tendon of flexor pollicis longus (see Fig. 9).

All adductor attachments described in the literature were found in the 14 hands studied besides some further attachments not mentioned in the literature, Fig. 10.

DISSECTION OF EXTENSOR POLLICIS LONGUS, EXTENSOR POLLICIS BREVIS, ABDUCTOR POLLICIS BREVIS AND FLEXOR POLLICIS LONGUS

Extensor pollicis longus

On application of a pull to adductor aponeurosis the "hood" was drawn in ulnar direction, and thereby dislocated the extensor pollicis longus tendon in ulnar direction. When the extensor pollicis longus tendon was pulled in proximal direction, the thumb was adducted in both the carpo-

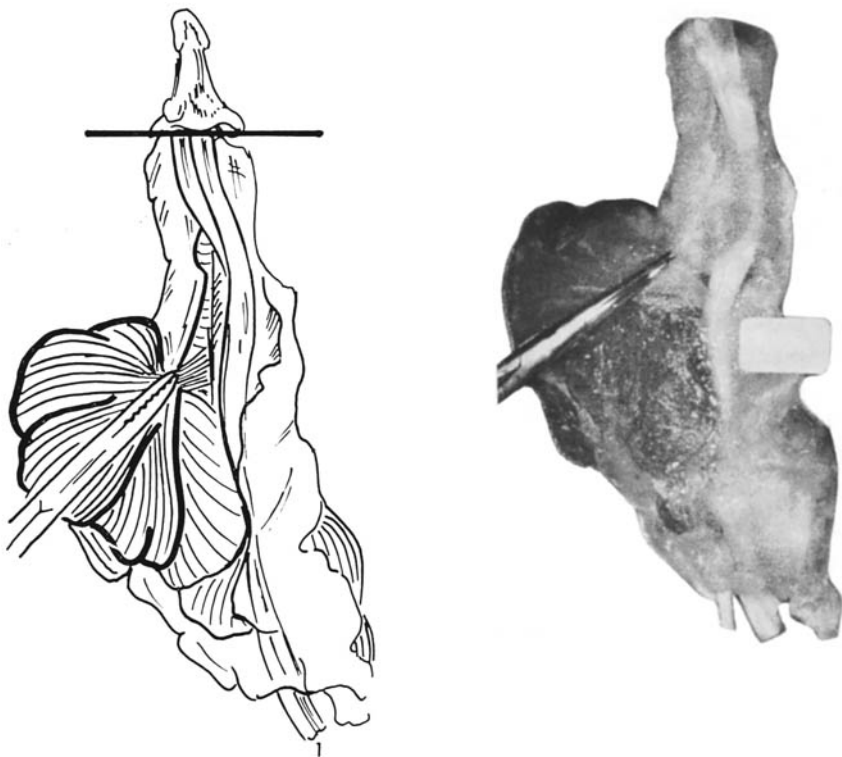


Fig. 8. Flexor tendon sheet split up and showing deep insertion of ADD POLL into radial sesamoid bone as a part of fibro-cartilago volaris. 1. FPL.

metacarpal joint I and somewhat in metacarpophalangeal joint I. At the same time the thumb was supinated. The extensor pollicis longus was embedded in loose tissue in all of the specimens from a point in the proximal part of the adductor and "abductor aponeurosis" (the hood) to the level of Lister's tuberosity.

The extensor pollicis brevis, on the other hand, was situated throughout its course in relatively dense or tight tissue and could not be moved sideways to any appreciable extent. When the extensor pollicis brevis was pulled in proximal direction it proved to have two functions: an extension of the metacarpo-phalangeal joint I, and abduction of the carpo-metacarpal joint I, which is in agreement with Duchenne's (1867) conception that the extensor pollicis brevis acts as an abductor on metacarpale I. The extensor pollicis brevis tendon is attached osseously to a tuberosity on the proximal-radial aspect on the basal phalanx. In one of the preparations

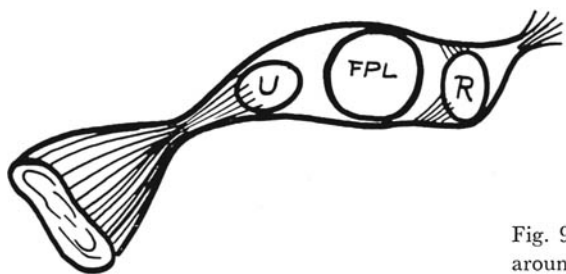


Fig. 9. Strands from ADD POLL around FPL.

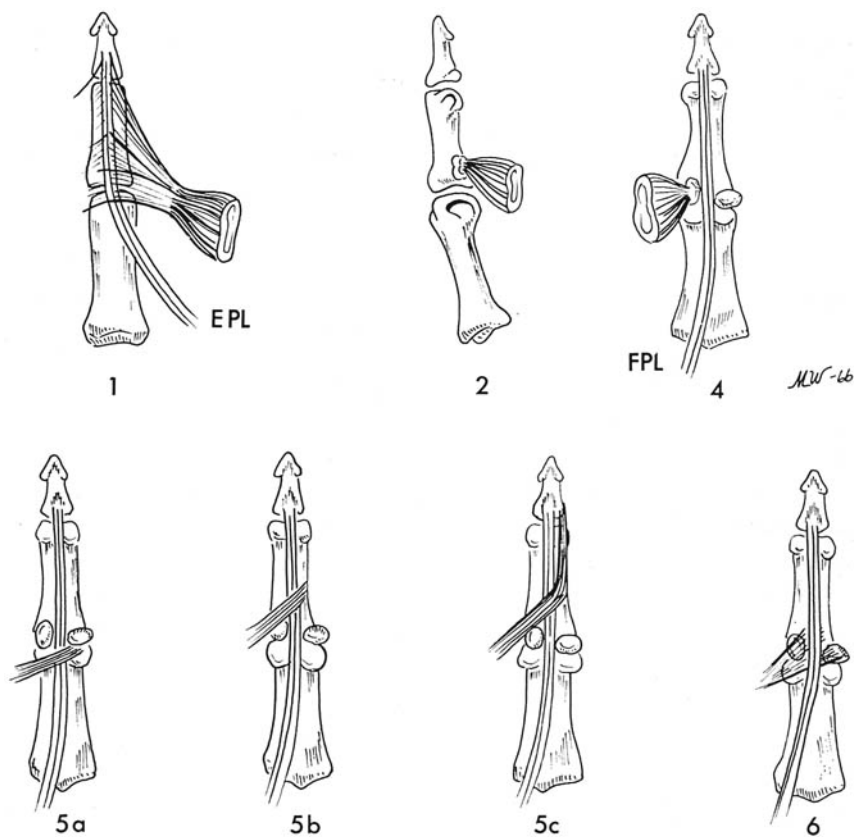


Fig. 10. Attachment of ADD POLL. 1. Adductor aponeurosis. 2. Tubérosité interne etc. (Poirier). 4. Ulnar sesamoid bone. 5 a. Distally on first metacarpal. 5 b. Proximally on the basal phalanx. 5 c. On the radial part of the base of the distal phalanx. 6. Strong strands reinforcing the fibro-cartilago volaris.

(No. 11) the extensor pollicis brevis was found to continue distally to become attached also on the proximal-dorsal aspect of the distal phalanx, an observation reported previously by Kaplan (1965). When the extensor pollicis brevis was pulled in proximal direction, it was followed a few millimetres by the hood. The extensor pollicis brevis is, however, not attached to the abductor-aponeurosis, but could be traced some millimetres distally below the latter as a free tendon.

The abductor pollicis brevis could, to a certain extent, be regarded as an antagonist of adductor pollicis but also as a synergist. As an antagonist it acts like a pure abductor; as a synergist, it acts together with the adductor pollicis by pulling the extensor aponeurosis and the "hood" in proximal direction as does the extensor pollicis longus (Bunnell 1956). The extensor pollicis longus can here be regarded as a prime mover of tension and proximal pull of the abductor-adductor aponeuroses. Tendon fibres extending from the adductor and the abductor brevis lie dorsally to the radio-ulnar axis of movement in the metacarpo-phalangeal joint I and thereby extend the distalmost joints of the thumb. When the pull of the extensor pollicis longus was released and the deeper part of the adductor pollicis and abductor pollicis brevis were pulled, I found like Bunnell (1956) that the abductor-adductor aponeurosis slipped in distal direction and that the metacarpo-phalangeal joint I flexed. From the musculature of the abductor pollicis brevis 2 tendons could be isolated. One of them extended into the hood towards the extensor pollicis longus tendon as a well defined abductor aponeurosis. Other strands, fairly strong, were osseously attached to the volar-radial aspect of the basal phalanx of the thumb. When this tendon was pulled it flexed and slightly abducted the metacarpo-phalangeal joint I.

The flexor pollicis longus in its own well defined sheath originating from the middle of the metacarpale I ran in distal direction. The tendon of the flexor pollicis longus lay between the bellies of the flexor pollicis brevis and opponens pollicis. The tendon could not be displaced sideways to any appreciable extent.

ADDUCTION EXPERIMENTS ON FRESH POST MORTEM SPECIMENS

The specimens were removed from fresh, not embalmed, autopsy specimens so that the tendons and joints could still be moved. Most of the specimens were taken in such a way that part of the distal phalanx, the entire basal phalanx and metacarpale I and multangulum majus as well as parts of the 2nd ray could be dissected. Adduction of the metacarpale I towards meta-

carpale II could be produced by pulling either the extensor pollicis longus tendon or the adductor musculature. Pull of the tendon of the flexor pollicis longus produced no adduction of metacarpale I towards metacarpale II.

When the adductor musculature was pulled, it tightened the superficial as well as the deep radiation in radial direction distally, see Figs. 6—8. Direct continuity was thus found between the adductor musculature and its tendons attached to 1) metacarpale distally 2) basal phalanx proximally and 3) in 1 case (No. 2) in the proximal-volar aspect of the distal phalanx of the thumb. The effect of this pull was therefore adduction, pronation and flexion of the carpo-metacarpal joint and flexion of metacarpophalangeal joint and of the inter-phalangeal joint in the one case (No. 2) where the tendon was inserted far out on the distal phalanx.

Certain interesting features of the carpo-metacarpal joint I were observed. On adduction of the thumb in palmar direction it was found that the proximal part of metacarpale I slid in radial direction. On careful dissection of the ligaments in the carpo-metacarpal joint I, as previously done by Haines (1944), Gedda (1954) and Napier (1955), found that a strong ligament extending from the proximal-dorsal part of metacarpale I converged down to a more isolated point on the distal-dorsal-radial surface of the multangulum majus. This ligament limited the radial gliding movement of the basis of metacarpale I on adduction. The ulnar-volar ligament, previously demonstrated by Gedda (1954) also limited the movement of this outward sliding of the proximal part of metacarpale I on adduction. Radially to the dorsal carpo-metacarpal ligament there is a thin capsule which is not reinforced with ligament. That this capsule is loose and has a yieldable radial side may have something to do with its function to allow the outward sliding of the basal part of the proximal metacarpale I (in radial direction) on palmar adduction. Adduction thus tightens the strong ligament extending from the distal dorsal radial aspect of the multangulum majus running fan-like in distal direction to its attachment on the dorsal part of metacarpale I. The volar-ulnar ligament (Gedda 1954) which is thereby also tightened, thus works as a limiting ligament in that it prevents hyperextension of the carpo-metacarpal joint I. The ligament that runs on the dorsal side between the bases of metacarpale I and II (dorsal inter-metacarpal ligament) prevents undue abduction of metacarpale I in the first carpo-metacarpal joint.

After having severed the dorsal carpo-metacarpal ligament, adduction in palmar direction was repeated. It was found that the basal part of metacarpale I glided out considerably more in radial direction. This dorsal carpo-metacarpal ligament thus acts as an important guide and brake.

EFFECT OF FIRST DORSAL INTEROSSEOUS ON FIRST RAY

On palmar adduction the thumb moves from abducted-pronated position to an adducted-supinated position towards the volar part of the base of the index finger. When the index finger was held still as a fixed part, pull of the 1st dorsal interosseous muscle was found to adduct the thumb. This is previously known. The examination of the specimens showed that the origin of the 1st dorsal interosseous muscle was situated on the dorsal-ulnar aspect of the metacarpale I. When this dorsal interosseous muscle was pulled, it adducted and supinated metacarpale I.

SUMMARY

Muscles, tendons, joints and ligaments were dissected in 14 hand specimens. Interest was focused mainly on muscles and tendons presumably taking part in the palmar adduction of the thumb. 10 different attachments of adductor pollicis muscle on the first ray could be demonstrated, some of them not mentioned before in the literature. Some adduction experiments on fresh post mortem specimens were made. Adduction movement of the first ray against the second was demonstrated by pulling the extensor pollicis longus tendon, which was not the case when the flexor pollicis longus tendon was pulled. Some detailed dissections of the CMC joint I gave information on the behaviour of the base of the first metacarpal in this joint during palmar adduction of the thumb. Radial sliding of the proximal part of this bone was then always demonstrated and the rôle of the ligaments around the actual joint was studied.

Part III On some normal functions of the hand

Chapter V On some normal functions of the hand

INTRODUCTION

If the hand is regarded as a tool then the arm is the handle. The function of the hand is dependent on the precision of its movements, combined with strength and stability. The performance of these functions requires the highest degree of sensibility of the gripping surfaces, so-called tactile gnosis (Broman 1945, Moberg 1958). It is this tactile gnosis that makes the hand seeing, *i.e.* even in the dark one can recognize the shape and size of anything held in the hand.

The total function of the hand therefore depends on its movability with strength as well as sensibility and in function tests both must be evaluated, preferably quantitatively (Moberg 1958, 1964).

SHORT SURVEY OF SOME FUNCTIONS OF THE 3 MAIN NERVES OF THE HAND

The radial nerve governs muscles and movements taking part in stabilisation of the wrist and opening of the grip. The nerve has a special area of innervation, *i.e.*, in the first interspace, and therefore partakes in the "key-grip".

The median nerve supplies impulses from the most important tactile surfaces of the hand. The nerve gives off motor branches to the abductor pollicis brevis, opponens pollicis and the superficial head of flexor pollicis brevis besides the two radialmost lumbricals. The nerve therefore governs abduction and opposition movements of the thumb and, broadly speaking, it may be regarded as one of the most important nerves of the hand.

The ulnar nerve occupies, from a functional point of view, an intermediate position between the radial nerve and the median nerve because it covers a fairly important tactile surface in the ulnar part of the hand, and because it governs muscles and movements of all of the small muscles of the hand except those innervated by the median nerve. Thus, the ulnar nerve is said to be responsible for the fine adjustment of many of the small movements of the hand, while the median nerve receives impulses from the most important tactile surfaces in the hand.

In ulnar paralysis the sensibility of the gripping surfaces on the radial aspect of the fingers is thus unimpaired. Certain function tests of such a hand are therefore not disturbed by loss of sensibility occurring in complete injury to the median nerve.

METHODS FOR QUANTITATIVE EVALUATION OF THE SENSIBILITY OF THE HAND

Brief review

The great importance of sensibility for adequate function of the hand is now so well known and has been examined so thoroughly by Hilgenfeldt (1950), Bunnell (1956), Moberg (1958, 1962, 1964) and Örne (1962) that it does not require further discussion here.

The examination methods now used are two-point discrimination (Weber 1835, Moberg 1958, Örne 1962), the ninhydrin method (Moberg 1958, Örne 1962), the picking up test (Moberg 1958) and demonstration of signs of wear and tear (Moberg 1958, Mannerfelt 1962). These methods allow good evaluation of the sensibility of the hand.

CONSIDERATIONS ON QUANTITATIVE MEASUREMENTS OF THE STRENGTH OF HAND MUSCLES

Methods for measuring the strength of the hand have long been available. The literature in this field is fairly voluminous. Good surveys have been given by Hunsicker and Donnelly (1955) and Tornvall (1963). The following methods have been used for measuring isometric contraction:

1. Mechanical spring balance methods.
2. Cable-tension methods.
3. Hydraulic methods.
4. Pneumatic systems.
5. Strain-gauge methods.

The examination methods fall largely into 2 groups. One working with ergometers (measures of work performed) and ergographs, the other comprising simpler methods using dynamometers (measurements of strength) and suitable for clinical use.

SURVEY OF ERGOMETERS, ERGOGRAPHS AND MORE COMPLICATED INSTRUMENTS FOR MEASURING THE STRENGTH OF THE HAND

According to Martin (1921), an ergograph is an apparatus for recording successive muscle contractions. It records the beginning of a contraction, its duration, and its cessation. These measurements can be recorded mechani-

cally or electronically. Common to these apparatuses is that the strength of various muscle functions can be measured while the patient is performing certain grips or movements of the hand (Brahme 1936, Hellebrandt, Kelso and Eubank 1950, Beasley 1956, Asmussen, Heebøll-Nielsen and Molbech 1959, Beasley 1961, Ebskow and Bonde-Petersen 1963). These apparatuses allow some detailed examinations of the hand, but they are complicated. They are also expensive and less suitable for routine clinical work, they are often large and not easy to use. These apparatuses were designed mainly because no simple reliable methods were available for measuring the strength of the hand and certain muscles of the hand.

SURVEY OF DYNAMOMETERS SUITABLE FOR CLINICAL USE

Martin (1921) defined a dynamometer as an apparatus useful for numerical estimation of the strength of a single contraction of a muscle. One of the oldest and most well-known dynamometers in daily use is Regnier's dynamometer (1807), which forms the basis of most spring steel dynamometers in use to-day. It was Collin who developed such dynamometers at the end of the 19th century ("Collin's dynamometer" — as quoted by Zoth 1936). Whipple (1914) described a pull-dynamometer with a handle. The pull applied was recorded on a dial. Lowett and Martin (1916) developed another method according to which the eccentric strength of various muscles was measured. They used a "break method". They measured "the breaking strength" of muscles, *i.e.* the muscular force required to overcome maximal resistance. The authors used their apparatus for measuring the strength of ulnar adduction of the adductor pollicis, for example. They did not give any values obtained by systematic examination with this method. Lewey, Kuhn and Juditski (1947) published a method, according to which with the aid of a grip connected to a spring-balance they recorded the strength of certain hand functions under more standardised conditions. The mechanics of the apparatus is based on stretching of steel-springs. Differences of less than half of pound were regarded as lying within the error of the method when testing the strength of the small muscles of the hand. Newman (1949) constructed a "myometer" with an inbuilt hydraulic system. The instrument has an extra indicator (a maximum reader indicator). Wainerdi (1950) constructed a grip dynamometer based on the principles according to which the strength is measured by compression of an air balloon. The force applied was registered on a dial. Bechtol (1954) devised a grip dynamometer, which was excellent in several respects. It had the advantage that it could be adjusted to fit hands of different sizes. The instrument is known as the Bechtol-Jamar-dynamometer.

A wide variety of dynamometers has been designed mainly because Collin's original dynamometer was both unreliable and complicated. The following objections have been raised against Collin's dynamometer: (Whipple 1914, Brahme 1936).

1. The time between two successive examinations is relatively long, because reading of the result and a second grip of the instrument take time.
2. Collin's dynamometer does not allow examination of the duration of maximum exertion nor how the grip is loosened, slowly or rapidly.
3. Collin's dynamometer can only be used by a painless hand. When used for estimating the strength of painful hands the values recorded will be misleadingly low.
4. In sweaty hands the dynamometer is apt to slip.
5. Collin's dynamometer is not constructed in such a way as to fit automatically into correct position in the hand. If the dynamometer is not gripped in the proper way the values will be artificially low.

S U M M A R Y

After a brief review of methods now used for evaluation of the sensibility of the hand a short survey is given of useful methods for measuring the strength of isometric contractions in the hand. Several apparatuses of dynamometer type are based on Regnier's (1807) principle with a spring steel dynamometer.

Chapter VI Quantitative methods for evaluating strength of muscles supplied by ulnar nerve

PREVIOUS METHODS

The literature on the symptoms and signs of paralysis of the ulnar nerve is abundant. But only few investigators have tried to estimate the loss of function quantitatively with special dynamometers. Some investigators used Collin's dynamometer and found half to two thirds of the strength of the hand to be lost in ulnar paralysis (Bunnell 1956 and others). Lowett and Martin (1916) measured the strength of ulnar adduction of the thumb. Pollock (1925), like Lowett and Martin (1916), used a spring scale dynamometer for measuring muscle strength. The apparatus was inserted between the hand of the examiner and that part of the patient to be examined. The authors gave no control values. Lewey, Kuhn and Juditski (1947) measured the strength of some grips dependent upon the ulnar nerve. They also used a spring scale dynamometer inserted between the examiner and the patient's hand. The normal value for abduction of the index finger was 9.0 lbs (=4.050 g), abduction of the little finger 8.9 lbs (=4.005 g) and ulnar adduction of the thumb 10.4 lbs (=4.680 g). The strength of abduction of the index finger and little finger was measured during isometric contraction. On adduction of the thumb the examinee gripped a disk between the index finger and the thumb with all joints extended. This disk was connected to a spring scale which was pulled with increasing force towards and by the examiner. The error of the method according to the authors was less than 1/2 pound (250 g). The authors gave no values for patients with ulnar paralysis.

Moberg (1948) measured the pinching grip with a spring scale, to which was connected a metal disk. The examiner pulled the spring scale while the patient tried to hold the metal disk between his index finger and thumb. When the disk slipped out of the patient's grip the value was noted by a maximum reading indicator on the scale. Normal values for the pinching grip are not given.

Newman (1949) designed a "myometer", based on the hydraulic principle, for measuring isometric contractions. The author recorded the strength of abduction of the index finger and the little finger, of the abductor pollicis brevis but not the strength of palmar adduction of the

thumb. The strength of adduction in the 2nd and 4th interstices could not be measured with this apparatus either. The normal range of values was not given.

Zadig (1962) designed a dynamometer based on the hydraulic principle. It is true that the apparatus was designed for measuring the strength of the arms and legs, but the pinching grip could also be measured with it. The examinee is instructed to compress the apparatus otherwise used for measurement of the strength of the pull. According to Zadig (1962), various objections can be raised against the use of apparatuses in which the strength is measured by compression of an apparatus.

1. It is difficult to hold the apparatus still.
2. Apparatus for measuring resistance requires special plates for application of pressure.
3. Application of such a plate can be painful to the patient.
4. It is difficult to control the direction of the counterpressure. The force should always be directed at right angles to the lever.

In view of these disadvantages Zadig tests muscle strength by resistance to pull.

In an electromyographic investigation of certain movements of the fingers governed by the ulnar nerve Egawa (1959) used a small balloon which, when compressed, actuates a mercury column. With this apparatus he studied the pinching grip between the thumb and the ringfinger of 2 controls and of 2 patients with ulnar paralysis. The normal value for this special pinching grip was 80 mm Hg.

After the ulnar nerve had been blocked in the controls the value was 40 mm Hg. Electromyographically Flexor digitorum sublimis IV worked much more than profundus IV in pinching grip between the thumb and ringfinger after ulnar nerve block.

Discussion

Most of the dynamometers described above can be used for measuring some movements of the hand governed by the ulnar nerve. Hardly any dynamometer can measure the strength of all these tests:

1. the pinching grip,
2. palmar adduction of the thumb,
3. radial abduction of the index finger,
4. adduction in the 2nd and 4th interspaces and
5. ulnar abduction of the little finger.

These 6 tests are useful mainly in the examination of ulnar function. Only one publication (Lewey, Kuhn and Juditski 1947) gave the normal values for some of these movements based on systematic examination of a large series. Some apparatuses register the strength of the pinching grip when the examiner between a dynamometer and the patient's pinching grip introduces a spring scale and a small metal block. Sweating of the hand is a source of error in this method.

It would appear that no systematic investigation using a suitable measuring instrument have been made of the residual function of the hand in a large series of ulnar paralysis. Isolated measurements of the strength of single groups of muscles have been reported but no analysis has been made of the strength of those groups of hand muscles controlled by the ulnar nerve. It therefore seemed necessary to construct an apparatus with which it would be possible to measure as many as possible of the grips and movements of the hand that are controlled partly or entirely by the ulnar nerve.

An apparatus satisfying these requirements was therefore designed by the author and is described in the next part of this chapter.

DESCRIPTION OF THE AUTHOR'S DYNAMOMETER

Purpose of the construction

The purpose was to design an apparatus fitting the following requirements.

- a. The method should be standardisable.
- b. The measurements should be precise and reproducible.
- c. The method should preferably be useful for both clinical and research use.
- d. The dynamometer should be able to measure isometric muscle contractions.

a—c are the requirements also set up by Beasley (1961).

The term isometric muscle contraction is now generally accepted. On such a contraction the origin of the muscle and its insertion do not approach one another or if so, only very slightly. It is a product of energy or strength and the work performed can be expressed biologically as strength $\times$ time (Hettinger 1964).

Range of use

The special dynamometer was originally designed to measure the strength of the palmar adduction of the thumb. I have, however, found that also

other movements influenced more or less by the ulnar nerve can be measured, namely:

- a. Pinching grip.
- b. Radial abduction of the index finger.
- c. Adduction movement in the 2nd and 4th interspaces.
- d. Ulnar abduction of the little finger.

The palmar adduction of the thumb, pinching grip and adduction in the 2nd and 4th interspaces were measured during isometric muscle contraction. Radial abduction of the index finger (mainly interosseus dorsalis I but also force exerted by extensor digitorum communis II) and ulnar abduction of the little finger (mainly abductor digiti quinti and flexor brevis digiti quinti but also of extensor digitorum communis V and extensor digiti quinti proprius) was measured against the so-called "breaking force" (De Lorme and Watkins 1951). By "breaking force" the authors mean the "amount of force necessary to produce lengthening of a muscle set in a maximum isometric contraction". Also these 2 tests are thereby based on isometric muscle contraction.

Construction

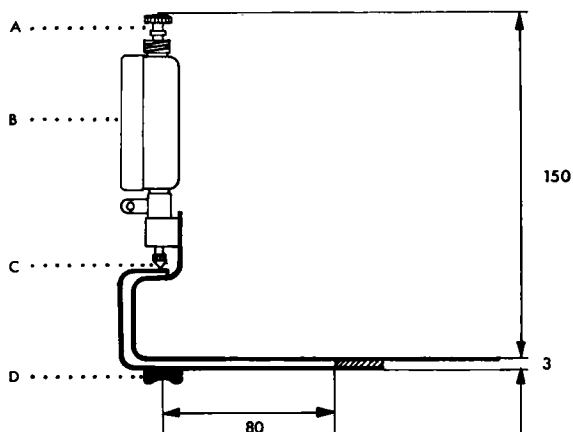
For several reasons use was not made of hydraulic or spring balance arrangements. The electronic technique with a strain-gauge-apparatus was not considered either. The construction of the apparatus should be as simple as possible and cover a measuring range from 0 to at least 5 kg. The design of the dynamometer is based on a spring technique, where 2 steel plates are pressed together and where the movement is recorded by a precision meter (Metron M 2—5 Figs. 11 and 13). The precision of this apparatus is high, 100 graduations on the dial correspond to 1 mm movement of the plates towards one another. The measuring range of interest was between 0 and 3 mm. The forces measured can therefore be regarded as virtually isometric.

Mode of action

The principle is that the examinee compresses the 2 plates as much as possible by pinching grip, palmar adduction of the thumb, and in the test of adduction strength in the 2nd and 4th interspaces. On registration of the strength of radial abduction of the index finger and ulnar abduction of the little finger the examiner holds the instrument, which is pressed against the radial aspect of the index finger and against the ulnar part of the little finger. Here the examination is done against breaking force and

Fig. 11.

- A. Adjustment screw.
- B. Precision dial.
- C. Active spring actuation tip of measuring rod of the dial.
- D. Pressure plate.



the force registered is that necessary to produce lengthening of the actual muscle set in maximal isometric contraction.

The principle of the dynamometer is apparent from Fig. 11. The steel is elastic (stainless steel—Fagersta Bruk R—320). The steel is free from inner and outer tension. The material is thus stable.

The precision meter (B) is mounted on the stationary steel plate (Fig. 11). The movable steel plate actuates the measuring tip of the precision meter (C). The friction between the active steel plate and this tip is considered to be negligible. The length of the lever from the inner end of the heel mounted between the two steel bars to the middle of the pressure plate (D) is 80 mm. The height of the heel is 3 mm. The indicator can be set at zero with an adjustment screw (A), before every measurement.¹

Calibration

The apparatus is set at zero and is loaded with increasing weights (0.25 kg, 0.5 kg, 1 kg, 2 kg and 5 kg). The compression of the active spring and the deflection of the indicator on the dial are proportional to the load. According to Hook's law the curve is therefore linear in this range of measurement (Fig. 12). The special dynamometer was calibrated at the beginning of the investigation in October 1962, the calibration was checked in October 1963, in January 1964 and finally in May 1964 when the entire investigation was finished. Though the dynamometer had been used for more than 30,000 measurements the spring had not stretched. The curves

¹ This instrument (Intrinsimeter) is now available from KIFA, Sweden.

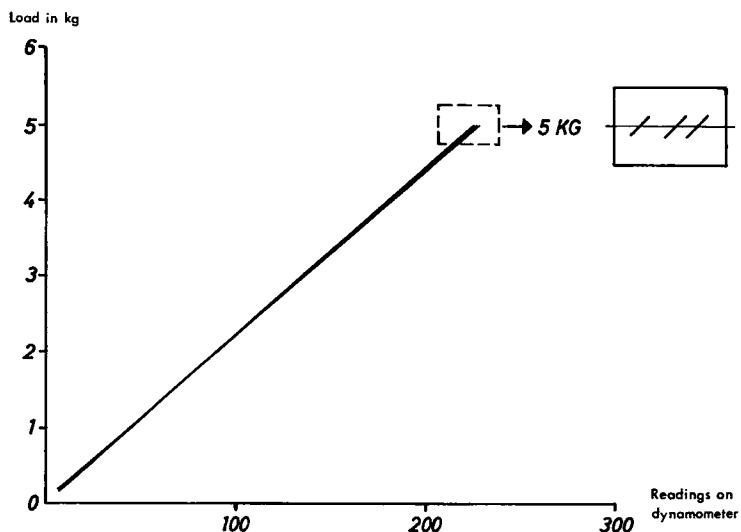


Fig. 12. Calibrating curve. Result of check-examinations between October 1962 and May 1964.

obtained at the various check-examinations were practically identical (See Fig. 12 and Table 3).

Calibration was done in exactly the same way on all occasions at which the temperature and the relative humidity in the examination room were noted. On Fig. 12 degrees on the dial are converted to kilogram.

Effect of temperature and relative humidity on the dynamometer

Control calibration in a climate chamber

The highest relative humidity (hair hygrometer) noted during the investigations was 74 %, the lowest 30 %. The highest temperature was 23.5° C; the lowest 18° C. At the end of the entire investigation in May 1964 the dynamometer was calibrated in a climate chamber with a constant relative humidity of 75 %. There is no reason to suppose that the recording of the dynamometer varies with the relative humidity down to 30 %.

The temperature in the climate chamber at the first control experiment was 15.0° C and on the second 25.0° C. In order to be sure that the dynamometer assumed the temperature prevailing in the chamber a thermoelement was placed on the metal plate of the dynamometer in the chamber where the control calibration was done. The thermoelement recordings (17.6° C and 24.2° C) coincided with those noted previously in the

Table 3. Control of author's dynamometer

Load	Date			
	9/10 1962	7/10 1963	18/1 1964	26/5 1964
0.25 kg	11,5	10	11	11
0.5 „	23	21	21	22
1.0 „	46	45	44	43
2.0 „	89	90	90	91
5.0 „	225	228	227	225

Table 4. Control test of dynamometer in climate chamber

	Climate chamber	Climate chamber	Laboratory
Relative humidity	75 %	75 %	40 %
Temp.	15.0° C	25.0° C	21.0° C
Temp. Thermoelem.	17.6° C	24.2° C	—
Dynamometer			
Load	Dynamometer readings		
0.25	11	10	11
0.5	21	21	21
1.0	44	46	44
2.0	89	89	90
5.0	225	228	227

examination room at the above mentioned temperatures. Table 4 shows the high degree of reproducibility of measurements at a relative humidity of 75 % and at a temperature of 17.6° and 24.2° C. The control examination in the climate chamber thus showed that at a relative humidity of 75 % variation of the temperature between 15.0°—25.0° C had no effect on the accuracy of the dynamometer.

SUMMARY

A review of previous apparatuses for evaluating strength of muscles governed by the ulnar nerve is given. Most of the dynamometers described could measure only some, but not all, of the muscles and grip functions included in the author's present investigation. It was therefore necessary

to construct an apparatus with which it would be possible to measure the strength of the grips and movements of the hand that are controlled partly or entirely by the ulnar nerve. A dynamometer satisfying these requirements was therefore designed by the author. The construction, mode of action, range of use and the method to calibrate the dynamometer are described.

The effect of temperature and relative humidity on the dynamometer was investigated. An examination in a climate chamber showed that variation of temperature between 15.0° C and 25.0° C at a relative humidity of 75 % had no effect on the accuracy of the dynamometer. This investigation was based on the lowest and highest temperatures in the author's laboratory while measuring the strength of grips and movements in the hand, both in controls and in volunteers subjected to ulnar nerve block.

During all these measurements the two steel plates of the dynamometer were compressed more than 30,000 times. It was therefore necessary to re-calibrate the dynamometer now and then during the investigation. The control calibrations gave practically identical curves, which made it possible to compare values from the beginning of the investigation to the end (Oct. 1962 to May 1964).

Chapter VII Control series

COMPOSITION

The control series consisted of 100 persons (50 male medical students and 50 female students of physiotherapy) aged 18 to 29 years. 88 per cent of the males were between 19 and 24 years and 78 per cent of the females were between 20 and 23 years. In Asmussen and Heebøll-Nielsen's (1961) large series of males and females, aged 15—60 years, the highest value for isometric contractions were noted for subjects between 18 and 30 years.

None of the 100 controls had had any disease known to affect the central or peripheral nervous system, nor had any of them any serious injuries to the hands in their history. Four males and 1 female were left handed.

ORDER OF TESTS PERFORMED

1. Strength of pinching grip.
2. Strength of palmar adduction of the thumb.
3. Strength of radial abduction of the index finger.
4. Strength of adduction in the second interspace.
5. Strength of adduction in the fourth interspace.
6. Strength of ulnar abduction of the little finger.

METHODS AND STANDARD POSITIONS

Measurements were always made of the better hand.

The temperature and the relative humidity in the examination room were measured.

The examinee was never allowed to see or hear the values recorded. The values were therefore never read aloud but recorded directly by an addition machine on a strip of paper after every test (Fig. 14). The subjects were therefore not induced to "compete" with other controls or to achieve higher values than at a previous test.

The subject was instructed not to be tense but to concentrate entirely on the actual test.

Jerky tests and tests in which the subjects evidently overexerted themselves or in which they pushed the lower arm forwards were not accepted.

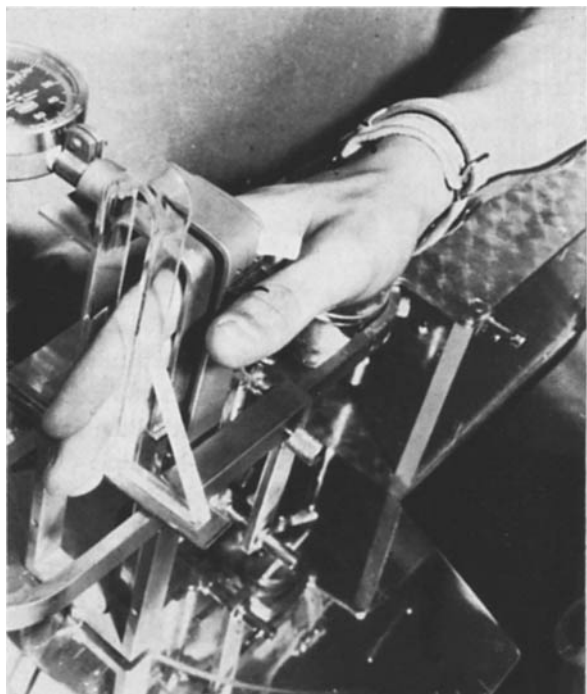


Fig. 13. Palmar adduction thumb.

The control group was examined and measurements were made, as planned, on day 1 and on day 13.

The experimental subjects were studied on day 1, on day 7 before and immediately after the induction of ulnar block and again on day 13. A small group of male students were examined daily for 13 days.

In order to keep the conditions under which the measurements were made as standardised as possible, the hand to be studied was adjusted and fixed in exactly the same way in relation to the active part of the dynamometer, *i.e.* the pressure plate, from one occasion to another. For this purpose a special fixation arrangement—an examination bridge—was designed. It consisted of a stationary and a movable part, (Figs. 13—18).

The upper arm, the elbow and the lower arm was fitted in and fixed to the stationary part. The elbow was set at 90° flexion. At this angle the strength in pro-supination is greatest (Salter and Darcus 1952). The lower



Fig. 14. General view of equipment.

arm was therefore held in midposition between pronation and supination by a transverse strap fixed around the distal part of the lower arm (Fig. 18). The lower arm was resting in a gutter.

According to the plan of the examination, the strength of the pinching grip, the strength of palmar adduction of the thumb and radial abduction of the index finger were to be measured at varying angles of the wrist. In the examination bridge the wrist could be moved around its radio-ulnar axis (volar flexion — dorsal extension). This axis runs through "the centre of an egg" (Hjortsjö 1959). The axis of movement extending from pole to pole of the egg runs approximately through the centre of the caput ossis capitati (Forsell 1902, Wright 1959, Hjortsjö 1959). The outer and ulnar projection of this level onto the wrist lies approximately at the level of the os pisiforme palpable from the outside (Fig. 18). After the upper arm, the lower arm and the hand had been placed in the bridge rotation

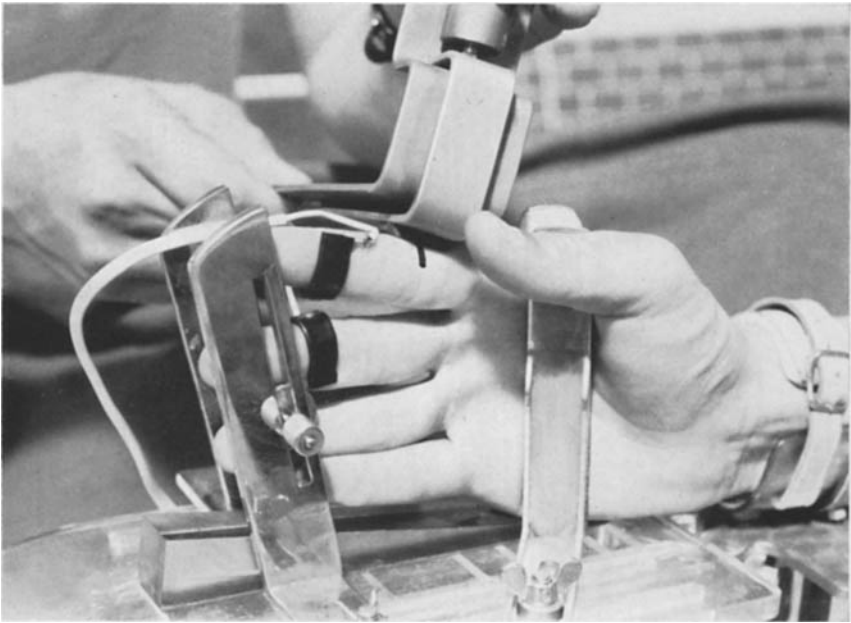


Fig. 15. Radial abduction of the index finger. The strength is measured against breaking force. Observe the two contact plates between index and long finger.

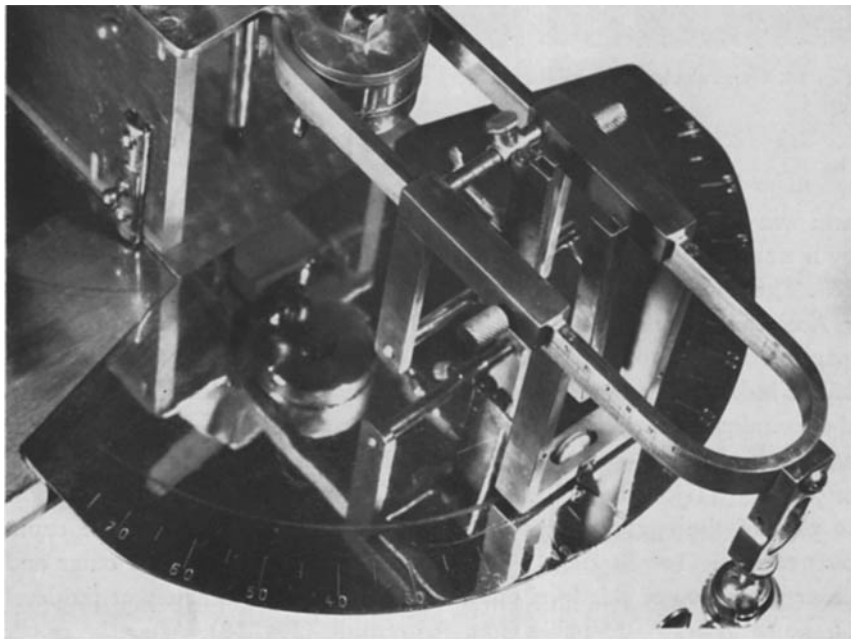


Fig. 16. Close-up of parts of attachment for the dynamometer and measuring device.

Fig. 17. Close-up of attachment for the dynamometer.

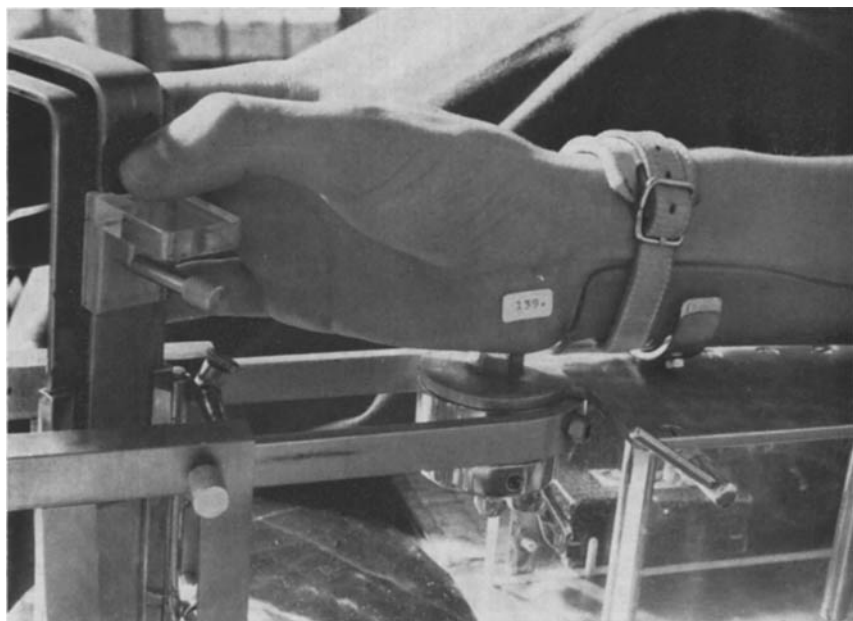
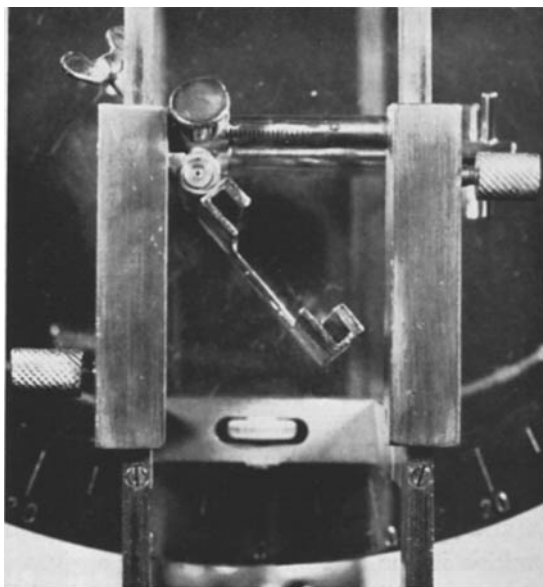


Fig. 18. Pinching grip. Observe the special bridge for adjusting the thumb in pronation. The pisiform bone is adjusted to the axis of movement of the device.

about the radio-ulnar axis of the wrist was possible and this was done around a largely vertical axis in the movable part of the fixation range (Fig. 16). The movable part of the fixation device can move about 75° dorsally and 75° volarly around its axis.

In this movable part of the bridge the dynamometer is mounted on a fixed part adjustable in two directions at right angles to one another and can be locked in desired position. The stationary arrangement for the dynamometer is thus movable in proximal-distal direction and laterally (Fig. 16). Movement to one side or the other corresponds to dorsal-volar in relation to the lower arm in midposition between pronation and supination. The dynamometer can also be turned about a vertical axis in the distal fixation arrangement (Fig. 17). The rotation is necessary for adjustment of the best position of the dynamometer when measuring the pinching grip. All adjustments can be set and registered on a millimeter scale (Figs. 16 and 17). Possibilities of variation are necessary because of differences in arm-length and hand-size of the person examined. The best standard position in the coordinate system for a given patient is recorded exactly. The same subject can therefore be examined in exactly the same position from one occasion to another.

Special reference lines were drawn the first time the hand was placed in the examination bridge, namely for:

palmar adduction of the thumb at the level of the IP-joint ulnarly (see Fig. 13),

radial abduction of the index finger on the radial side at the level of the PIP-joint of the index finger (Fig. 15),

adduction in the 2nd interspace on the radial side at the level of the PIP-joint of the long finger,

adduction in the 4th interspace on the ulnar side at the level of the PIP-joint of the ringfinger,

ulnar abduction of the little finger on the ulnar side at the level of the PIP-joint of the little finger.

The movable sledge (Figs. 16, 17) is used for fastening the dynamometer when measuring the strength of *the pinching grip* and *palmar adduction*. In the latter case a T-formed support locks the 4 ulnar fingers (Fig. 13). A special bridge replaces this sledge when measuring the strength of *radial abduction of the index finger* (Fig. 15). This special arrangement keeps the hand fixed and the only movable part is the index finger, which performs radial abduction against breaking force. To secure stability in lateral direction the index finger is guided by a side support. Contact plates are applied to the ulnar side of the index finger and the radial side of the long finger. The subject is instructed to perform maximal radial abduction

with the index finger. The examiner presses the dynamometer in ulnar direction and with the plate of the dynamometer in proper position against the reference line drawn at the level of the PIP-joint radially on the index finger (Fig. 15). The subject is gradually unable to resist the increasing pressure and the two metal plates come into contact with one another and thereby close an electric circuit, which starts an electric buzzer. The value on the dial is then read. During this examination the thumb is abducted.

In the measurement of the strength of *ulnar abduction of the little finger* the gutter holding the lower arm is raised. This examination is carried out under somewhat less standardised conditions, the hand being stabilised only by the subject's other hand. The same fixation technique is used as for measurement of the strength of *adduction in the 2nd and 4th inter-spaces*.

In 3 of these last-mentioned tests contact plates are applied to the two surfaces which later contact one another.

The examination apparatus is constructed in such a way that its use for the contralateral hand requires only a few simple manipulations.

SPECIAL TESTS

Strength of pinching grip

In this and the following 5 tests the subject sat comfortably beside the examination bridge in which the upper and lower arm was strapped with the elbow flexed 90° and the lower arm in midposition between pronation and supination. The pisiform bone was placed exactly over the vertical axis of rotation of the examination bridge (Fig. 18). With the aid of an extra small bridge the thumb was placed in a suitable pronated position against the pressure plate (Fig. 18). The examinee was instructed to perform a firm round pinch, which was demonstrated. The strength of the pinching grip was measured in 3 successive tests at 5 different angles of the wrist (-30° , $\pm 0^\circ$, $+30^\circ$, $+50^\circ$, $+70^\circ$, see definitions). At $+30^\circ$ the metacarpale I was in line with the lower arm. Only the thumb and the index finger were examined in this test, the 3 other ulnar fingers were extended actively by the patient. Short pauses between the tests were allowed.

Strength of palmar adduction of the thumb

The patient was sitting with the upper and the lower arm and wrist in the examination bridge.

A reference line was drawn at the level of the IP-joint on the ulnar aspect of the thumb. This reference line coincides with the midline of the pressure plate on the dynamometer (Fig. 13). The thumb presses the plate

in ulnar direction. Three tests at 5 different angles of the wrist joint were performed (-50° , -30° , $\pm 0^\circ$, $+30^\circ$, $+50^\circ$ see definitions). On change of angle of the wrist the instrument had to be reset so that the reference line of the thumb coincided with the midline of the black plate of the dynamometer. The 4 ulnar fingers were kept extended in all joints and were guided by a special T-shaped support (Fig. 13).

Strength of radial abduction of the index finger

The patient was sitting with the upper and lower arm strapped in the examination bridge. The entire hand with exception of the index finger was placed in a special holding device. A reference line was drawn radially at the level of the PIP-joint of the index finger. The breaking force was measured. Three tests were performed at 3 different angles of the wrist joints (-30° , $\pm 0^\circ$, $+30^\circ$, see definitions). Measurement of radial abduction of the index finger measures, of course, not only the interosseus dorsalis I but probably also extensor digitorum communis II and the first lumbrical.

Strength of adduction in second interspace

The patient was sitting with upper and lower arm in the examination bridge. A reference line was drawn at the level of the PIP-joint on the radial side of the long finger. The hand to be examined was supported by the examinee's other hand. Three test with extended (180°) and flexed (120°) MP-joints were done with the wrist joint at an angle of $\pm 0^\circ$ (see definitions).

Strength of adduction in fourth interspace

The examination was identical with the last mentioned one except that the adduction strength between the little finger and the ring finger was tested. A reference line was drawn on the ulnar side of the ring finger at the level of the PIP-joint.

Strength of ulnar abduction of the little finger

The gutter supporting the lower arm was raised 10 cm. The examinee supported the hand to be examined with the other hand. The strength of ulnar abduction of the little finger was measured against breaking force in essentially the same way as in the examination of the index finger. But here 3 tests were done at only 1 angle ($\pm 0^\circ$) of the wrist, but with the MP-joint V at 180° and at 120° .

Ulnar abduction of the little finger must be regarded as the result of a combined action of abductor digiti quinti, extensor digitorum communis V and extensor digiti quinti proprius.

RESULTS

Error of the method

The error of the method — ε — is given in degrees of the dial of the dynamometer and was calculated according to the following formula:

$$\varepsilon = \sqrt{\frac{\sum \sum (X_{ij} - M_i)^2}{N(n-1)}}, \text{ where}$$

i = one of the fifty controls between numbers 1 and 50.

j = one of the three measurements.

X_{ij} = the value measured for the i th person in the j th measurement.

M_i = arithmetic mean of the three measurements in a given test for the i th person.

N = number of subjects studied.

n = number of measurements in the test.

The error of the method reflects the accuracy of the method and is based on measurements made in the controls (50 males, 50 females).

The above formula is generally applicable and can therefore be used in the estimation of the error of the measurements in the group in which the ulnar nerve was blocked.

The error of a single measurement in a person with the wrist extended (angle = +30°) and for the pinching grip was ± 13 on the scale of the dynamometer with 68 % certainty. If one chooses instead the accuracy for 95 % or 99.7 % ε must be doubled or trebled. Is this error small? The error of the method in per cent of the actual mean value in a given test is presented in Table 5. For the pinching grip, for example, with the wrist in $\pm 0^\circ$, ε is 6 % for the males. The error of the method is generally between 5 and 7 %.

In the discussion of the error of the method two points must be considered, namely (1) difficulty in reading the value from the dial and (2) the variation in the ability of the examinee in the final phase of the isometric contraction to maintain a constant pressure so that the indicator on the dial does not quiver too much.

Together with an assistant almost 11,000 measurements were made of the controls. Occasionally the assistant recorded the value indicated, while I studied the actual grip. Sometimes both of us read the values simultaneously and the differences between our recordings were insignificant.

Judging from the analysis above, the accuracy of the method was satisfactory.

Standard deviation

Only the better hand was examined with the dynamometer. The means were calculated for the controls as the arithmetic mean of the median values of the 3 measurements for each person. The standard deviation was calculated with the formula:

$$s = \sqrt{\frac{\sum (X_i - M)^2}{N-1}}, \text{ where}$$

X_i = the median value measured for the i th person.

M = arithmetic mean of the median values of the 3 measurements on every person.

N = number of persons.

Table 5. Error of method — ε — in controls

Examination	Angle of wrist	Angle of MP joint	ε	$100 \frac{\varepsilon}{M}$	Normal values		
					N	M	s
Pinching grip							
♂	+30°	—	13	6	50	233	57
♀			11	6	50	171	36
Palmar adduction of thumb							
♂	±0°	—	6	5	50	141	31
♀			7	6	50	109	26
Radial abduction of index finger							
♂	±0°	180°	10	4	50	245	40
♀			10	6	50	186	38
Adduction in second interspace							
♂	±0°	180°	7	7	50	94	19
♀			7	9	50	91	13
Adduction in fourth interspace							
♂	±0°	180°	5	7	50	66	22
♀			7	11	50	52	22
Ulnar abduction of little finger							
♂	±0°	180°	6	6	50	101	19
♀			6	7	50	83	9

Results of studies on controls

The mean values noted for the controls on days 1 and 13 are given in Tables 6—12 at the end of this Chapter. These tables give the values noted at different angles of the wrist and include also the number of subjects studied and the arithmetic mean of the median values of the 3 measurements on each person. The standard deviation was calculated according to the above formula.

*Comments***Pinching grip**

1. The values noted for the male students were invariably larger at all angles of the wrist than those noted for the females.

2. No appreciable difference was noted between the values noted on the 13th day and those noted on the 1st day.
3. In both sexes the lowest values were noted when the wrist was dorsally extended maximally ($+70^\circ$). At other angles of the wrist the values were higher and equally high.

Palmar adduction of the thumb

1. The values noted at all angles of the wrist were higher for the males than for the females.
2. The lowest values were noted for the 2 extreme positions of the wrist, *i.e.*, dorsal extension and volar flexion.

With the wrist dorsally extended the extensor pollicis longus cannot act to the same extent as an adductor substitute (Fick 1845, Duchenne 1867). Maximal volar flexion of the wrist (-50°) also reduces the strength of palmar adduction. The extensor pollicis longus tendon then lies over the first metacarpal and in this position it is probably close to the axis of movement on the palmar adduction. This point is discussed further in Chapter VIII.

Radial abduction of the index finger

In both sexes the lowest values were noted when the wrist was in volar flexion.

Why is the strength of radial abduction of the index finger reduced when the wrist is flexed volarly? The origin and the insertion of the interosseus dorsalis I is the same in both positions. In volar flexion of the wrist the effect of long flexors is decreased because the origin and the insertion are then closer to one another (active insufficiency Hjortsjö 1959). It is therefore possible that also the first lumbrical becomes slack. One might also imagine that the extensor digitorum communis II of the index finger is of almost maximum length and in this position becomes weaker. It is known that the amplitude of the extensor tendons is smaller than that of the flexor tendons (Strandell 1955, Bunnell 1956).

Change in strength of adduction in the 2nd and 4th interspaces as well as of ulnar abduction of the little finger with the metacarpo-phalangeal joints flexed

The values increased with increasing flexion of the metacarpo-phalangeal joints in the measurement of adduction in the 2nd and 4th interspaces, while ulnar abduction of the little finger became weaker with increasing flexion of the metacarpo-phalangeal joint.

These variations were noted in both sexes. What is the cause of this change? As early as 1867 Duchenne showed that on stimulation of the extensor musculature the little finger was abducted. It is known that when the little finger is adducted towards the ring finger, it is adducted by the 3rd volar interosseous and to some extent by the 4th lumbrical. This movement is counterbalanced on the ulnar side by the long extensors, extensor digitorum communis V and extensor digiti quinti proprius and abductor brevis digiti quinti. When the little finger is adducted towards the ring finger with the metacarpo-phalangeal joint flexed, these long extensor tendons are thrown out of action. Together with long flexors, the 3rd volar interosseous and 4th lumbrical can therefore add to the strength of adduction. This may be regarded as functionally useful when the hand is used as in grasp and hook, such as when carrying a bag or a pail of water. For such purposes the stronger the adduction of the 4 ulnar fingers the better.

As for the little finger, it is stronger in ulnar abduction when the metacarpo-phalangeal joint is extended than when it is flexed. This is readily explained. When the fifth metacarpo-phalangeal joint is extended, the extensor digiti quinti proprius and extensor digitorum communis are thrown into action and abduct the little finger (Duchenne 1867) together with the abductor brevis digiti quinti. When the metacarpo-phalangeal joint is flexed, the long extensors are prevented from exerting any abducent effect because of the antagonistic and locking effect of the tightened radial and ulnar collateral ligaments in the fifth metacarpo-phalangeal joint. Moreover, the effect of the short abductor muscles in the little finger decreases because of approximation of their origins and insertions (active insufficiency).

It is therefore obvious that adduction in the 2nd and 4th interspaces increases in strength when the metacarpo-phalangeal joints is flexed, while the strength of ulnar abduction of the little finger decreases with increasing flexion of the metacarpo-phalangeal joint.

Conclusions from investigations on controls

1. The males were invariably stronger than the females.
2. No appreciable increase was noted between the values recorded on the 13th day and those noted on the 1st day. Thus the values did not improve with training.
3. The pinching grip did not decrease with increasing volar flexion.
4. The strength of palmar adduction of the thumb decreased somewhat in the males on extreme dorsal extension of the wrist. On extreme volar flexion (-50°) of the wrist the values were also somewhat lower.

This might be related to a change in position of the tendon of the extensor pollicis longus towards the radial side (See Chapter VIII).

5. Radial abduction of the first finger was weakest when the wrist was flexed volarly. This might be ascribed to decreased strength of the 1st lumbrical. The amplitude of the extensor tendons is small in relation to that of the flexor tendons, and this may also contribute to the lower values.
6. Adduction in the 2nd and 4th interspaces increased with volar flexion of the metacarpo-phalangeal joints. This was ascribed to increasing weakness of the long extensors in this position of the metacarpo-phalangeal joints.
7. Increasing flexion of the fifth metacarpo-phalangeal joint decreased the strength of abduction of the little finger. Tightening of the collateral ligaments, weakness of the long extensors and active insufficiency of abductor brevis dig. quinti seems to be the cause of the decrease in strength.

ANALYSIS OF NORMAL PALMAR ADDUCTION OF THE THUMB DEFINITION

This is given in Part I, page 15.

The extensor pollicis brevis abducts the thumb (Duchenne 1867) and, according to the definition, the adduction of the thumb from abducted position is called palmar adduction (Kendall and Kendall 1949, Haymaker and Woodhall 1953, Chusid and McDonald 1962).

WHAT MUSCLES TAKE PART IN PALMAR ADDUCTION?

Palmar adduction is brought about by action of adductor pollicis and interosseus dorsalis I. It also comes an adducing force from the extrinsic side. Whether this force comes from the extensor pollicis longus or flexor pollicis longus is debatable (Table 27), page 143.

In the present investigation special attention was given to this problem (see analysis of palmar adduction of the thumb in ulnar paralysis, Chapter X).

Stabilising muscles on palmar adduction

On palmar adduction the thumb must be stabilised in volar, dorsal, ulnar and radial direction. The thumb is stabilised in dorsal direction mainly by the extensor pollicis longus but also by extensor pollicis brevis. In volar

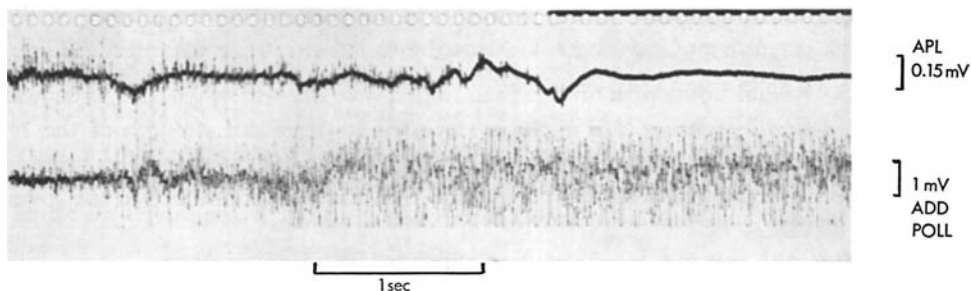


Fig. 19. Palmar adduction of thumb against resistance. In APL muscle a bipolar needle electrode, in ADD POLL muscle a concentric needle electrode. The marking indicates the moment when the thumb with force presses against the volar proximal part of the index finger.

direction it is stabilised by several muscles, namely: the adductor pollicis, abductor pollicis brevis, flexor pollicis brevis, flexor pollicis longus and in certain positions also by the weight of the thumb. In the radial direction it is stabilised by the extensor pollicis brevis (Duchenne 1867) and the abductor pollicis brevis and longus.

In ulnar direction the thumb is stabilised mainly by the adductor pollicis and interosseus dorsalis I. The extensor pollicis longus or flexor pollicis longus also stabilise the thumb in ulnar direction (Table 27), page 143.

If any of these structures are insufficient palmar adduction cannot be performed under standardised conditions. Thus the thumb drops in radial paralysis or in rupture of the extensor pollicis longus in such a way that the thumb can no longer reach and contact the volar proximal surface of the index finger. The performance of a coordinated and balanced palmar adduction movement thus requires the action of several muscles innervated by the radial nerve, the median nerve and the ulnar nerve.

PERSONAL INVESTIGATION OF NORMAL PALMAR ADDUCTION OF THE THUMB

The examination was carried out under standardised conditions with the hand in the examination bridge.

If the thumb starts palmar adduction movement from maximal abduction, the tendon of the abductor pollicis longus can be felt to be tight at the level somewhat proximal to the first metacarpal. During palmar adduction movement this tendon is still tight but in the final phase, when the ulnar lateral surface of the thumb presses hard against the volar proximal part of the index finger, it can be felt and seen by aid of electromyography (Fig.

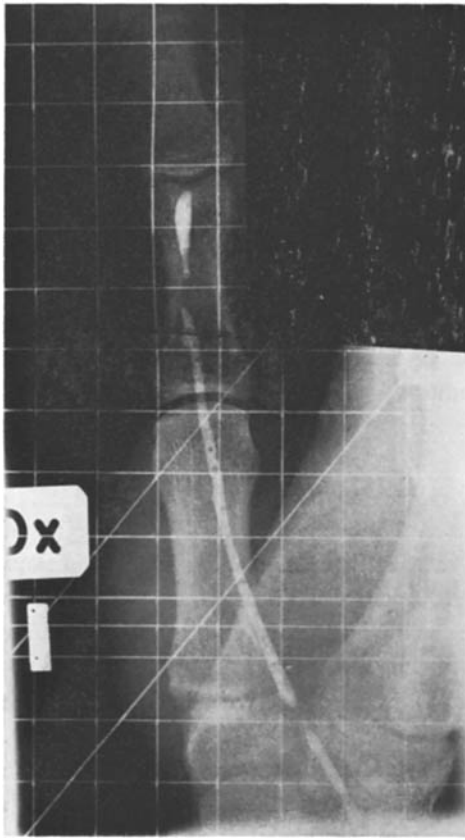


Fig. 20. Thumb in resting position between abduction and adduction. The EPL tendon is marked with barium contrast.

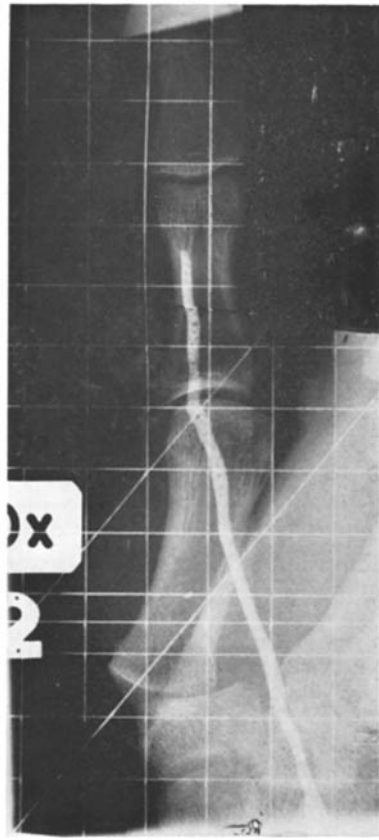


Fig. 21. Palmar adduction of the thumb with hard pressure on the plate of the dynamometer. Observe the position of the base of the first metacarpal in the CMC joint I.

19) how the tension in the abductor pollicis longus tendon suddenly decreases. I have ascribed this to what happens in the CMC joint I in the final phase of palmar adduction (Cf. Chapter IV), where the base of the first metacarpal slides out in radial direction in this joint, see Figs. 20, 21. The roentgenograms were taken with the hand in the examination bridge in standard position. The extensor pollicis longus tendon is marked with barium contrast. The first picture (Fig. 20) shows the thumb in resting position between abduction and adduction, the second reproduction (Fig. 21) shows how the thumb on marked adduction changes its position in the CMC joint I. The base of the first metacarpal slides out in radial direction.

A certain laxity adines in radial direction occurs in the MP-joint of the thumb also and here as much as the ulnar collateral ligament allows. The dorso-volar axis of movement of the palmar adduction thus cannot lie in the CMC-joint but distally to it. The position of the axis of movement of the first metacarpal is discussed in further detail in the analysis of the possibilities of palmar adduction of the thumb in ulnar paralysis (See Chapter X).

The known pronation and supination movements of the long axis of the thumb in abduction-adduction (Duchenne 1867) were also observed in the present investigation of the palmar adduction movement. It would therefore appear justified to speak of an abduction-pronation movement and an adduction-supination movement.

S U M M A R Y

The strength of a number of grips and movements at different angles of the wrist and the MP joints were measured under standardised conditions with the author's dynamometer in 100 controls. These values were used as reference in the estimation of the residual capacity of the hand in ulnar paralysis (Chapter X).

Changes of positions in the radioulnar axis of the wrist had no influence on the values for pinching grip except in position $+70^{\circ}$ (see definitions). Within positions $+30^{\circ}$ and -30° the values in palmar adduction of the thumb also were equal. With the wrist flexed to position -30° the strength of the radial abduction of the index finger was lowest. The probable reason for this is discussed. Strength of adduction in the second and in the fourth interspace increased with the MP joints in flexion. Strength of ulnar abduction of the little finger decreased with the MP joint in flexion. The reasons for this discrepancy is discussed.

Statistical treatment of the values obtained is given in tabular form at the end of this Chapter.

An analysis of the palmar adduction of the thumb under normal conditions was performed. With the aid of roentgen- and electromyographic examinations the author has showed that the axis of movement of the palmar adduction cannot lie *in* the CMC-joint I but somewhat distal to it. This is discussed in detail in Chapter X.

Table 6. Mean values in kg on day 1 for 50 male and 50 female volunteers

	PINCH	ADD POLL	ABD II	ADD II i	ADD IV i	ABD V
Position of wrist joint	+30°	±0°	±0°	±0°	±0°	±0°
Position of MP joint	—	—	180°	180°	180°	180°
♂	4.75	2.85	4.9	2.35	1.45	2.55
♀	3.8	2.45	3.9	1.7	1.4	2.0

Table 7. Mean values pinching grip in control series

Position of wrist joint		+70°			+50°			+30°			±0°			—30°		
Sex	Day	N	M	s	N	M	s	N	M	s	N	M	s	N	M	s
♂	1	50	160	32	50	209	36	50	214	36	50	218	36	50	214	35
	13	50	158	41	50	210	39	50	221	44	50	222	43	50	208	44
♀	1	6	122	52	50	163	39	50	169	37	50	168	38	6	161	33
	13	6	118	34	50	166	33	50	175	35	50	172	38	6	174	31

Table 8. Mean values palmar adduction of thumb in control series

Position of wrist joint		+50°			+30°			±0°			—30°			—50°		
Sex	Day	N	M	s	N	M	s	N	M	s	N	M	s	N	M	s
♂	1	50	108	27	50	122	28	50	127	27	50	125	25	50	115	22
	13	50	114	25	50	127	26	50	133	27	50	131	27	50	120	27
♀	1	6	102	10	50	107	19	50	111	18	50	113	20	6	111	19
	13	6	103	17	50	109	20	50	113	20	50	117	21	6	116	11

Table 9. Mean values radial abduction of index finger in control series

Position of wrist joint		+30°			±0°			—30°		
Sex	Day	N	M	s	N	M	s	N	M	s
♂	1	50	212	36	50	220	34	50	197	34
	13	50	220	37	50	223	34	50	207	29
♀	1	50	171	30	50	177	29	50	163	29
	13	50	174	28	50	180	27	50	166	27

Table 10. Mean values adduction in second interspace in control series

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	50	105	20	50	134	24
	13	50	109	17	50	134	23
♀	1	50	76	14	50	109	24
	13	50	80	15	50	113	24

Table 11. Mean values adduction in fourth interspace in control series

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	50	66	15	50	102	19
	13	50	68	17	50	105	19
♀	1	50	64	18	50	86	18
	13	50	61	13	50	89	16

Table 12. Mean values ulnar abduction of little finger in control series

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	50	116	18	50	87	18
	13	50	123	22	50	88	16
♀	1	50	89	15	50	64	18
	13	50	90	12	50	57	18

Part IV Clinical picture in ulnar nerve paralysis

Chapter VIII Clinical picture in ulnar nerve paralysis

In ulnar paralysis the muscle balance in the hand will be so upset from loss of action of the intrinsic muscles that the hand will have lost its skill and be awkward at work (Boyes 1964).

HISTORICAL

The clinical picture of ulnar paralysis has long been known. As early as 1832 Calder gave a brief description of some of the features of the clinical picture of injury to the ulnar nerve at the level of the sulcus.

Duchenne (1867) may be regarded as the first to have analysed the imbalance of the muscles and its cause in ulnar paralysis. Duchenne demonstrated the functions of the muscles of the hand by faradization. With this method he showed *inter alia*:

1. that in paralysis of interosseus dorsalis I the index finger could be abducted in radial direction by the extensor digitorum communis II,
2. that on stimulation of the extensor indicis proprius the index finger was abducted in ulnar direction,
3. that the little finger was abducted in ulnar direction on stimulation of the long extensors of the hand (Duchenne thought, however, that even Galenus had shown how the action of the extensor musculature of the 4 ulnar fingers produced spreading of the fingers),
4. that the little finger could not be adducted radially towards the ring finger on stimulation of the long flexors of the hand,
5. that the thumb was adducted towards the index finger on stimulation of the extensor pollicis longus (This had already been shown in 1845 by Fick, who called the extensor pollicis longus "extensor pollicis adducens"),
6. that on stimulation of the flexor pollicis longus the thumb was not adducted towards the index finger.

In model experiments and in cadavers Duchenne investigated the cause of clawing, *i.e.*, hyperextension in metacarpo-phalangeal joints and flexion of the proximal and distal interphalangeal joints in isolated intrinsic paralysis. He appears to have been the first to demonstrate how the interossei and lumbricals function as extensors of the 2 distal phalanges and as flexors of the proximal phalanx.

Certain objections can be raised against Duchenne's technique. For ex-

ample, he studied the effect of individual muscles with the aid of faradization but without having influenced the antagonists. Neither did he analyse the action of the muscles taking part in grip functions. He also admitted that faradization was only of limited value in investigation of function of the thumb. Nevertheless his work of 1867 still forms the basis of our knowledge of certain hand functions controlled by the ulnar nerve.

PREVIOUS INVESTIGATIONS

Later authors base their investigations largely on Duchenne's work of 1867. The expansion of our knowledge of the clinical picture of ulnar paralysis since then is a result of details reported by individual authors.

SYMPTOMS AND SIGNS

Thus most symptoms and signs have with time been described, some of them are known by the names of the authors who described them. Table 13 gives some of the symptoms and signs arranged in chronological order. The Table can be used for diagnosis of the level of ulnar injury in zones III and IV. It can also be used as a guide in the investigation of cases in which anomalous innervation is suspected.

Of those who have studied the deformation in ulnar paralysis, mention should also be made of af Björkesten (1946), Bruner (1948), Littler (1952), Vallone (1953), Eyder-Markee (1954) and Zancolli (1957).

It has long been known that the volar side of the little finger and the ulnar aspect of the volar side of the ring finger are desensibilised in ulnar lesions (Head and Sherren 1920). It is important to ascertain whether the sensibility of the dorsal side of the little finger has been lost in injury to the lower part of the lower arm. If the sensibility of the dorsal aspect of the little finger is good and there is loss of sensibility of the little finger on the volar side and half of the ring finger with total intrinsic paralysis, there is reason to assume that the injury lies distal to the origin of the *ramus dorsalis manus*. Of authors who have discussed the pattern of sensibility of the ulnar nerve, mention might be made of Stopford (1918) and Foerster (1929). In a few per cent of Stopford's (1918) cases the ulnar nerve supplied the entire ring finger and the ulnar half of the middle finger.

The type of ulnar paralysis depends on the zone in which the nerve is injured and where in that zone. It was therefore considered justified to divide the description of ulnar paralysis according to zones, c. f. Fig. 1.

Symptoms and signs of ulnar paralysis in zone I

Paralysis of the flexor carpi ulnaris and flexor digitorum profundus IV—V cause atrophy of these muscles reflected by change in profile of the proxi-

Table 13. Symptoms and signs in ulnar nerve paralysis

Author	Year	Symptoms and signs
<i>Duchenne</i>	1867	Clawing of the ring- and little fingers. Little finger cannot be adducted to the ring finger. Inability to play high notes on the violin. Reason: Flexor carpi ulnaris and opponens digiti quinti paralytic together with loss of sensibility of the little finger.
<i>Jeanne</i>	1915	Hyperextension of the MP-joint of the thumb in pinching grip. Jeanne's sign. (Fig. 22)
<i>Froment</i>	1915	Pronounced flexion of IP-joint of the thumb on adduction towards index finger. Froment's sign (Signe du Journal). (Fig. 23)
<i>Masse</i>	1916	Flattened metacarpal arch.
<i>André-Thomas</i>	1917	Wrist tends to fall into volar flexion on action of long finger extensors. (Fig. 24)
<i>Pollock</i>	1919	Inability to flex distal phalanx on dig. V.
<i>Pitres-Testut</i>	1925	Transverse diameter of hand decreased. Radial-ulnar abduction of dig. III in MP-joint III impossible. Inability to shape the hand to a cone. (Fig. 25)
<i>Wartenberg</i>	1939	Inability to adduct the extended little finger to the extended ring finger. Wartenberg's sign. (Fig. 26)
<i>Sunderland</i>	1944	Inability to rotate-oppose-supinate little finger towards thumb. 'Sunderland's sign.
<i>Fay</i>	1954	Inability of thumb to reach little finger in true opposition. (Probably misinterpretation of author because little finger cannot always reach thumb in paralysis of the opponens of little finger)
<i>Bunnell</i>	1956	The thumb no longer pinches against the index finger to make a good O.
<i>Egawa</i>	1959	Inability of the flexed long finger to abduct radially-ulnarly and to rotate in MP-joint III
<i>Mumenthaler</i>	1961	On abduction of the little finger against resistance no normal dimple in hypothenar because of paresis of palmaris brevis-musculature.

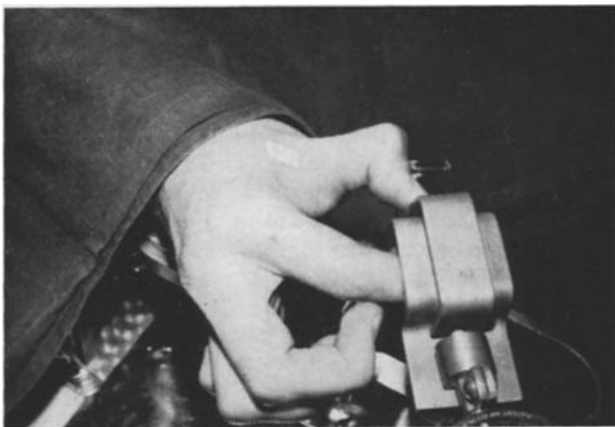


Fig. 22. Jeanne's sign.



Fig. 23. Froment's sign. Model made by J. Froment, now in possession of Professor R. Froment, Lyon. Photograph taken with kind permission of the owner.

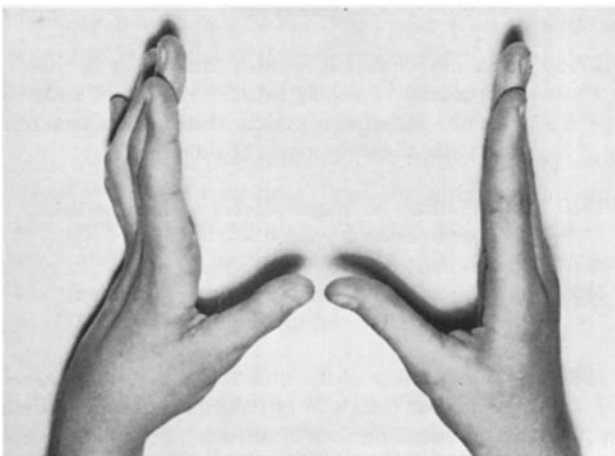


Fig. 24. André-Thomas's sign.

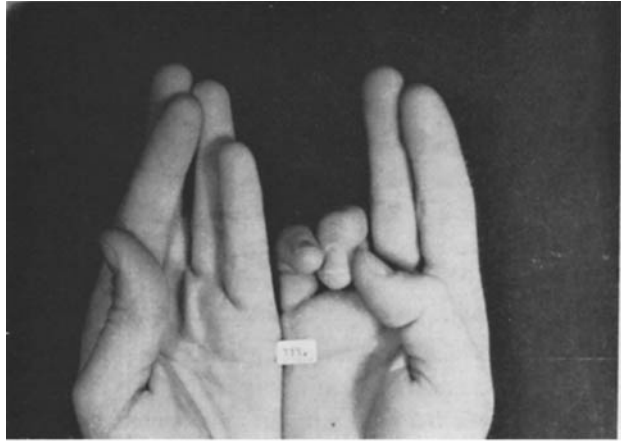


Fig. 25. The Pitres-Testut sign.

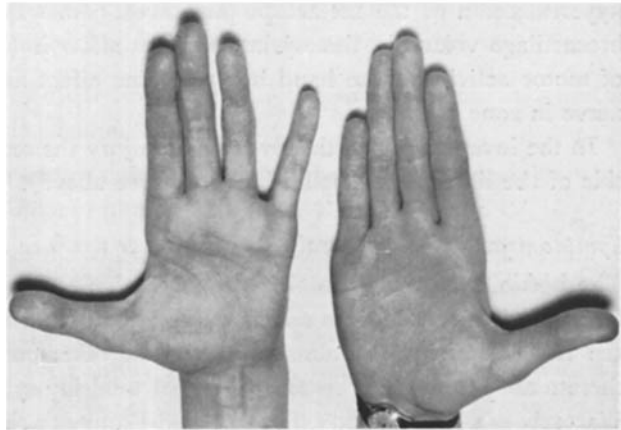


Fig. 26. Wartenberg's sign.

mal volar ulnar part of the lower arm. Volar flexion of the wrist about the radio-ulnar axis is thereby weakened and when making a fist, the pulps of the ring finger and little finger lands in a more proximal area of the palm. The final phase of the grip is thereby weakened around a handle. When the hand is palm down the little finger cannot scratch the edge of the table. Since all interossei and hypothenar muscles, 2—3 ulnar lumbricals, adductor pollicis and to a varying extent flexor pollicis brevis are thrown out of action, the typical signs of ulnar paralysis naturally appear. It should be observed that the clawing is only moderate and often only slight because the flexor digitorum profundus IV and V are paralytic.

Paralysis of flexor carpi ulnaris limits ulnar abduction about the dorso-volar axis of the wrist and makes it difficult to work with a hammer or an axe, for example.

The entire little finger and the ulnar part of the ring finger have lost their sensibility. The sudomotor function also ceases in these areas (Moberg 1958) and the skin gradually becomes thin and atrophic. "Trophic ulcers" are typical in total ulnar lesions. They should be regarded as sequelae after loss of protection sensibility and not as "trophic".

Symptoms and signs of paralysis of ulnar nerve in zone II

Two types of clawing can occur depending on the level of total ulnar injury in this zone. If the injury is high, little or moderate, clawing occurs. If the injury is below the origin of the motor branches of the flexor digitorum profundus IV—V, clawing is more severe. Sometimes there is no hyperextension of the metacarpo-phalangeal joints IV and V because fibrocartilago volaris in these joints will not allow it (Zancolli 1957). Loss of motor activity of the hand has the same effect as injury to the ulnar nerve in zone I.

In the investigation of the level of the injury the sensibility of the dorsal side of the little finger should be tested (see above).

Symptoms and signs of paralysis of the ulnar nerve in zone III

The possibilities of ascertaining the level of ulnar injury in zone III are fairly good. If sensibility is adequate in the little and ring finger as well as the motor activity of palmaris brevis but other motor functions distal thereto are lost, there is reason to suspect total injury of ramus profundus. Wartenberg's, Sunderland's, Egawa's and Froment's signs are positive. The patient cannot form the finger to a cone. The pinch grip is broken down. In injury at the transition between zone III and IV Sunderland's sign will be negative, but Wartenberg's sign will be positive, as will other signs of paralysis of the distal ulnar nerve.

Symptoms and signs of paralysis of ulnar nerve zone IV

Here, too, it is fairly easy to ascertain the level of the injury. If in table 1, injury should be presented between the nerves 21 and 22, it would cause the following picture: Sunderland's sign would be negative, Wartenberg's negative, Egawa's sign positive and the other signs of paralysis of ulnar nerve distal to this level would be positive. Another example, in a relatively distal ulnar injury the long finger can be abducted with considerable strength in ulnar direction but not radially, and the index finger cannot be adducted with strength towards the long finger. The injury is then most likely just distal to the origin of the nerve supplying the 3rd dorsal inter-

osseous. Egawa's sign is then no longer completely positive. Froment's sign is however, positive and the pinching grip is disintegrated. Jeanne's sign is positive.

In the analysis of ulnar injuries distal to zone IV the behaviour of interosseus dorsalis I and adductor pollicis must be studied carefully. Inability of the index finger to be abducted radially in a particular injury where palmar adduction of the thumb is normal, suggests a lesion of the deep ulnar branch distal to the origin of the branches supplying the transverse and oblique heads of the adductor pollicis.

By classifying the nerve injuries according to these zones it is often possible to ascertain the level at which the ulnar nerve is damaged. These examinations can be refined by anatomically correct electromyographic examination and by careful examination of the strength of individual muscle movements (see below).

It is thus clear that certain quick methods for testing the function of the ulnar nerve may be misleading. Some examples are given below:

1. Spreading of the 4 ulnar fingers does not mean that ulnar function is intact (Galenus, Duchenne 1867).
2. Radial abduction of the index finger therefore does not mean that the ulnar function is intact either.
3. Ulnar abduction of the index finger need not mean that the function of interosseus volaris I is intact (Extensor dig. com. II, Duchenne 1867).
4. Some decrease of the residual strength of adduction of the thumb need not mean partial ulnar injury (Fick 1845, Extensor pollicis adducens).

These so-called trick movements can instead mislead and trick the examiner.

WHAT IS THE DISABILITY?

af Björkesten (1946) appears to be one of the few who have systematically tried to assess the disability of persons with total ulnar paralysis. Otherwise the literature simply says that the hand becomes weak and awkward and that clawing is common. The disability due to loss of sensibility of the entire little finger and half of the ring finger is often belittled. Loss of sensibility is thus classified as inconvenient, but hardly as appreciably impairing the use of the hand.

The loss of extension of the interphalangeal joints with increasing atrophy can, with time, result in contractures which impair hand function still more. The hand may become so weak that it can no longer grip or hold things properly, the patient may find it difficult to write, and many

of the coordinated hand- and finger functions are impaired. The strength of the grip falls by one third to one half of the total strength of the hand (Bunnell 1956). af Björkesten (1946) studied the strength of the hands of 56 patients with ulnar lesions. The author measured the strength of the injured hand numerically with the strength of the uninjured hand set at 1. He divided his material of 56 injuries into high and low injuries with an equal number of patients in the two groups. The strength of the hand of most patients was only about half of that of the uninjured hand in high as well as in low lesions. Thirteen patients had lost less than half of the strength and 22 more. The author mentions that the values were not very reliable because the patients were insurance cases (war injuries). af Björkesten believes that this dynamometric examination is not an ideal method for measuring the strength of the hand of patients with ulnar lesions but he had no better method. af Björkesten questioned 56 patients with total ulnar lesions in detail regarding their symptoms. The most striking defect the patients complained of was loss of strength of the hand. A substantial number of them complained about loss of ability to grip because of extreme clawing when the interphalangeal joints were strongly flexed. The ability of extension was markedly impaired so they could not open the hand and grip things. Now and then the patients took things first with the healthy hand and placed them into the disabled hand. All the patients complained of a feeling of clumsiness of the hand, especially when doing precision work. af Björkesten examined the patients' ability to do up small buttons with the injured hands and nearly all managed well. Only 2 of the 27 right-handed patients with injuries on that side had gone over to write with the left hand, but 15 of the 27 found it difficult to write. Weakness of the pinching grip appeared to be the cause of this difficulty in writing.

Present conception of clinical picture of ulnar paralysis according to the literature

Though much attention has been given to symptoms and signs of ulnar paralysis, only few attempts have been made to analyse grip function and qualitatively to analyse the effect of ulnar injury. Exceptions to this rule are Duchenne (1867), Froment (1915), af Björkesten (1946) and Bunnell (1956). Interest has been concentrated mainly on the clinical signs and symptoms which enable diagnosis. According to most authors the strength of the injured hand is decreased by about one third to one half compared with that of the healthy hand. af Björkesten appears to be one of the few who have shown that the strength of the injured hand is decreased sometimes still more. But then again af Björkesten's figures were unreliable because his material consisted of insurance cases (war injuries). The measuring method he used was unreliable.

S U M M A R Y

Based on the literature a review is given of symptoms and signs in ulnar nerve paralysis. Duchenne's work of 1867 forms the basis of much of our knowledge of certain hand functions controlled by the ulnar nerve. 13 clinical signs in ulnar nerve paralysis are given in tabular form. Regarding the question of the degree of the disability, af Björkesten seems to be one of the few to have penetrated the problem more in detail. Nevertheless, his figures obtained after measuring the residual strength were unreliable because his material consisted of insurance cases (war injuries).

Part V On blocking of nerves

Chapter IX On blocking of nerves

HISTORICAL

According to Collins (1960), Halstead appears to be "the father of nerve blocking" (1884), but it was apparently Frank (1892) who coined the term "nerve blocking". Frank assigned the procedure to a "physiologic nerve section".

Interest in diagnostic problems bearing on nerve injuries increased during the world war II. Highet (1942) was one of the first to use diagnostic nerve blocking. He utilised this method in a series of more than 50 cases in an investigation for anomalous innervation of muscles and for studying disturbed sensibility in partial and total peripheral nerve injuries.

PREVIOUS INVESTIGATIONS

Intraneural versus extraneural block

Highet (1942) induced the block intraneurally. Other authors who used this technique are Chase, Brandom, Macomber and Wang (1959), Dhunér, Edshage and Wilhelm (1960), Albèrt and Löfström (1961) and Moore (1961). According to Moore, nerve blocking is a measure to obtain "reversible chemical section of the nerve".

Bonica (1959) and Collins (1960) advice against intraneural blocks. Bonica claims that it involves a risk of so-called "post injection neuropathy" but believes that sensibility disturbances, pareses or disturbances of the autonomic nervous system after nerve blocking with local anesthetics are rare. Such neuropathies, according to him, are due to mechanical injury by the tip of a needle. This view is incompatible with Matson's (1950) report of the treatment of nerve injury following erroneous injection of antibiotics. He believes that it is the antibiotics that are toxic for the nerve and that the penetration of the nerve by the needle per se is not dangerous. Collin's (1960), who defines nerve blocking as a procedure in which the nerve conduction is blocked and in which loss of function is reversible, believes that intraneural block should be avoided but at the same time says that one can very well inject when the patient feels paresthesia. This

statement that a patient experiences paresthesia probably means that the needle is nevertheless within the nerve.

Other authors, who have used nerve blocking for different purposes are Murphey, Kirklin and Finlayson (1946), Braithwaite, Channell, Moore and Willis (1948), Cliffton (1948), Rowntree (1949), Haymaker and Woodhall (1953), Goldner (1953), Eyler and Markee 1954), Moberg (1958) and Egawa (1959). They do not, however, say whether nerve blocking should be induced intraneurally or not.

Nerve blocking has been used for scientific and practical purposes. Several authors used nerve blocking as an instrument for investigating troublesome problems in suspected anomalous innervation. Dhunér et al. (1960) and Albèrt and Löfström (1961) have used nerve blocking to test the effect of different anaesthetic media. Several of the authors have studied the effect of blocking of the ulnar nerve.

Criteria and evidence of total nerve block

Various methods have been used by different authors to find evidence of a total nerve block in human being. Highet (1942), for example, used the 4 criteria :

1. Complete vaso-dilatation.
2. Anhidrosis.
3. Anesthesia and analgesia.
4. Complete paralysis of the muscles supplied by the nerve distally to the level of the block.

Various objective methods for testing anhidrosis are available. Of known methods, mention might be made of the iodine-starch method (Minor 1928, Dole and Thaysen 1953). Moberg's ninhydrin printing test (1958) has also proved suitable.

Technique for avoiding nerve injury in induction of nerve block

According to the literature, complications after intraneural nerve block appear to be rare.

It is true that Bonica (1959) stresses the risk of "post injection neuropathy" following intraneural anesthesia. No cases have been published in his work. Dhunér *et al.* (1960) reported no neurogenous injury demonstrable by conventional neurological methods or by the ninhydrin method after 41 intraneural blocks. Also Highet (1942) believed intraneural injection of a local anesthetic to be safe.

Moore (1961) gave a careful description of precautions to be observed before inducing nerve block. A nerve block should thus be performed with great care and under sterile cautions. All needles should be inspected be-

fore use—the tips should be satisfactory. Moore also emphasises the risk of the tip of the needle coming into contact with bone and thereby being hooked. If the tip of the needle is hooked it can cause injury when withdrawn after injection. If the above precautions are observed and only a reasonable amount of local anesthetic is injected, intraneural block should be safe.

ULNAR BLOCK BY AUTHOR'S METHOD

Technique

In the investigation of the residual capacity of the hand in ulnar paralysis it was decided to block the ulnar nerve intraneurally in the distal part of zone I. 1 % Carbocain® without adrenalin was used. In the beginning a fine needle (0.35 mm in diameter) was employed, but a needle of this size soon proved too small to maintain the paresthesia, for which reason a larger needle was then used (diameter 0.45 mm No. 18 Injecta, Sjuco). The local anesthetic was injected a few centimetres proximal to the sulcus nervi ulnaris. It is indefensible to inject a local anesthetic into the osseofibrous cubital channel (Feindel and Stratford 1958) because of the unavoidable subsequent oedema in the nerve after intraneural block. Intraneural block was induced in the following way. With the patient lying comfortably on his back on an examination table with the upper arm abducted and rotated outwards and the elbow flexed the ulnar nerve was palpated and gripped between my finger and thumb. The skin was disinfected with alcohol. The fine needle was inserted through the skin and at right angles into the nerve. When the patient felt paresthesia down into the little finger 2—3 ml of 1 % Carbocain® without adrenalin was injected into the nerve. Afterwards 2—3 ml of the same anesthetic was deposited around the nerve at the same level. Both before and after use of the needle the tip was drawn through a sterile compress, in order to check that the tip was not hooked. On no occasion in the 57 blocks (cf page 111) was any such hooking found.

Author's criteria of completeness of intraneural block

The following criteria were used.

1. Complete anhidrosis in the volar distal surface of the little finger.
2. Vasodilatation in the ulnar part of the hand.
3. Complete loss of sensibility of the little finger.
4. Paralysis of muscles normally innervated in the ulnar nerve.
5. The following signs should be positive:
 - a. Wartenberg's
 - b. Sunderland's
 - c. Egawa's
 - d. Froment's

6. Electromyographic evidence. Supramaximal stimuli proximal to the block should produce no action potentials when surface electrodes were placed over the musculature of the interosseus dorsalis I and abductor digiti quinti, while supramaximal stimulation distal to the site of injection produce a normal response.

Criterion 1

Anhidrosis in the distal-volar surface of the little finger was assessed objectively with the ninhydrin printing test (Moberg 1958), quantitated in the way used by Örne (1962). The active surface of the paper in the ninhydrin printing test was 19.6 mm² (a circular area 5 mm in diameter). A series of impressions were made, beginning immediately after the injection. The finger was said to be anhidrotic when no sweat spots were demonstrable.

Criterion 2

Vasodilatation was recorded partly by the subject himself, who reported that the ulnar part of the hand felt warm after the block. The examiner controlled the patient's statement by comparing the warmth of the ulnar and of the radial part of the subject's hand. (Skin temperature was measured in only 1 case. It was case ♂ 8 where the skin temperature in the hypothenar region before the blockade was 34.0° C and 36.6° C after the block.)

Criterion 3

Loss of sensibility was said to be complete when the patient no longer felt a hard pinch of the pulp of the little finger. Even protective sensibility had thus disappeared. Moberg (1958) has shown that after nerve block anhidrosis and loss of sensibility occur simultaneously. A ninhydrin test without spots of sweat was therefore taken as a sign of total loss of sensibility.

Criterion 4

Paralysis of flexor carpi ulnaris and flexor dig. com. V was demonstrated clinically. As to the testing of the intrinsic musculature, see below.

Criterion 5

a. A *positive Wartenberg's sign* (1953) means that the abducted and extended little finger can no longer be actively adducted to the ring finger.

b. *Sunderland's sign* (1944) was regarded as positive when the patient could no longer rotate and supine the flexed little finger towards the thumb in opposition. Now and then the little finger passed the radial side of the thumb so that the tactile surfaces of the thumb and little finger could never contact to form grip. The little finger could never reach the thumb in proper opposition after ulnar neural block that the distal phalanx of the little finger was in line with the distal phalanx of the thumb. Instead, there was a more or less pronounced radial open angle between the distal phalanges of the thumb and little finger. The smaller the radial open angle the smaller the opposition-supination of dig. V. If Sunderland's sign is positive there is also an absence of hypothenar elevation, which is due to loss of function of opponens dig. V., decreased range of flexion of MP-joint V and predominance of long extensors over the metacarpophalangeal joints of the little finger (clawing).

c. *Egawa's sign*. Egawa (1959) showed that the flexed long finger can no longer pro-supinate in the palm. Then the long finger can not move its tactile surface on the base of the thenar eminence in ulnar-radial-ulnar direction. Egawa's sign is due, of course, to loss of function of the 2nd and 3rd interossei. In the present investigation these were also tested by allowing the patient to extend the 4 ulnar fingers and on request to try to actively abduct the extend long finger radially and ulnarly.

d. *Froment's sign*. This sign was tested according to Froment's original paper in 1915. The subject was requested to hold a disk between the thumb and index finger and requested to draw the hands from each other with the result that the distal phalanx of the thumb on the paralysed side flexed. Now and then supination of the thumb occurred and sometimes pronation. What was registered was, above all, flexion of the distal joint of the thumb. On the healthy side the patient could hold the distal joint of the thumb extended.

Criterion 6

Electromyographic evidence of completeness of intraneural block distal in zone I

A. Standard EMG investigation

It was considered necessary to produce also electromyographic evidence of the completeness of the block. The method used was based largely on the paper of Hodes, Larrabee and German (1948). These authors used their technique for registering the conduction velocity of motoraxons. This method was used by me to show that not even after stimulation with supra-

maximal stimuli proximally to the block could any action potentials be demonstrated in the musculature of the abductor digiti quinti and interosseus dorsalis I.

The ulnar nerve was stimulated with a stimulator (Multistim-DISA 13 G 04) and with bipolar surface electrodes Fig. 27. The interelectrode distance was about 25 mm. Rectangular impulses of 1.0 msec duration were used. The potential of the muscle response was taken up by surface electrodes made of tin plates 12×6 mm. One electrode was placed over the muscle and one over the tendon of the muscle. The abductor digiti quinti and interosseus dorsalis I were used as receptors. The potentials were recorded with an electromyograph (DISA 13 A 69). Single sweeps were used with a sweep velocity of 1 or 2 msec. The cathode ray sweep was triggered off by a prepulse from the stimulator, a marking pulse indicated the instant of stimulation.

Before the block was induced the conduction velocity of the ulnar nerve was measured. The ulnar nerve was stimulated somewhat proximal to the sulcus nervi ulnaris. The lowest strength necessary to produce a response was determined. This intensity was increased by 100 % and was thereby regarded as supramaximal.

The surface electrodes were kept in position and the subject was given an intraneural block in the ulnar nerve distally in zone I, *i.e.*, just proximal to the sulcus nervi ulnaris. Supramaximal stimuli were then given proximal to the block and high sensitivity (10μ V/mm) was used.

When no action potentials could be seen, the block was regarded to be complete — cf Figs. 37, 38.

Certain objections can be raised against this technique. Thus, it may be questioned whether needle electrodes were not used to take up action potentials from abductor digiti quinti and interosseus dorsalis I. The reason why needle electrodes were not used was that the subject could then readily feel pain when measuring certain grips in which interosseus dorsalis I and abductor digiti quinti take part. Insertion of these needles can cause haematomas. Another objection is that needle electrodes take up a relatively smaller volume of activity from the actual muscle while surface electrodes take up a relatively larger volume of activity from the actual muscle. A third objection is, that the needle electrodes can slip out on examination of the grip directly after the block. A standardised position of the needle electrodes could therefore be jeopardized. In view of the above objections it was decided to use surface electrodes over the muscles in question. It was, however, useful in certain special cases to use needle electrodes in examinations for voluntary maximal contractions, (cf chapter X, Martin-Gruber anastomoses).

As to the skin impedance, no attempts were made to measure it. When

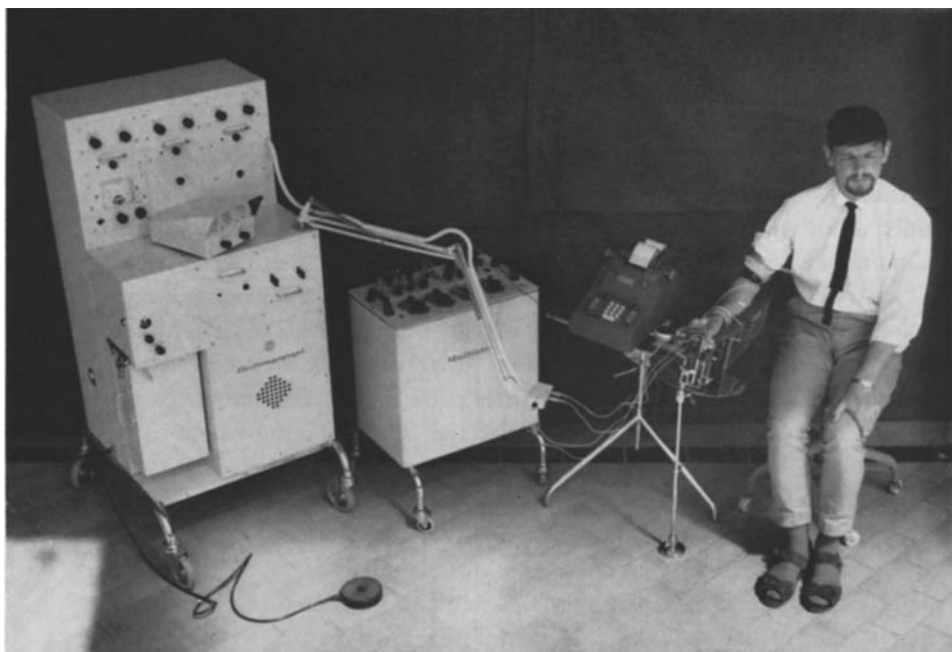


Fig. 27. Set-up for demonstrating complete ulnar nerve block.

using skin electrode stimulation the skin impedance should presumably be the same before and after induction of the block. The skin was not examined for any change of impedance due to the vaso-constrictive effect of Carbocain®, 1 % without adrenalin.

B. More rigorous EMG test of completeness of intraneural block in distal part of zone I

A more refined method for demonstrating completeness of intraneural block would be to stimulate the nerve proximally to the level of anesthesia by percutaneously inserted needles placed as near the nerve as possible. A test was carried out on one 27 year old male medical student. The conduction velocity of the ulnar nerve was determined. The nerve was stimulated by the juxtaneural needle electrodes (distance 3 cm from one another) and the action potentials were picked up with needle electrodes in m. abductor digiti quinti and m. interosseus dorsalis I. The site of nerve stimulation was somewhat proximal to the sulcus nervi ulnaris.

3 ml of 1 % Carbocain® without adrenalin was injected intraneurally in the ulnar nerve and 2 ml extraneurally.

Nine minutes later the ulnar nerve was stimulated again as before, and

a new recording was performed from the above mentioned muscles with the needle electrodes. The duration of stimulation was 2 msec. The stimulation strength was supramaximal (17 volt). The sensitivity of the electromyograph was set at $7.5 \mu\text{V/mm}$. Action potentials could not be demonstrated in the muscles although several electrode positions were used. This was taken as a proof that the block was complete but it could also be explained as a diminution of the conduction velocity of the action potentials.

Conduction velocity decreases in a nerve which is anesthetised (Rud 1961). In order to check that the finding did not mask a decrease in conduction velocity, the following experiment was performed. The ulnar nerve was stimulated as before. By using a second stimulator of the type Multistim (Disa 13 G 04), which was triggered by the first stimulator the sweep of the EMG-apparatus could be delayed. Thereby a maximum range of 300 msec. after the onset of the stimulation could be covered. The maximum conduction velocity for the ulnar nerve is 65–68 m/sec (Hodes, Larrabee and German 1948, Moritz 1963). The conduction velocity varies with the diameter of the nerve and the lowest velocity is roughly 3 m/sec. If half of this value is considered the maximum permissible decrease in conduction velocity before block occurs this will give us 1.5 m/sec over a distance of 4.5 cm which is estimated as the maximum distance of the nerve subjected to the influence of the local anesthetic. This is an addition to the transmission time of 30 msec. The conduction velocity in the nerve is normal distally to the anesthetized portion (Rud 1961). Therefore 150 msec. must be added to the transmission time corresponding to 45 cm of nerve conduction at 3 m/sec. If a few msec. are allowed for synaptic transmission and propagation within the muscle to the electrodes we are able to say that we have to look for potentials within the range of 180–185 msec after the onset of stimulation.

The described experiment covers this range with a good margin.

SUMMARY

Published techniques of blocking nerves with local anesthetics are discussed. Thus there is controversy concerning intra-versus extraneural block techniques.

Criteria of total nerve block are given by Highet (1942). The present author has used these criteria but thought there could be more rigorous proofs of a total ulnar nerve block. Therefore an electromyographic technique was added. This was based on the work by Hodes, Larrabee and German (1948) and with a more refined technique it was shown by the present author that it is possible to obtain an electromyographically total ulnar block after intraneural injection of a local anesthetic 1 % Carbocain® without adrenalin.

Part VI Evaluation of some residual functions of
the hand in high ulnar block

Chapter X Evaluation of some functions of the hand in high ulnar block

AUTHOR'S SERIES

COMPOSITION OF THE MATERIAL

The material consisted of 40 volunteers, 30 male medical students and 10 female students of physiotherapy.

Of the males, 28 were 19—24 years of age and 2 were 26 years. Of the females, 8 were between 20 and 23 years, one 24 and one 25 years. The age distribution of the series was thus very similar to that of the controls. None of the 40 volunteers had ever sustained injury to the hand tested, and none of them had had any diseases of the central or peripheral nervous system.

In order to form a personal opinion of the effect of ulnar paralysis, the author participated in the trial as No. 41.

Since the induction of ulnar block sometimes failed and since special investigations were sometimes necessary, the total number of blocks induced was 57.

PERFORMANCE OF THE INVESTIGATION

The 41 persons in whom ulnar block was induced were subjected to the same examination on day 1 as the controls. This examination was repeated on day 7. Ulnar block was induced immediately after this examination and the subjects were re-examined on day 13.

Twenty-five male students (♂ 1—25), 10 female students (♀ 1—10) and the author (♂ 41) were examined in this way.

A small group of 5 students (♂ I—V) were examined daily for 13 days. In these 5 ulnar block was induced on day 7.

The course of the examination in the various groups is given in Table 14.

The better hand was studied. One of the males, but none of the females, was left-handed.

As in the examination of the controls, the temperature and the relative humidity of the examination room were measured at every examination.

Table 14. Course of the investigation

Day of investigation	♂ I—V N=5	♂ 1—25 N=25	♀ 1—10 N=10	Author N=1	Σ
1	×	×	×	×	41
2	×				5
3	×				5
4	×				5
5	×				5
6	×				5
7	×	×	×	×	41
7 Block	×	×	×	×	41
8	×				5
9	×				5
10	×				5
11	×				5
12	×				5
13	×	×	×	×	41

BLOCKING OF THE ULNAR NERVE

After basic examination on day 7, the ulnar nerve was blocked intra-neurally a few centimetres proximal to the sulcus nervi ulnaris. Carbocain® 1 % without adrenalin was used. This level was chosen for the following reasons:

1. At this level the nerve has not yet given off any motor branches.
2. This level is proximal to Martin-Gruber anastomosis, if present, in the lower arm.
3. At this level the ulnar nerve is so far from the median nerve that the latter is less likely to be affected by the local anesthetic.
4. Because of the risk of oedema after intraneural injection. The local anesthetic should therefore not be deposited in sulcus nervi ulnaris but proximal to it. At the level of and in the sulcus nervi ulnaris the nerve is in an osseofibrous tunnel (so-called cubital tunnel—Seindal and Stratford 1948).
5. This is a common level of clinical injury.
6. The nerve here is readily accessible for injection and for electrical stimulation.
7. Block at this level, when properly performed, is safe.

The technique described in Chapter IX was used to prove the completeness of the block. Not until after this completeness was proved was the subjects' arm and hand placed in the examination bridge and examined in the way described above. Ninhydrin printing tests were taken immediately before this examination.

EXAMINATION METHODS

1. The strength of the hand was measured with *Collin's dynamometer* before and after examination with the author's dynamometer.
2. The subject's hand was then placed in the examination bridge in the way described for the control group in Chapter VII. The following values were thus determined with the *author's dynamometer*:
 - a. The strength of pinching grip.
 - b. The strength of palmar adduction of the thumb.
 - c. The strength of radial abduction of the index finger.
 - d. The strength of adduction in the 2nd interspace.
 - e. The strength of adduction in the 4th interspace.
 - f. The strength of ulnar abduction of the little finger.

Here, as in the control series, the subjects were unaware of the values recorded. Jerky movements and tests in which the subjects obviously over-exerted themselves were not accepted.

3. Then followed the *picking-up test* and the *pin-test*.
4. *Sensibility* was assessed with the ninhydrin printing test immediately after these measurements.
5. *Subject's auto-investigation*. After these examinations each subject was given two paper strips and requested to take ninhydrin impressions:
 - a. When he began to feel paresthesia of the little finger. The time of onset of such paresthesia was noted.
 - b. When he thought that he had recovered normal sensibility of the finger. He should also here note the time.

The subjects were also requested to outline the area of loss of sensibility on the volar and dorsal aspects of the hand after induction of ulnar block. This test was crude because only the sense modality of touch was studied.

The subject was requested to note the time when it was again possible for him to adduct the extended little finger towards the ring finger, *i.e.* when Wartenberg's sign had become negative. Finally, he was requested to state the time of recovery of the normal pinching grip, *i.e.* when the thumb and index finger could form a firm normal round O.

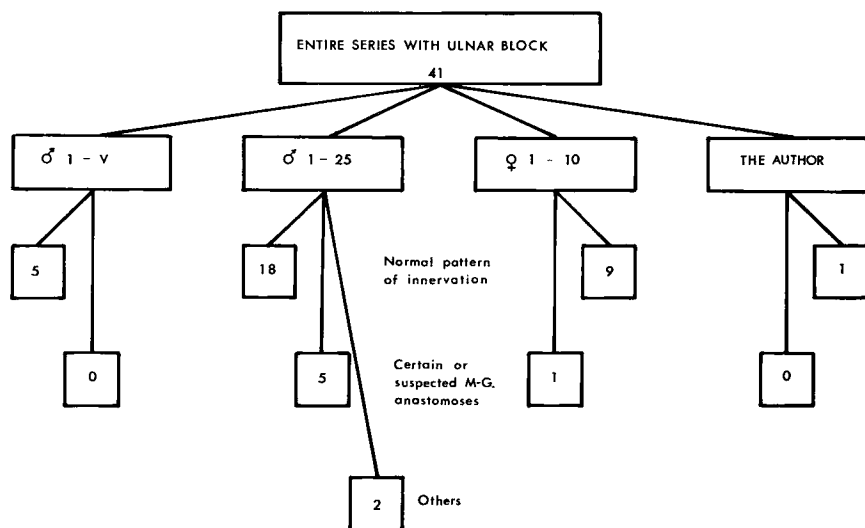


Fig. 28.

The subjects were also requested to describe in their own words what they thought was difficult to perform after they had come home to their ordinary environments with ulnar paralysis.

RESULTS

Groups

The series was divided into 3 groups according to the measurements noted during ulnar paralysis (Fig. 28).

a. The largest group was homogeneous, and the values obtained in high ulnar block suggested that paralysis of the muscles conventionally believed to be supplied by the ulnar nerve were paralysed. In this group the *innervation pattern* was regarded as *normal*.

b. In this group the values obtained were far too high. Paralysis was not complete. Some of them did not fill the criteria of complete block (Chapter IX). Certain electromyographic signs suggested persistent function of the nerve in 14 of the subjects. A second attempt to induce ulnar block in these 14 subjects proved successful in 6 of them. They were then transferred to group I. This left 8 subjects with a varying degree of paresis. Of these 8, one (♂ 8) appeared to have complete ulnar paralysis except regarding the pinching grip — this was probably due to a measuring error in that he

always pulled the index finger in flexion and thereby obtained a high pinch value. In another subject the first injection failed to produce ulnar block and the subject refused a second attempt (Case ♂ 3—transferred to group “others”). A further subject (Case ♂ 5 group “others”) may have had a Riche-Cannieu anastomosis, but also here the injection failed to produce complete ulnar block, even in a second attempt and the subject refused a third. The remaining 6 subjects were examined for Martin-Gruber anastomosis. These subjects were assigned to a special group called “*certain or suspected Martin-Gruber anastomoses*”.

c. *Others*-cases ♂ 3 and ♂ 5, see above.

Tables 30—41, at the end of the book, give a statistical analysis of the measurements made on days 1, 7 and 13 as well as in ulnar block. As for group ♂ 1—25, only 15—18 subjects are included in the tables. The reason for this is given in Table 15.

Error of method

The error of the method — ε — is expressed in degrees of the dynamometer dial and is calculated according to the formula:

$$\varepsilon = \sqrt{\frac{\sum \sum (X_{ij} - M_i)^2}{N(n-1)}}$$

The symbols are the same as those used in the discussion of the error of the method in the control series (Chapter VII). The error of the method reflects the reliability of the measuring method, the values are given in Table 16. The error of the method thus implies, for example, that for pinching grip with the wrist at an angle of $+30^\circ$ the error with 68 % certainty is ± 6 degrees on the scale. If a reliability of 95 % or 99.7 % be chosen, ε must be doubled or trebled. The table also gives the error of the method in per cent of the actual mean in a given test.

In the discussion of the error of the method the following variables must be considered:

1. The difficulty the examiner has in reading the value on the dynamometer dial.
2. The ability of the subject to maintain a constant pressure in the end phase of isometric muscle contraction, *i.e.*, the degree of quivering of the indicator. The error of the method must, of course, be greater in a group with ulnar paralysis than in a control group. In ulnar paralysis there is marked incoordination of practically all grips and movements. In view of the above mentioned variables the error of the method was low and acceptable.

Standard Deviation

In the statistical treatment of the data obtained in the above tests with the dynamometer the median value was used. Three measurements were made in each test. The means of the values were calculated as the arithmetic mean of the median

Table 15. Reasons for exclusion of certain subjects in group ♂ 1—25

	PINCH	ADD POLL	ABD II	ADD II i	ADD IV i	ABD V	COLLIN
Martin-Gruber-anastomosis Subjects ♂ 2, 9, 14, 21, 25	5	5	5	5	5	5	5
Unsuccessful blocks. Riche- Gannieu-anastomosis? Subjects ♂ 3, 5	2	2	2	2	2	2	2
Later block successful, but subject not completely measured Subjects ♂ 4, 8, 24	(2)	(2)	(2)	2	3	2	2
Faulty performance Subject ♂ 8	1	—	—	—	—	—	—
Remainder	17—15	18—16	18—16	16	15	16	16

Table 16. Error of method — ε — in block group (♂ 1—25 and ♀ 1—10)

Examination	Angle of wrist joint	Angle of MP joint	ε	$100 \frac{\varepsilon}{M}$	Block values		
					N	M	s
Pinching grip							
♂	+30°	—	6	15	17	39	12
♀			4	14	9	30	11
Palmar adduction of thumb							
♂	±0°	—	5	20	18	27	9
♀			3	13	9	25	12
Radial abduction of index finger							
♂	±0°	180°	4	11	18	34	17
♀			4	15	9	25	9
Adduction in second interspace							
♂	±0°	180°	5	16	15	28	12
♀			3	16	9	22	9
Adduction in fourth interspace							
♂	±0°	180°	—	—	16	0	0
♀			—	—	9	0	0
Ulnar abduction of little finger							
♂	±0°	180°	2	12	17	14	10
♀			2	27	9	9	6

values of the 3 measurements for each subject. The standard deviation — s — was calculated according to the formula:

$$s = \sqrt{\frac{\sum (X_i - M)^2}{N-1}}, \text{ where}$$

X_i = measured median value for the subject

M = arithmetic mean of the median values of the 3 measurements for each subject

N = number of subjects

I. GROUP WITH NORMAL PATTERN OF INNERVATION

RECORDINGS WITH AUTHOR'S DYNAMOMETER

General

1. On day 1 the basic values noted for all 40 subjects were largely the same as those noted in the control group on that day. The group of subjects was therefore representative.
2. On day 13 the values noted in the experimental series were somewhat higher in certain tests (*inter alia* pinching grip, palmar adduction of the thumb and radial abduction of the index finger), but this was only in group ♂ I—V. Here, then, there was a certain training effect. This could be detected already before day 7. In group ♂ 1—25 and ♀ 1—10 there was no such increase of the values recorded on day 13.
3. Some of the female subjects showed somewhat lower values in some of the tests on day 13. These subjects were re-examined 6 months later and then the values were comparable to those noted on day 1.

Below and in the discussion of the values noted during ulnar paralysis after ulnar block each test is dealt with separately. Table 17 gives mean values in kilograms in ulnar nerve block. For details see Tables 30—41 at the end of the book.

Pinching grip

The measurements made during ulnar paralysis did not vary with the degree of flexion or extension of the wrist about the radio-ulnar axis. This applies to all three groups, ♂ I—V, ♂ 1—25 and ♀ 1—10.

Palmar adduction of the thumb

The values noted during ulnar paralysis showed a slight tendency to fall with increasing flexion of the wrist (♂ 1—25 and ♂ I—V). This tendency was, however not seen in group ♀ 1—10.

When the wrist was flexed more than -50° , the values noted in special subjects decreased continuously towards nil. This phenomenon is discussed later in this Chapter, pages 142—148.

Radial abduction of the index finger

The values noted during paralysis seemed to be higher in group ♂ I—V than in group ♂ 1—25. This was regarded as a training effect which was noted already before day 7. It might have been an increase in the strength of the extrinsic musculature, and then particularly of the extensor digitorum communis II.

Table 17. Mean values in kg for block group (♂ 1—25 and ♀ 1—10)

	PINCH	ADD POLL	ABD II	ADD II i	ADD IV i	ABD V
Position of wrist joint	+30°	±0°	±0°	±0°	±0°	±0°
Position of MP joint	—	—	180°	180°	180°	180°
♂	0.85	0.6	0.75	0.61	0	0.35
♀	0.65	0.6	0.55	0.5	0	0.2

In the group ♂ I—V there was a slight difference between the values measured during paralysis at an angle of the wrist at +30° and —30°. No statistically significant difference was found in the groups ♂ 1—25 and ♀ 1—10. No explanation can be offered for this discrepancy.

Adduction strength in the 2nd interspace

Normally, the adduction strength in the 2nd interspace is greater when the metacarpo-phalangeal joints are flexed than when extended. The reason for this difference has been discussed previously in the description of the examination of the control group. Also during ulnar paralysis, the values were higher when the metacarpo-phalangeal joints II—III were flexed than when they were extended. This is probably because the abducting effect of the long extensors is less when the metacarpophalangeal joints are flexed. The long flexors probably contribute to the increased strength of adduction when the metacarpo-phalangeal joints are flexed.

This difference between the values noted when the metacarpo-phalangeal joints II—III are flexed and extended applies to all groups (♂ I—V, ♂ 1—25, ♀ 1—10).

Adduction strength in 4th interspace

In ulnar paralysis the little finger could, of course, not be adducted to the ring finger. The values are therefore marked as 0. This loss of adduction of the little finger is due to paralysis of the 3rd volar interosseous (Wartenberg's sign positive).

Table 18. Residual strength in percent in high ulnar block. — Approx. values

Test	Group	Position of wrist or MP joint							
		+70°	+50°	+30°	±0°	—30°	—50°	180°	120°
PINCH	♂ I—V	21	15	16	15	16			
	♂ 1—25	20	14	17	18	18			
	♀ 1—10	27	19	17	11	19			
ADD POLL	♂ I—V		29	22	25	18	16		
	♂ 1—25		24	18	18	15	13		
	♀ 1—10		27	23	22	22	21		
ABD II	♂ I—V			24	20	16			
	♂ 1—25			14	14	12			
	♀ 1—10			15	13	13			
ADD II i	♂ I—V							19	21
	♂ 1—25							27	30
	♀ 1—10							24	27
ADD IV i	♂ I—V							0	0
	♂ 1—25							0	0
	♀ 1—10							0	0
ABD V	♂ I—V							17	2
	♂ 1—25							14	0
	♀ 1—10							11	0

Ulnar abduction of little finger

The values noted for the 2 positions of the metacarpo-phalangeal joint V (180° and 120°) were largely the same in the 3 groups ♂ I—V, ♂ 1—25 and ♀ 1—10. When the metacarpo-phalangeal joint was extended, the means for these 3 groups were 16 ± 9 , 14 ± 10 and 9 ± 6 on the scale. The strength of ulnar abduction of the little finger when the metacarpo-phalangeal joint was flexed was low and was mostly measured as 0. This may be explained in the following way. The extensor digiti quinti proprius and extensor digitorum communis V are abducting in ulnar direction when the metacarpo-phalangeal joint V is in extended position. On flexion of the metacarpo-phalangeal joint V the effect of the long extensors is weakened. In addition the collateral ligaments are tightened. It is therefore not surprising that the strength of ulnar abduction of the little finger decreases with increasing flexion of the metacarpo-phalangeal joint V in ulnar paralysis.

Residual amount of strength in per cent is given for each test in Table 18.

Table 19. Residual strength in high ulnar block Collin's dynamometer

Group	N	Normal value kgf	Block value kgf	Residual capacity in % approx.
♂ I—V	5	40±9	9±6	22
♂ 1—25	16	45±11	13±7	29
♀ 1—10	9	30±6	8±4	27

RESIDUAL CAPACITY MEASURED WITH COLLIN'S DYNAMOMETER

Thirty subjects of group ♂ I—V, ♂ 1—25, and ♀ 1—10 were tested regarding their ability to perform a power grip around Collin's dynamometer with the wrist in 30° dorsal extension. Standing with the upper and lower arm extended along the side of the body the subject was instructed to grip the dynamometer as hard as he could. During ulnar block group ♂ I—V had a residual capacity of 9±6 kgf, group ♂ 1—25 13±7 kgf, and group ♀ 1—10 8±4 kgf (Table 19). The residual capacity measured in this way was 22—29 % of the normal.

RESIDUAL CAPACITY MEASURED WITH PICKING-UP TEST

In Moberg's picking-up test (1958) the patient picks up small objects from the table and places them in a receptacle with and without his eyes blind-folded. During the test the examiner watches the way the patient grips the objects. Moberg described the test as a refined test where the sensibility governs the grip. The main purpose of the picking-up test according to Moberg (1958) is to examine the grip function of patients with impaired or complete loss of sensibility of the median nerve.

The test was, however, considered useful in the present investigation of residual capacity of the function of the hand in persons with ulnar nerve block. To enable statistical analysis the test was quantitated and performed under standardised conditions. The subject was instructed to pick up a predetermined number of objects from a smooth surface and place them in a receptacle. The time was noted from the moment the subject touched the first object until he had dropped the last object in the receptacle. Each subject performed the test 3 times with the eyes blind-folded and 3 times without.

Table 20. Picking up test. Group ♂ 1—25 and ♀ 1—10.
Figures in seconds

Sex	Day	Performance					
		Seeing			Blindfolded		
		N	M	s	N	M	s
♂	1	16	6.3	0.7	16	17.2	3.2
	7 A	16	6.4	0.9	16	14.7	2.6
	7 B	14	9.0	1.8	14	25.3	5.8
	13	16	6.4	0.8	16	15.0	2.8
♀	1	9	6.0	0.5	9	16.5	3.2
	7 A	9	5.9	0.5	9	14.5	2.8
	7 B	9	10.2	1.9	9	30.0	8.5
	13	9	6.0	0.6	9	14.2	1.7

Table 21. Picking up test

Performance and comparison	Lengthening factor	
	♂	♀
<i>Seeing</i> . Blocked versus not blocked	1.4	1.8
<i>Blindfolded</i> . Blocked versus not blocked	1.7	2.1
<i>Blocked</i> . Blindfolded versus seeing	2.8	2.9
<i>Blocked and blindfolded</i> versus <i>not blocked and seeing</i>	4.0	5.1

Material

The original controls were not tested with this test. Instead 25 subjects were tested before induction of ulnar block and served as their own controls. The picking up test was studied in 16 male and 9 female students.

Results

The times noted for the females and males when seeing were 6.3 ± 0.7 and 6.0 ± 0.5 seconds respectively and when blindfolded, 17.2 ± 3.2 and 16.5 ± 3.2 seconds, respectively.

Tables 20 and 21 show that, when blind-folded, the males and females required about 3 times as long a time for the picking-up test as when they could see. The lengthening time factor is here 2.8 and 2.9 respectively. When the subjects were not blind-folded the corresponding factors when the ulnar nerve was blocked and not blocked were 1.4 for the males and 1.8 for the females.

When the subjects were blind-folded the males required 1.7 and the females 2.1 times as long to perform the test when the nerve was blocked.

The largest lengthening factors, 4.0 and 5.1, were noted on comparison of the scores achieved by the subjects with ulnar block and blind-folded compared with those noted when they were not blind-folded and when the ulnar nerve was not blocked.

Summary

The picking-up test was standardised and timed. The normal values were largely the same for males and females — both when they were blind-folded and when they were not. When blind-folded the subjects required about 3 times as long to perform the test. Subjects blind-folded and with ulnar block required 4—5 times as long for the test as they did when seeing and before induction of the block.

The ability of a person to perform certain precision movements in the dark with the ulnar nerve blocked is thus severely impaired.

RESIDUAL CAPACITY MEASURED WITH PIN TEST

In the examination of that part of the hand function tested with the picking-up test all of the subjects thus found it difficult to pick up a small needle from the table and place it in the receptacle. The picking-up test was therefore extended to include picking up a small needle from the table and piercing a paper 0.10 mm thick with the needle. Eight squares and 2 crosses should be pierced and the time required was noted. The needle was held between the thumb and the tip of the index finger. The head of the needle was 3 mm in diameter. The result of the test served as a base for evaluation of the patient's capacity to perform a precision grip with preserved sensibility. Each subject performed the test three times and the time required was noted and the median value was used for statistical evaluation.

Material

Nineteen male and 9 female students.

Results

The values varied within each group. This could be explained by natural differences in the dexterity of the subjects. The method proved less suitable, but in testing the functional capacity of the hand in ulnar paralysis it revealed certain phenomena of interest.

The method was unsuitable for statistical treatment. The mean value for the males with ulnar nerve blocked varied between 16.5 ± 9.5 sec. and 24.0 ± 22.6 sec. (Normal 7.7 ± 2.2 sec.)

With the ulnar nerve blocked the mean value found for the female students was 12.7 ± 6.9 sec. (Normal 7.1 ± 1.4 sec.)

The pinching grip of some of the students was too weak to enable them to force the needle through the paper. The head of the needle slipped between the thumb and the tip of the index finger and fell onto the table.

Summary

A method for testing the residual functional capacity of the hand in ulnar paralysis is described. According to this test the person presses a needle through a sheet of paper of certain thickness. Some of the subjects were so weak that they could not force the needle through the paper. The scatter of the values obtained was too wide to allow statistical analysis.

SYMPTOMS AND SIGNS

ONSET AND DISAPPEARANCE OF BLOCK

Loss of sensibility in high ulnar block

The loss of sensibility was complete in the distal volar part of the little finger in all 41 subjects and was demonstrated objectively by Moberg's ninhydrin printing test (Moberg 1958), here quantified.

The loss of sensibility occurred 4.3 ± 2.6 min. after induction of high ulnar block in 24 persons especially investigated for this purpose (Table 23).

The spread of the loss of sensibility in the volar and dorsal part of the hand is apparent from Table 22. The material consisted of 10 females and 22 males, including the author. In this series the subjects were requested to outline the area of loss of sensibility (sense modality of touch).

Results

A. Volar aspect

1. Little finger

In all 32 subjects studied high ulnar block was followed by complete loss of sensibility on the ulnar and radial parts of the distal volar surface of the little finger.

2. Ring finger

Thirty-one of 32 subjects lost all sensibility of the distal-ulnar-volar surface of the ring finger. Only 5 lost sensibility of the distal-radial-volar surface.

3. Long finger

None of the 32 subjects lost sensibility on the volar aspect of the long finger. Neither did any of them lose sensibility of the index finger or thumb.

Table 22. Spread of loss of sensibility in high ulnar block

Finger Group	N	Volar			Dorsal		
		V U—R	IV U—R	III U—R	V U—R	IV U—R	III U—R
♂ 1—25	21	21—21	21—4	0—0	21—21	17—4	0—0
♀ 1—10	10	10—10	9—1	0—0	10—9	9—1	0—0
Author	1	1—1	1—0	0—0	1—1	1—0	0—0
Σ	32	32—32	31—5	0—0	32—31	27—5	0—0

Table 23. Onset of block

Investigation	N	M _{minutes}	s
1 Loss of sensibility	24	4.3	± 2.6
2 <i>Wartenberg</i> sign pos.	34	2.2	± 1.6
3 <i>Sunderland</i> sign. pos.	33	2.3	± 2.0
4 Pos. hyperflex. sign I—IV	23	2.3	
I—III	21	2.2	
I—II	22	4.5	

B. Dorsal aspect

1. Little finger

All of the 32 subjects lost sensibility of the distal-ulnar-dorsal aspect of the little finger. 31 of 32 lost sensibility of the distal-radial-dorsal aspect.

2. Ring finger

27 of 32 subjects lost sensibility of the distal-ulnar-dorsal surface of the ring finger, 5 of the distal-radial-dorsal side. None of them lost sensibility of long finger, index finger or of thumb.

Discussion

According to some anatomical textbooks (Villiger-Ludwig 1946, Monrad-Krohn 1948 and v. Lanz-Wachsmuth 1959) loss of sensibility in patients with ulnar nerve injury affects the ulnar part of the distal-dorsal aspect

of the long finger. This opinion is not shared by *inter alia* Foerster (1929) and Chusid and McDonald (1962). In only 3—4 % of Stopford's series (1918) was there any sensibility of the ulnar nerve from the ulnar part of the long finger. The results of the present investigation thus are in accord with those of Stopford (1918), Foerster (1929) and Chusid and McDonald (1962). The findings made in the present investigation did not confirm the assertion in some conventional anatomical textbooks regarding the sensibility of the dorsal part of the long finger.

Muscular paralysis and onset of the block

Since the block in some cases tended to be short and since testing of the residual capacity of the hand requires a fairly long time (1—2 hours), not all of the 41 subjects were examined with all the tests described in chapter VIII. Wartenberg's, Sunderland's, Egawa's and Froment's signs were, however, invariably demonstrated. Practically all the subjects found it difficult to shape the hand to a cone. A special sign, the so called hyperflexion sign was also very often seen.

Hyperflexion sign

In paralysis of the ulnar nerve the pinching grip is weak, disintegrated and uncoordinated. Bunnell (1956) and Boyes (1964) believe this weakness to be due mainly to loss of the function of the abductor of the index finger, *i.e.*, interosseus dorsalis I and to loss of the adductor of the thumb. Boyes (1964) believes that on marked flexion the IP-joint of the thumb tightens the extensor pollicis longus muscle which can thereby serve better as an adductor substitute.

In the present series of ulnar nerve block the pinching grip was invariably found to be weakened. Furthermore, the grip was disintegrated in a very typical way: the MP-joint of the thumb is slightly hyperextended, but not more than is allowed by the fibro-cartilago volaris and that part of the flexor pollicis brevis innervated by the median nerve (Masse's sign). In the index finger the MP-joint is only slightly flexed and the PIP-joint sets in "hyperflexion", *i.e.*, more than 90° flexion. The DIP-joint is slightly hyperextended, but not more than what is allowed by the fibro-cartilago volaris. The thumb and the index finger are in a supinated position and the index finger is occasionally deviated towards the ulnar side of the hand (Fig. 29).

If the subject tries to strengthen the already weakened pinching grip the following sequence of events occur in the thumb and index finger.

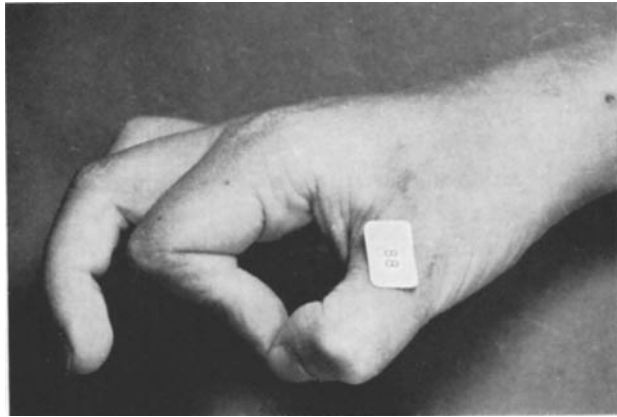


Fig. 29. Hyperflexion sign.

Thumb

There is increased flexion of the IP-joint, and the MP-joint is still slightly hyperextended. The thumb is markedly supinated, but varies occasionally in pronation.

Index finger

Flexion of the MP-joint decreases. The flexion in the PIP-joint increases and the pulp of the index finger slides in proximal direction along the volar surface of the thumb. The DIP-joint remains hyperextended. Finally, the tactile surface of the index finger slips past that of the thumb and the grip is broken down.

This disintegrated pinching grip—here called the *hyperflexion sign*¹—was also demonstrated in the present investigation between the thumb and the long and ring finger. Because of positive Sunderland's sign the subjects often found it difficult to perform a pinching grip between the thumb and the little finger.

In 26 of 28 subjects the hyperflexion sign was positive between the thumb and the ring finger, in 22 of 26 examined it was positive between the thumb and the long finger, and in 25 of 35 examined it was positive between the thumb and the index finger.

¹ The probable cause of this so called *hyperflexion sign* is described more in detail in: "Analysis of the pinching grip under normal conditions and in ulnar nerve paralysis" (to be published).

The time of onset and disappearance of the sign of hyperflexion is given in Tables 23 and 24.

Wartenberg's sign

This sign was positive in all 41 subjects examined. In 34 in which the time of appearance of Wartenberg's sign was noted it was on the average 2.2 ± 1.6 min. after induction of the block, see Table 23. In 14 of the 34 cases the sign was positive within 1 minute.

Sunderland's sign

This sign appeared 2.3 ± 2 min. after induction of block in 33 subjects examined, see Table 23.

DISAPPEARANCE OF BLOCK

Table 24 refers to the examination performed by the subjects with ulnar nerve block, after they had come home. They were requested to state the time of appearance of paresthesia and recovery of "full sensibility". This sensibility was tested in a cruder way, namely by recovery of the sensation of touch. But since a ninhydrin print was taken at this time the investigation nevertheless was acceptable. The subjects were also requested to note the recovery of the ability of the little finger to adduct towards the ring finger (negative Wartenberg's sign) and to state the time of recovery of a normal pinching grip between the thumb and index or long finger. This means that the pathological hyperflexion sign had disappeared. The values are given in Table 24.

Discussion

Dhunér, Edshage and Wilhelm (1960) and Albèrt and Löfström (1961) have tried anesthetics and recorded onset and duration of their effect. Both groups of authors used ulnar nerve block as an instrument. Dhunér et al. demonstrated loss of sensibility on the average 5 minutes after induction of ulnar nerve block in 15 cases. Loss of sensibility was demonstrated by the ninhydrin method according to Moberg (1958). Albèrt and Löfström demonstrated loss of sensibility after ulnar block with Carbocain® in 25 female volunteers and 10 male medical students. The loss of sensibility after ulnar nerve block with 1 % Carbocain® occurred on the average after 4 minutes. While Dhunér *et al.* used different anesthetics the spread in their series may have been somewhat greater than in Albèrt and Löfström's. However, the results obtained by both groups were in fairly good agreement with those found in the present investigation.

The interval before full recovery of sensibility demonstrated with the

Table 24. Disappearance of block

Investigation	N	M _{minutes}	s
1 Recovery of paresthesia	31	126	± 43
2 "Full sensibility"	31	181	± 47
3 Wartenberg sign neg.	31	127	± 42
4 Neg. hyperflex. sign I—II, I—III	24	118	± 57

ninhydrin method of Dhunér et al. was on the average 156 min. and after 133 min. in Albèrt and Löfström's series. In the present investigation the period of anesthesia lasted somewhat longer (181 ± 47 min., see Table 24). In addition, in the present investigation the figures were based on subjective evaluation by the subjects themselves, *i.e.*, when they thought that they had recovered sensibility.

In Albèrt and Löfström's experiments after ulnar block with 1 % Carbocain® the duration of complete *muscle-paralysis* was about 60 min. In their series the motility was tested by examining the subjects capacity to flex the little finger with the Flexor digitorum profundus V. Their technique differs therefore from that used in the present investigation (demonstration of negative Wartenberg's sign). I thus studied the recovery of motility of a distal intrinsic muscle, *i.e.*, third volar interosseus. Moreover in the present investigation the ulnar nerve block lasted at last twice as long on the motor side and the series are therefore not comparable.

The anesthesia in the present investigation also differs from that in the series of the aforementioned two groups of authors in that my subjects received a larger amount of 1 % Carbocain® without adrenalin intraneurally. The dose used in the present investigation was 2—3 ml and in one case 3.5 ml intraneurally deposited. The present subjects also received 3—4 ml extraneurally and one as much as 7 ml. The total amount of anesthetic applied in the present 41 subjects was therefore on the average 6—7 ml (in 2 cases 8 ml).

WHAT IS THE DISABILITY?

The subjects were requested to note what they found difficult to perform at home as long as the ulnar block persisted.

It should be remembered that on arrival home the block was decreasing. It should also be recollected that none of the subjects were aware of the functions of the hand to be examined.

Material and Results

Twenty-seven students reported what they found difficult to perform. The answers are given in Table 25.

Discussion

Difficulty to put on gloves is, of course, due to difficulty in extending the 2 ulnar fingers. The other difficulties are probably due to the weakness of the pinching grip and disturbed coordination, disturbances which also make it difficult to turn off water taps, to turn keys, to cut with a knife, and to do up buttons.

II. GROUP WITH CERTAIN OR SUSPECTED MARTIN-GRUBER ANASTOMOSES

Introduction

The anatomy of this anastomosis has been discussed in Chapter I. Suffice it here to point out that the anastomosis lies between the median and the ulnar nerve in the lower arm and distally to the site of induction of the high ulnar block.

In 6 of 41 cases high ulnar block failed to paralyse some of the muscles usually supplied by the ulnar nerve. After repeated injections at the same level a certain degree of strength persisted in inter alia the interosseus dorsalis I and adductor pollicis.

Martin-Gruber anastomosis was suspected and 6 of the subjects were given an extra injection at a lower level, *i.e.*, proximal to zone III, See Fig. 1.

Material

The 6 patients were ♂ 2, 9, 14, 21, 25 and ♀ 7. They all belonged to the group examined on days 1, 7 and 13 and in whom the nerve was blocked on day 7.

Methods for demonstrating the anastomosis

With the technique described (Chapter IX) it was shown that ulnar block at this level was complete. Full anesthesia of the distal volar aspect of the little finger was shown with a ninhydrin printing test according to Moberg (1958). The residual strength of certain grips and muscles was measured, *i.e.* pinching grip, palmar adduction of the thumb, radial abduction of the index finger, the strength in the 2nd and 4th interspaces and ulnar abduction of the little finger.

The median nerve proved to be unaffected by the high ulnar block, as judged from the results of the picking-up test according to Moberg (1958),

Table 25. Difficulties in high ulnar block

Difficulties	♂ N	♀ N	Σ
Put on gloves	9	5	14
Write	8	4	12
Turn off taps	4	7	11
Turn key	4	6	10
Cut with knife	6	1	7
Do up buttons	3	2	5
Comb hair	1	4	5
Carry heavy bag	3	1	4
Type-write	3	—	3
Strike a match	2	1	3
Fill a smoking pipe	3	—	3
Hold a tee-cup	1	2	3
Blow the nose	2	—	2
Wash	2	—	2
Hold and count coins	2	—	2
Do up shoe-lace	2	—	2
Spread butter on bread	1	—	1
Shake hands	—	1	1

the ninhydrin test (Moberg 1958) and in some cases by electromyographic examination of the abductor pollicis brevis muscle together with measurement of the strength of that muscle.

However, electromyography with needle electrodes in the interosseus dorsalis I and in adductor pollicis showed activity at maximal voluntary contraction. It should be stressed that the high ulnar block was complete according to the previously defined electromyographical criteria.

Ulnar block was then induced proximally in zone III, *i.e.*, somewhat proximal to os pisiforme. The activity in the interosseus dorsalis I and adductor pollicis then disappeared. This was accepted as proof of a true Martin-Gruber anastomosis. The strength of the pinching grip, of adduction of the thumb and radial abduction of the index finger was remarkably decreased, and at the level of, or in some cases somewhat lower than, that measured after block in subjects with a normal innervation pattern in group I.

Technical sources of error

The following sources of error were borne in mind throughout the examination :

1. Spread of stimulus from ulnar nerve to median nerve at level of high ulnar block.
2. Volume conduction from an approximate muscle innervated by the median nerve.
3. Spread of anesthetic to the median nerve at the level of the wrist.

These sources of error were also shown by Gassel (1964).

Results

The results are summarized in Table 26, page 141, which gives the normal values and those recorded after high and low ulnar block. The possible extent and nature of the Martin-Gruber anastomosis are recorded in Figs. 30—36, pages 139—140.

The cases are described below.

Case ♂ 2

Though the high block was complete (Fig. 37, 38), the values noted for the strength of radial abduction of the index finger (Fig. 39) and of the pinching grip were too high. But the block had resulted in complete loss of sensibility of the little finger and in paralysis of flexor carpi ulnaris. The strength of ulnar abduction of the little finger was also markedly reduced. Martin-Gruber-anastomosis was suspected and low ulnar block was induced, after which the values noted for the radial abduction of the index finger and of the pinching were much lower. The ninhydrin printing test showed satisfactory sensibility in the region of the median nerve, and electromyography of the musculature of abductor pollicis brevis showed that the motor branch of the median nerve had not been influenced by low ulnar block. There was no unequivocal evidence that the Martin-Gruber anastomosis supplied the adductor pollicis muscle. Martin-Gruber anastomosis probably supplies interosseus dorsalis I. It cannot, however, be excluded that in this case the interosseus dorsalis I is also innervated to some extent by the median nerve (Fig. 40). This case was not investigated further because high ulnar block had already been induced on 4 occasions in this subject.

Summary

The investigation suggested the existence of a Martin-Gruber anastomosis supplying interosseus dorsalis I.

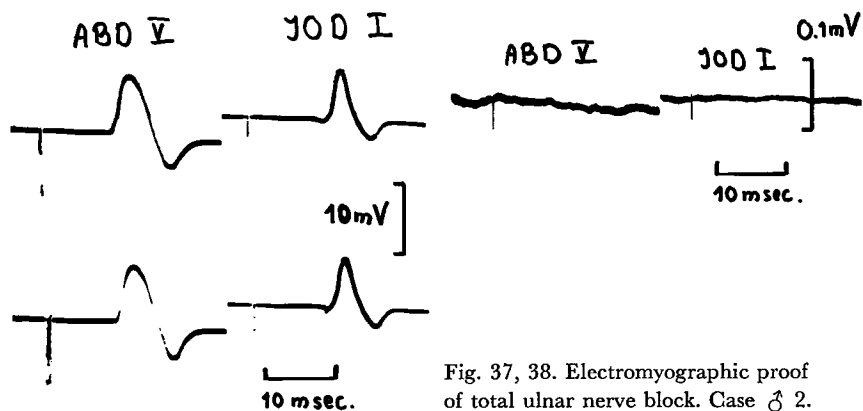


Fig. 37, 38. Electromyographic proof of total ulnar nerve block. Case ♂ 2.

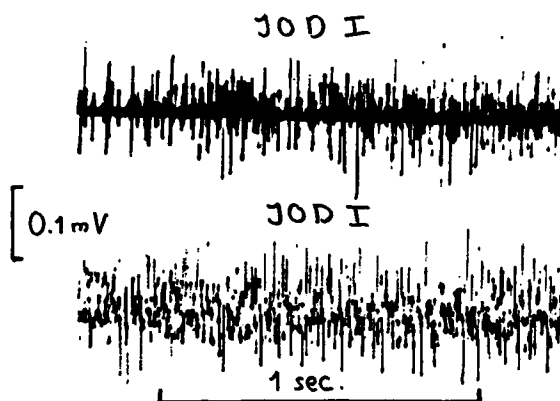


Fig. 39. See text.

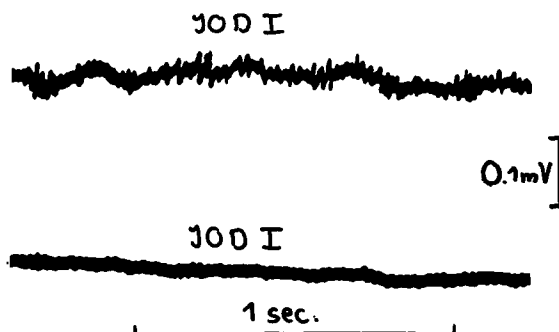


Fig. 40. See text.

Case ♂ 9

The high ulnar block was found to be complete. This block resulted in total loss of sensibility of the little finger, paralysis of flexor carpi ulnaris musculature and very weak abduction of the little finger. Compared with what was seen in the large group with a normal innervation pattern, the pinching grip was found to be unusually strong, as was radial abduction of the index finger and palmar adduction of the thumb. On maximum voluntary contraction in the interosseus dorsalis I an electromyographic response was obtained from this muscle (see Fig. 41). Martin-Gruber anastomosis was suspected and low ulnar block was induced, after which the electromyographic activity in the interosseus dorsalis I disappeared, Fig. 42. The low ulnar block had not spread to the median nerve. Electromyographic examination with needle electrodes in the abductor pollicis brevis-muscle showed normal activity, Fig. 43. The strength of radial abduction of the index finger decreased from 95 to 14 on the scale of the dynamometer, from 85 to 19 for the pinching grip, and from 90 to 52 for the palmar adduction of the thumb. When this palmar adduction was measured with the wrist flexed in the -50° position the value measured on the dynamometer was 2. This suggests that, clinically, the adductor pollicis musculature was paralysed and that the measuring value of 52 was due largely to the substituting strength exerted by the extensor pollicis longus (cf page 145).

Summary

A case of Martin-Gruber anastomosis supplying interosseus dorsalis I and adductor pollicis is demonstrated.

Case ♂ 14

High ulnar block was found to be complete and resulted in a total loss of sensibility of the little finger and paralysis of the flexor carpi ulnaris. The strength of ulnar abduction of the little finger decreased from 95 to 22 on the scale of the dynamometer, and Wartenberg's sign was positive. But the residual strength in the interosseus dorsalis I and that of the pinching-grip and of palmar adduction of the thumb were unusually high. Martin-Gruber anastomosis was suspected and low ulnar block was induced. This resulted in complete paralysis of interosseus dorsalis I, low values for the pinching grip and for palmar adduction. When the hand was flexed -50° the subject could not adduct the thumb towards to 2nd ray. This suggests that the value of 30 on the scale in this case was due to the extensor pollicis longus acting as a substituting muscle in adductor paralysis (cf page 145).



Fig. 41. See text.

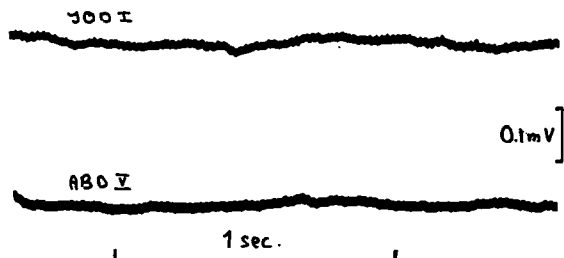


Fig. 42. See text.

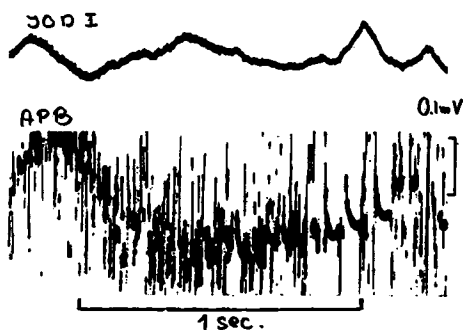


Fig. 43. Martin-Gruber anastomosis. Case ♂ 9.

Summary

The examination suggested Martin-Gruber anastomosis supplying interosseus dorsalis I and adductor pollicis.

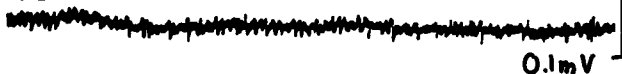
Case ♂ 21

The high ulnar block proved to be complete. The block resulted in complete loss of sensibility of the little finger and paralysis of the flexor carpi ulnaris muscle. The strength of ulnar abduction of the little finger was markedly decreased and Wartenberg's sign was positive. The strength of radial abduction of the index finger was also markedly reduced, as was

ADD POLL



JOE I



ABD I

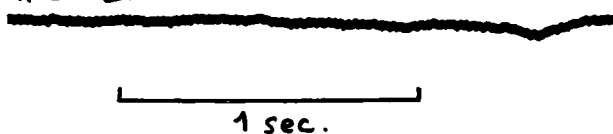


Fig. 44. Martin-Gruber anastomosis to ADD POLL.
Case ♂ 21.

the pinching grip. However, the strength of the palmar adduction was measured as 80 on the scale of the dynamometer, which is unusually high in high ulnar block. Electromyography with needle electrodes in interosseus dorsalis I and abductor digiti quinti showed clinical paralysis while electromyographic examination of the adductor pollicis-musculature with needle electrodes, however, showed activity on voluntary contraction (Fig. 44). Martin-Gruber anastomosis supplying adductor pollicis was suspected and a low ulnar block was induced, after which the value measured for the adductor pollicis decreased from 80 to 30 on the scale. Electromyography with the needle electrodes in the same position in the adductor pollicis now showed a different picture (Fig. 45). The innervation pattern was now markedly reduced.

Summary

The examination suggested that a Martin-Gruber anastomosis supplied adductor pollicis.

Case ♂ 25

High ulnar block was proved to be complete, and resulted in loss of sensibility of the little finger and paralysis of the flexor carpi ulnaris muscle.

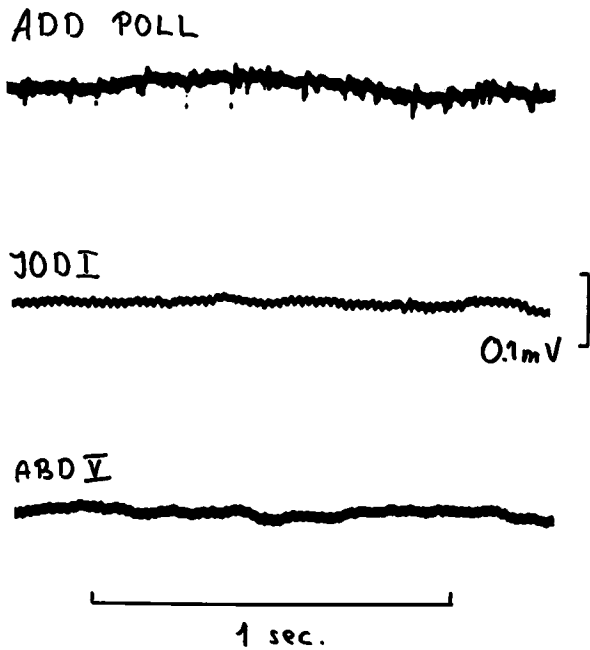


Fig. 45.
Case ♂ 21, see text.

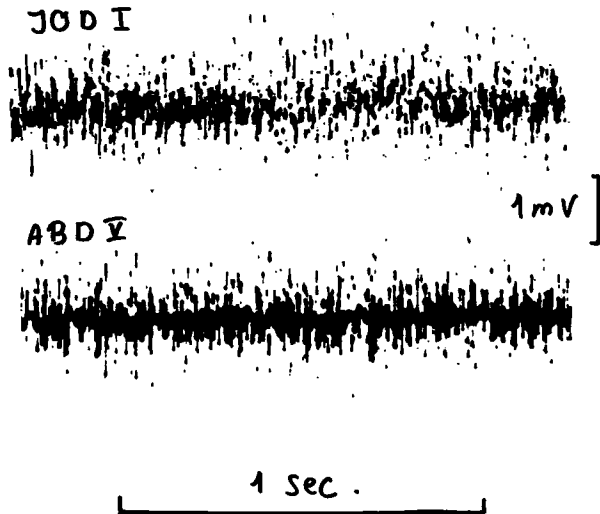


Fig. 46. Martin-Gruber ana-
stomosis. Case ♂ 25, see text.

Electromyographic examination of the interosseus dorsalis I and the abductor digiti quinti with needle-electrodes showed residual activity on maximum voluntary contraction of these muscles (Fig. 46). To check that the high ulnar block was still complete, examination was repeated with high sensitivity and with needle-electrodes in the interosseus dorsalis I and abductor digiti quinti. A Martin-Gruber anastomosis was suspected

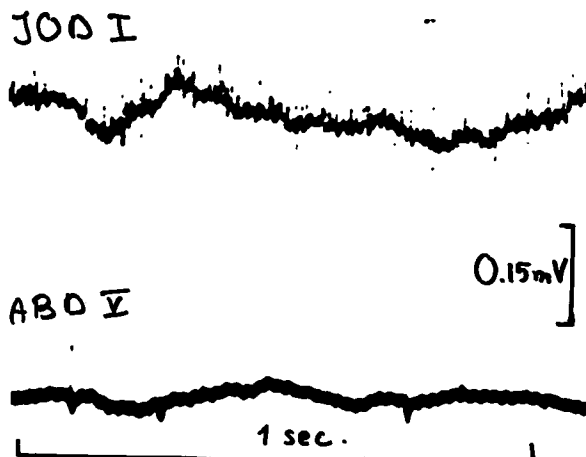


Fig. 47. Martin-Gruber anastomosis. Case ♂ 25, see text.

to supply interosseus dorsalis I and abductor digiti quinti and therefore a low ulnar block was induced, after which the values for pinching grip fell from 95 to 18 on the dynamometer. Unfortunately, the strength in interosseus dorsalis I and abductor digiti quinti had not been measured after induction of the high block. Electromyographic examination of interosseus dorsalis I and abductor digiti quinti with needle-electrodes after induction of the low block showed a severely reduced innervation pattern in both muscles on maximum voluntary contraction and only some motor units could be reproduced representing abductor digiti quinti and a somewhat increased innervation pattern of interosseus dorsalis I, Fig. 47. This could depend on a subtotal low block or that interosseus dorsalis I may receive some innervation also from the median nerve. This was not further investigated.

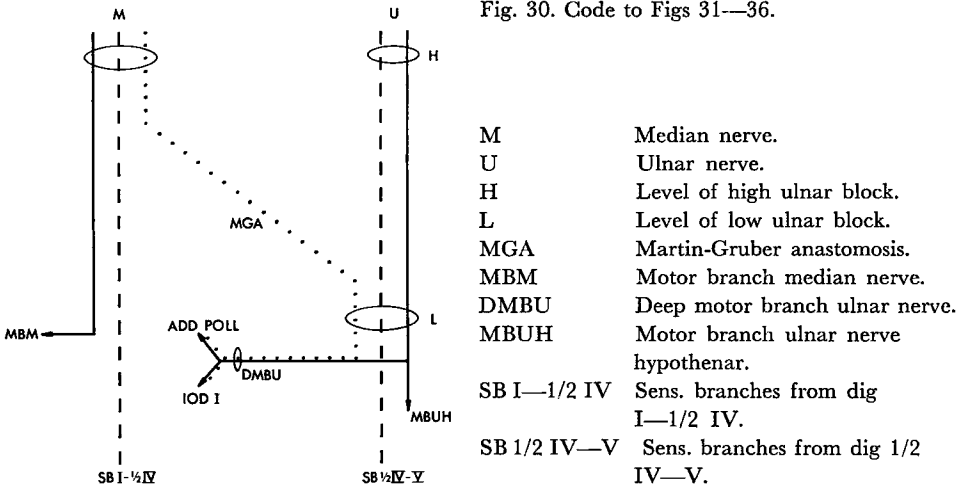
Summary

The examination suggested presence of Martin-Gruber-anastomosis supplying interosseus dorsalis I and abductor digiti quinti.

Case ♀ 7

High ulnar block was induced and resulted in loss of sensibility of the little finger, even though 2 ninhydrin spots could be identified in the quantitative ninhydrin printing test. Paralysis of flexor carpi ulnaris muscle could be clinically demonstrated. The strength of ulnar abduction of the little finger fell from 80 to 25 on the dynamometer and the strength of the radial abduction of the index finger fell from 250 to 95. Palmar adduction fell from 110 to 32 and the pinching grip from 180 to 55 on the dynamometer.

Fig. 30. Code to Figs 31—36.



The high ulnar block was not complete with certainty but nevertheless Martin-Gruber anastomosis was suspected and a low ulnar block was induced, after which the electromyographic pattern changed considerably in interosseus dorsalis I and in abductor digiti quinti action potentials were severely reduced.

Summary

The case is uncertain. There might have been a Martin-Gruber anastomosis supplying abductor digiti quinti, interosseus dorsalis I and adductor pollicis. The possibility of incomplete high ulnar block cannot be excluded. The low ulnar block seemed to be complete. A double innervation of the first dorsal interosseus from the median nerve was also possible as shown in some cases by Murphey, Kirklin and Finlayson (1946) and Rowntree (1949). Nor could one exclude the presence of a double innervation of abductor digiti quinti from the median nerve as shown in some cases by Murphey, Kirklin and Finlayson (1946), Gassel (1964) and Marinacci (1964).

Further investigation on this subject was not possible since this was the second time block was not totally successful and the subject would not consent to a third attempt.

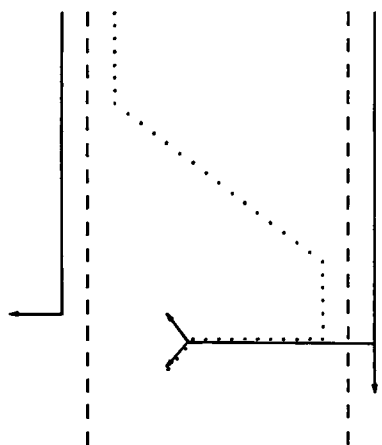


Fig. 31.
♂ 2.

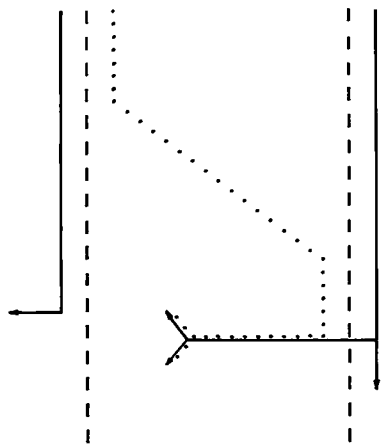


Fig. 32.
♂ 9.

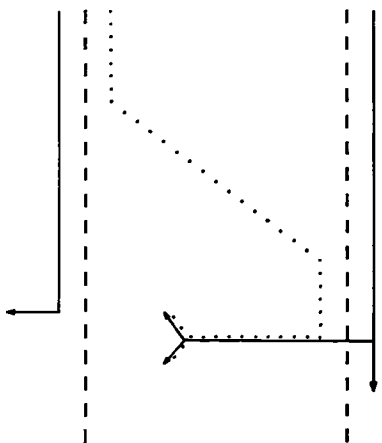


Fig. 33.
♂ 14.

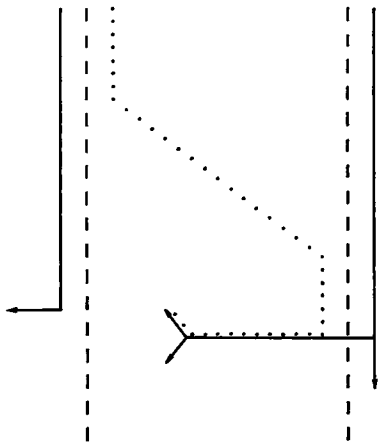


Fig. 34.
♂ 21.

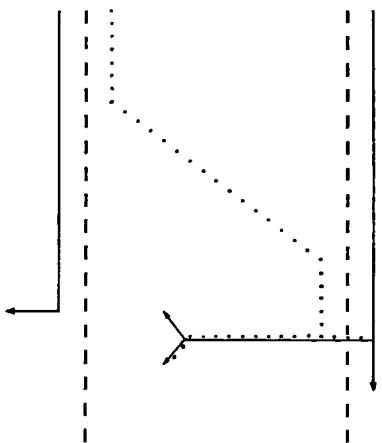


Fig. 35.
♂ 25.

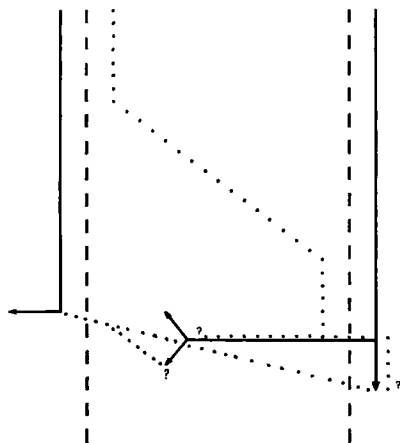


Fig. 36.
♀ 7.

Table 26. *Martin-Gruber* anastomosis

1	2	3	4	5	6	7	8	9	10	11	12	13	14
♂	2	N	>25		110	75	225	130	260				
		H	0	+	35	20	105	50	140	+	(+)	(+)	
		L	0	+	20	W:+	30	26	36	+	+	+	—
♂	9	N	>25		80	65	225	165	230				
		H	0	+	12	*	95	90	85	+	(+)		
		L	0	+	12	W:+	14	52 ¹	19	+	+		—
♂	14	N	>25		95	53	240	180	185				
		H	0	+	22	W:+	95	75	80	+	(+)		
		L	0	+	*	W:+	0	30 ²	45	+	+		
♂	21	N	>25		155	80	255	175	185				
		H	0	+	15	W:+	25	80	25	+	+	(+)	
		L	0	+	*	W:+	20	30	11	+	+	+	
♂	25	N	>25		110	60	335	90	225				
		H	0	+	*	W:+	*	*	95	(+)	(+)		
		L	0	+	15	W:+	35	11	18	+	+		
♀	7	N	>25		80	65	250	110	180				
		H	2	+	25	W:+	95	32	55	(+)	(+)		
		L	0	+	12	W:+	12	20	22	(+)	(+)		

¹ —50°: value 2 on the dynamometer.² —50°: value 0 on the dynamometer.

* Not investigated.

Code for reading table 26.

- 1 Sex
- 2 Subject
- 3 Normal (N) value and values obtained after high (H) and low (L) block
- 4 Quantitative Ninhydrin printing test dig. V distally-volarly
- 5 Flexor carpi ulnaris affected—paralysed—by the block
- 6 ABD V with MP joint in 180°
- 7 Add IV i with MP joint in 180°; W+=*Wartenberg's* sign pos.
- 8 ABD II with wrist joint in $\pm 0^\circ$
- 9 ADD POLL with wrist joint in $\pm 0^\circ$
- 10 PINCH with wrist joint in $+30^\circ$
- 11 EMG in ABD V
- 12 EMG in IOD I
- 13 EMG in ADD POLL
- 14 EMG in APB

+ = affected by the block, (+) = in a certain degree affected by the block
 — = not affected by the block

Discussion

The nature of Martin-Gruber's anastomosis has been elucidated by Ranschburg (1917), Borchart and Wjasmenski (1917) and others. They performed their investigations on cadavers. According to Ranschburg, Martin-Gruber anastomosis supplies both the hypothenar musculature and most of the intrinsic muscles on the radial side of the hand.

Borchart and Wjasmenski, who used a refined technique, dissected some nerves in fasciculi and found Martin-Gruber anastomosis to terminate in the deep motor ulnar branch.

SUMMARY

Of 41 subjects in whom high ulnar block was induced, a Martin-Gruber-anastomosis was suspected in 6, including 4 in whom the anastomosis was of true Martin-Gruber type, 1 in whom it was probably and 1 in whom it was possibly of a Martin-Gruber type. The nature of Martin-Gruber-anastomosis, *i.e.* the muscles finally innervated by this anastomosis, is discussed and the results are represented graphically. A preliminary report of these findings was given in 1964 by the author.

ANALYSIS OF ADDUCTION MOVEMENT OF THUMB IN ULNAR BLOCK

It has long been known that in ulnar paralysis the thumb can perform an adduction movement towards the 2nd ray (Fick 1845). There must thus be some muscles acting as substitutes to replace the loss of adductor pollicis and interosseus dorsalis I in ulnar paralysis. Remaining stabilisers in dorsal direction are the extensor pollicis longus and brevis, in volar direction flexor pollicis longus and that part of the flexor pollicis brevis innervated by the median nerve. In radial direction the thumb can still be stabilised by the extensor pollicis brevis and to some degree by the abductor pollicis brevis and longus. In ulnar direction the thumb can no longer be stabilised by the adductor pollicis or by the interosseus dorsalis I. Possible structures exerting a pull in ulnar direction here are the extensor pollicis longus and flexor pollicis longus.

The normal value found for 18 male students before ulnar block with the wrist at an angle of $\pm 0^\circ$ was 141 ± 31 measured with the author's dynamometer. After ulnar block the gross strength of palmar adduction in these subjects was 27 ± 9 . This strength must thus represent the gross strength of the substitute muscles (extensor pollicis longus and/or flexor pollicis longus).

Table 27. Muscles substituting the loss of adductor pollicis in total ulnar nerve lesion according to literature

Author	Extensor pollicis longus	Flexor pollicis longus
1 <i>Fick, L.</i> (1845)	+	
	(Extensor pollicis adducens)	
2 <i>Duchenne</i> (1867)	+	—
3 <i>Babinski and Froment</i> (1918)	+	
4 <i>Foerster</i> (1929)	+	(+)
5 <i>Boyes</i> (1935)	+	
6 <i>Villiger-Ludwig</i> (1946)		+
7 <i>Bodechtel et al.</i> (1951)		+
8 <i>Wartenberg</i> (1953)		+
9 <i>Kaplan</i> (1965)	+	
10 <i>Bunnell</i> (1956)	+	
11 <i>v. Lanz-Wachsmuth</i> (1959)		+
12 <i>Bowden and Napier</i> (1961)		+
13 <i>McFarlane</i> (1962)		+

+ =Adductor substitute
 (+) =Weak adductor substitute
 — =Denies adductor substitute

Is the extensor pollicis longus or flexor pollicis longus an adductor substitute in ulnar paralysis?

This question has received attention by various authors in this field (Table 27).

In an attempt to clear up this question 4 subjects with rupture of the extensor pollicis longus tendon and 2 subjects with lesions of the flexor pollicis longus tendon were studied (Table 28).

Comments on Table 28

The subjects with rupture of the extensor pollicis longus tendon were examined before and after induction of ulnar block. The following typical case is illustrative. The patient, a woman (A.W.) had a subcutaneous rupture of extensor pollicis longus tendon on the right side after right-sided fracture of the radius. The patient was examined after the fracture had healed and was painless. Under standardised conditions the palmar adduction strength of the healthy (left) hand was measured and found to be 135 on the dial of the dynamometer. After total ulnar block on the same

Table 28. Analysis of adductor substitute in ulnar nerve paralysis

				Strength of palmar adduction of the thumb			
				Injured hand		Healthy hand	
	Pat.	Sex	Year	Before	After block	Before	After block
Rupture EPL	AW	♀	53	75	0	135	34
	IL	♀	56	61	0	86	27
	RE	♀	53	70	0	70	*
	KA	♂	20	70	0	120	*
Lesion FPL	AN	♀	63	105	19	*	*
	TI	♂	43	160	25	*	*

* Not investigated.

side the measurement was 34. Then the right hand with subcutaneous rupture of the extensor pollicis longus was examined. Under equal, standardised conditions the strength of palmar adduction was found to be 75. After complete ulnar block on this side the strength of palmar adduction was measured again. Then the patient was unable to adduct the thumb from complete abduction against the pressure plate of the dynamometer; the value registered was 0. The flexor pollicis longus was undamaged. This tendon could evidently not perform any substitute adduction movement against the metacarpale II. A further 2 patients with rupture of extensor pollicis longus gave similar results after ulnar block. In addition 1 case with laceration of the extensor pollicis longus was examined. The results obtained were the same as in the other three.

Two patients with lesions of the flexor pollicis longus were examined in the same way as the 4 patients with injured extensor pollicis longus tendon. The gross strength of palmar adduction movement was before induction of ulnar block 105 and 160 respectively. After high ulnar block the strength of palmar adduction fell to 19 and 25, respectively, on the dynamometer.

Summary

Four patients with rupture of extensor pollicis longus but with intact ulnar nerve function were examined regarding the strength of palmar adduction. The strength varied between 61 and 75. After high ulnar block none of the

patients could adduct the first metacarpal towards the second. In all these patients the function of the flexor pollicis longus tendon was intact.

Two patients with a lesion of flexor pollicis longus tendon but with an intact ulnar nerve function were examined regarding palmar adduction movement. Both before and after induction of high ulnar block these 2 patients could adduct the first metacarpal towards the second. In these 2 patients the function of the extensor pollicis longus was preserved.

These examinations show the significance of the extensor pollicis longus in loss of function of adductor pollicis and interosseus dorsalis I and that it can adduct the first metacarpal towards the second. The flexor pollicis longus has no effect on this movement. These findings correspond with those I obtained in experiments on fresh autopsy specimens as described in Chapter IV.

CHANGE IN THE STRENGTH OF PALMAR ADDUCTION IN HIGH ULNAR BLOCK WITH INCREASING VOLAR FLEXION OF THE WRIST

After induction of high ulnar block the strength of palmar adduction invariably decreased with increasing volar flexion (Fig. 48) and when the wrist was in maximum volar flexion, the first metacarpal could no longer be adducted to the second metacarpal bone. What is the cause of this? The preceding investigations showed that the extensor pollicis longus is the adductor substitute in ulnar paralysis. On increasing volar flexion of the wrist the position of the extensor pollicis longus tendon shifts to the radial side of the first metacarpal. On measurement of the strength of palmar adduction of a subject with increasing volar flexion of the wrist the extensor pollicis longus tendon could be made out by palpation. This tendon was marked on the skin with barium contrast and under standard conditions the results of the examination were recorded with the help of roentgenography, (see Fig. 49). In this subject high ulnar block was induced and a certain amount of adduction of the thumb was possible with the aid of extensor pollicis longus. Observe the gliding of the base of the first metacarpal in radial direction. The extensor pollicis longus tendon here as normally—(see Fig. 21)—was clearly on the ulnar side of the dorso-volar axis in the adduction movement. When the wrist was placed in maximum volar flexion, the subject could no longer adduct the first metacarpal towards the second after induction of high ulnar block. It is true that the extensor pollicis longus tendon was still intact, but it lies over or on the radial side of the dorso-volar axis of movement. Fig. 50 shows the position of the extensor pollicis longus tendon after induction of ulnar block with the wrist in maximum volar flexion. The tendon is situated

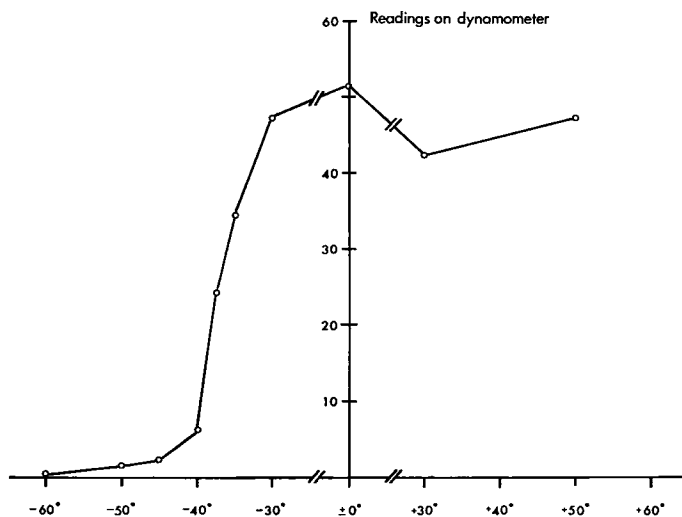


Fig. 48. Case ♂ 9 after induction of high ulnar block. The strength of palmar adduction of the thumb decreases with increasing volar flexion in the wrist joint. With the wrist in maximum volar flexion (-60°) the first metacarpal could no longer adduct towards the second. Cause: EPL tendon is on or radial to the axis of movement.

radially to the median plane of the first metacarpal. This suggests that the extensor pollicis longus tendon lay radially to the axis of the movement of palmar adduction. On normal palmar adduction the radial proximal part of the first metacarpal glides in radial direction; therefore this dorso-volar axis of movement should be distal to the carpo-metacarpal point I. It did not prove possible to estimate the distance of the axis of movement from the carpo-metacarpal joint in distal direction. The examination simply showed that the axis of movement of palmar adduction is situated distally to the carpo-metacarpal joint and ulnarly to the position of the tendon of the extensor pollicis longus in the last mentioned experiment where the subject was examined regarding palmar adduction with the wrist in maximum volar flexion after induction of high ulnar block.

Some other experiments were also performed regarding the ability of the extensor pollicis longus tendon to adduct the first metacarpal towards the second. After induction of high ulnar block the wrists of the subjects to be examined were placed in maximum volar flexion in the examination bridge. As in the experiments just mentioned, the subjects could not adduct the first metacarpal towards the second. But when the examiner

Fig. 49. Palmar adduction in high ulnar block. Case ♂ B.C. The adduction is performed by EPL marked with barium contrast. The wrist joint is in slight dorsal extension.

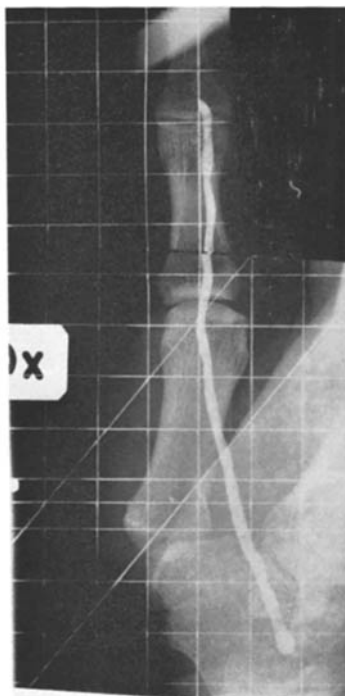


Fig. 50. Same case as in Fig. 49. Wrist joint in maximum volar flexion. Palmar adduction not more possible. Cause: EPL tendon on or radial to the axis of movement.



pressed the extensor pollicis longus tendon in ulnar direction and, so to say, shifted this tendon on the ulnar side of the supposed dorso-volar axis of movement of palmar adduction the subject could adduct the first metacarpal towards the second, (see Fig. 51). This was recorded by films and by cineradiography. About 3 ml Urographin 60 % was injected into the tendon sheath of the extensor pollicis longus in a person with ulnar paralysis. At various angles of the wrist the patient was instructed to adduct the first metacarpal towards the second. When the wrist was in maximum volar flexion the subject could not adduct the first metacarpal to the second unless the examiner first pressed the tendon of the extensor pollicis longus in ulnar direction and, so to say, past the position of the supposed dorso-volar axis of movement.

Another interesting observation was made on cineradiography after the tendon sheath of the extensor pollicis longus had been marked with Urographin 60 %. When the wrist joint was in maximum volar flexion the patient could not adduct the first metacarpal towards the second. The extensor pollicis longus tendon was thus situated radially to the supposed dorso-volar axis of movement. When the patient was then requested to perform palmar adduction at the same time as the hand was slowly extended dorsally in the wrist joint the extensor pollicis longus tendon in a certain position suddenly glided over in ulnar direction, after which the patient could adduct the first metacarpal towards the second. The experiment was repeated several times and the extensor pollicis longus tendon always slipped over in ulnar direction at the same angle of the wrist.

SUMMARY

After induction of high ulnar block the strength of palmar adduction decreases with increasing volar flexion of the wrist. This appears to be due to the fact that the only substituting muscle, namely the extensor pollicis longus, with its tendon slips more and more in radial direction with increasing volar flexion of the wrist. At maximum volar flexion of the wrist the tendon glides so far in radial direction that it slides radially to the dorso-volar axis of movement of the palmar adduction. Thus the dorso-volar axis of movement of the palmar adduction of the thumb lies distally to the first carpo-metacarpal joint and ulnarly to the position of the extensor pollicis longus tendon on maximum flexion of the wrist. It was not possible to determine the site of the axis more precisely.

IS INTRANEURAL ULNAR BLOCK HAZARDOUS?

All values recorded on day 13, *i.e.*, 6 days after induction of ulnar block, were the same as those recorded on day 1, *i.e.*, 6 days before the induction

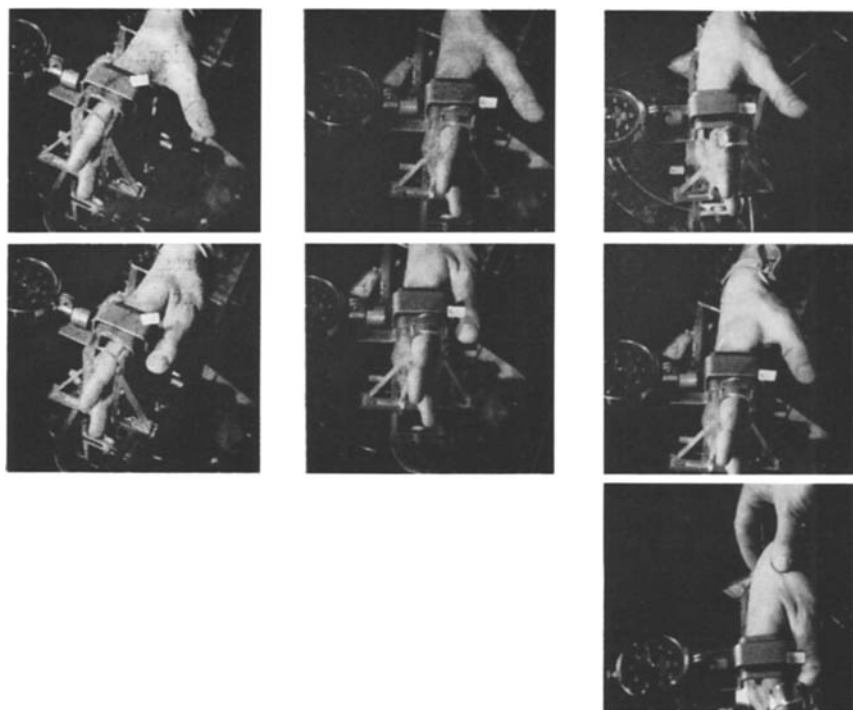


Fig. 51. Palmar adduction in high ulnar block. Case ♂ 21. Palmar adduction possible with the aid of EPL. In volar flexion of the wrist joint the subject could not adduct the thumb against the index finger unless the examiner displaced the EPL tendon to the ulnar side of the axis of movement.

of the block except for some of the tests on some of the female students on day 13 which were lower than on day 1. At re-examination half a year later on these females the values noted were the same as or higher than, those originally recorded on day 1.

When questioned, all 41 subjects taking part in the investigation denied any sequelae after the block. Only 1 subject (♂ 3) had temporary pain for a period of 2 weeks and therefore electromyography was performed and nerve conduction velocity was determined some time after the intraneural block. The electromyographic pattern and the nerve conduction velocity at the re-examination were normal.

It would therefore appear safe to study paralysis in the region of the hand by the method used in the present investigation, *i.e.*, intraneural block of the ulnar nerve at the level just above the sulcus nervi ulnaris, with 1 % Carbocain® without adrenalin. Clinical experience supports this conclusion since only rarely do patients complain of subsequent pain at

the site of the injection. Such pain may be related to ischaemia of the nerve because of too large an amount of adrenalin in the local anesthetic or of the tip of the needle becoming hooked by contact with bone and consequent injury to a nerve fasciculus on withdrawal of the needle after the injection. No such hooking was noted in the present material.

SUMMARY CHAPTER X

The main purpose of the investigation was to evaluate the residual capacity of the hand in a state of ulnar nerve paralysis. 41 persons including the author subjected to a high ulnar nerve block were examined under the same standardised conditions as the controls (Chapters VI+VII). The ulnar blocks were classified as total according to the technique described in Chapter IX. The residual capacity was determined both with the authors dynamometer and with Collin's dynamometer. Moreover, two other tests were used, Mobergs picking-up test (Moberg 1958) with registration of the time required and a so-called pin test (piercing through a paper with a needle). Finally, the pattern of loss of sensibility was determined. Statistical treatment of the values obtained in the group with normal pattern of innervation is given in tabular form at the end of the book. The results are discussed under: "General discussion and conclusions." The results after analysis of the palmar adduction in ulnar paralysis are also discussed under these headings.

The question whether ulnar block is hazardous is discussed. The values recorded 6 days after the ulnar block were not lower than those obtained before the block, and none of the subjects complained of any pain at the site of injection with the exception of one subject, who complained of some pain in the arm and hand 2 weeks after induction of a high ulnar nerve block and a low median nerve block. Electromyographic investigation including estimation of nerve conduction velocity was therefore performed some time after the nerve blocks and at that re-examination everything was normal. Intraneural ulnar block performed with 1 % Carbo-cain® without adrenalin at the level just above the sulcus nervi ulnaris therefore appears to be safe and can thus be used in the study of ulnar nerve paralysis.

When analysing the results it soon became obvious during the investigation that in certain subjects—6 of 41—the injection did not produce ulnar paralysis, but only a certain degree of ulnar palsy (paresis). A Martin-Gruber anastomosis was suspected and these 6 subjects were then given an intraneural injection in the ulnar nerve proximal to zone III with the same local anesthetic. Ulnar paralysis now occurred in 4 of these subjects and a Martin-Gruber anastomosis was thereby evident. In the other 2 a Martin-Gruber anastomosis could not be excluded by this technique.

Part VII Clinical series

Chapter XI Clinical series

From 1962—1964 some 50 nerve injuries of the upper limb were examined and treated at the Department of Orthopaedic Surgery, University Hospital, Lund. Not few of the patients had total or partial ulnar nerve lesions. Some of the total ulnar lesions were not studied primarily with the author's technique. This was because the primary injury was so extensive that loss of ulnar function could not be fully measured. Other ulnar nerve lesions were associated with tendon lesions and/or fractures. Some of them were associated with median nerve injury. Some of the injuries occurred in children who were difficult to examine. This left 11 patients (Table 29). All of them had total lesion of the ulnar nerve with the exception of the patients in cases 2 and 11 who had total lesion of only the motor branch of the ulnar nerve. The material consisted of 10 men and 1 woman, aged 7—68 years. The injuries involved zone I to zone III. In none of them was zone IV injured. In case 3 (KEN ♂ 48 years) there may have been a Martin-Gruber anastomosis. After induction of low ulnar block distally in zone III the value for the pinching grip dropped from 105 to 40 degrees.

Table 29 and Fig. 52 show some agreement between the values measured in the 11 patients with total motor injury of the ulnar nerve compared with the block values noted in the volunteers. In this comparison, however, it should be borne in mind that the clinical material with ulnar injury is heterogeneous and that the figures are only rough means. Nor were the measurements always made under standardised conditions. Even if these factors be considered, it would appear justified to give the arithmetic means for 11 patients with injury of the motor branch of the ulnar nerve alongside of the normal and blocked values, see Fig. 52.

SUMMARY

In 11 patients with total ulnar nerve injury in various zones the average values found for strength of the pinching grip, palmar adduction of the thumb, radial abduction of the index finger and ulnar abduction of the little finger tended to resemble those found in subjects with induced ulnar

Table 29. Clinical cases with ulnar nerve paralysis

No.	Pat.	Age	Sex	Zone	PINCH	ADD POLL	ABD II	ABD V
1	VS	68	♂	III	45	20	—	—
2	AH	60	♂	III	42	20	0	0
3	KEN	48	♂	I	105/40	25	40	0
4	GG	45	♂	I	43	31	15	10
5	AP	32	♂	III	46	14	0	—
6	KA	18	♂	III	28	48	30	18
7	HA	15	♂	I	35	30	20	—
8	AP	14	♀	II	45	45	5	12
9	SG	11	♂	II	45	10	12	0
10	KJ	10	♂	III	15	40	10	16
11	SC	7	♂	III	45	19	10	2
Highest		68		I	46	48	40	18
Lowest		7		III	15	10	0	0

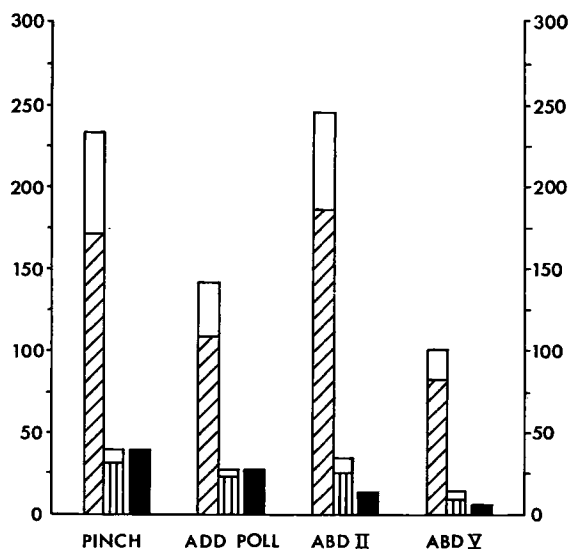


Fig. 52.



Arithmetic mean of median values of 3 measurements in each subject in each test under normal conditions.



Arithmetic mean of median values of 3 measurements in each subject in each test in high ulnar block.



Arithmetic mean of entire clinical series.

block. The clinical series was small, inhomogeneous and not always measured under standardised conditions. It was nevertheless considered justified to include it in the present investigation for comparison.

General discussion and conclusions

The hand is supplied by three main nerves, the radial, the median and the ulnar nerve.

During the first world war the most commonly damaged nerve in the upper limb was the radial nerve (Pollock 1919, Foerster 1929) but during the second world war and also in modern civil practise, it was the ulnar nerve — af Björkesten (1947), Woodhall (1947), Zachary (1954), Zachary and Roaf (1954), Nicholson and Seddon (1957), Bateman (1962), Mumenthaler and Schliack (1965). This difference can be explained by advances made in our knowledge of the anatomy and function of the hand. In other words, the diagnosis of lesions of the median and ulnar nerves has improved.

No systematic study of the residual capacity of the hand in ulnar nerve paralysis seems to be available. The reason for this is at least twofold: the lack of an adequate method for estimation of loss of strength of muscles governed by the nerve and a lack of a uniform series with ulnar nerve paralysis.

Mumenthaler (1961) in his monograph on ulnar nerve palsy refers to more than 350 papers concerning ulnar nerve lesions, but the published series are either too small or too inhomogenous to serve as a reliable basis for judging the residual capacity of the hand in ulnar nerve paralysis.

To overcome these disadvantages, in the present investigation a dynamometer was designed and measurements were made under standardised conditions in a control group of 100 healthy persons studied twice, once on day 1 and again on day 13. The isometric strength of the following grips and movements was determined: pinching grip, palmar adduction of the thumb, radial abduction of the index finger, adduction in the second and fourth interspaces and ulnar abduction of the little finger. The values obtained were used as references in the evaluation of the residual capacity of some functions of the hand in ulnar nerve paralysis in a group of 40 volunteers investigated 3 times, *viz.* on days 1, 7 and 13. On day 7 intra-neural block of the ulnar nerve was induced at the level of the elbow with a local anesthetic, 1 % Carbocain® without adrenalin. A special technique was devised to check that the ulnar nerve block was complete. When

supramaximal stimuli proximal to the nerve block did not produce action potentials in the abductor digiti quinti muscle or in the musculature of the first dorsal interosseus, the nerve block was said to be complete. Nevertheless, some objections against this technique could be raised. Therefore a more refined pilot test was performed, which showed that the technique used was satisfactory.

With the measuring technique used the residual capacity proved to be much lower than that formerly believed. Thus, af Björkstén (1947) and Bunnell (1956) estimated the residual capacity of a hand in ulnar nerve paralysis as half or a third of normal. The figures in the present investigation showed that the residual capacity of the pinching grip and of palmar adduction of the thumb was 17—20 % of normal. Although these measurements were made during acute ulnar nerve paralysis, they indicate a higher sensitivity of the measuring technique used. The error of method was small and acceptable.

In 6 of the 40 persons repeated injections failed to induce ulnar nerve paralysis. A Martin-Gruber anastomosis was suspected and all 6 subjects were given an additional ulnar nerve block in the region of the wrist. Four of the subjects proved to have a true Martin-Gruber anastomosis. In the fifth such an anastomosis was probable, and in the sixth it could not be excluded. This Martin-Gruber anastomosis, which was first described in 1763 by the Swedish anatomist Martin, passes between the median and the ulnar nerve in the forearm. Despite serious later attention (Gruber 1870, Borchart and Wjasmanski 1917 and Ranschburg 1917) the nature of the anastomosis, *i.e.* which end organs it finally supplies, remained obscure. With the technique used in the present investigation the anastomosis was sometimes seen to supply the first dorsal interosseus and/or the abductor pollicis muscles. Moreover, in one or two cases it could not be excluded that the anastomosis supplied also the musculature of the abductor digiti quinti. These findings have also been published in a preliminary report (Mannerfelt 1964). Goldner and Jones (1966) reported some instances of the anastomosis, but otherwise the clinical literature on this important communication between the median and ulnar nerves in the forearm is meagre. The occasional rapid regeneration after suturing of an ulnar nerve severed at the level of the elbow can doubtless be explained by the presence of this anastomosis. The technique described for demonstrating the presence of such an anastomosis is simple and reliable.

There is also another sort of anomalous innervation of importance, *viz.* the so called Riche-Cannieu anastomosis running between the motor branch of the median nerve and the deep branch of the ulnar nerve in the radial part of the hand. It has been described by several authors (Turner 1874, Riche 1897, Cannieu 1897, Ranschburg 1917, Gehwolf 1921, Foerster

1929), but it is still an open question whether it is of sensory, motor or mixed function. Nor is it known whether the anastomosis is a constant phenomenon. Finally, it is of interest to know whether the nerve passes from the ulnar to the median nerve or in the opposite direction. Judging from the literature, these problems are still unsolved. In the present series of 40 ulnar nerve blocks possibly one subject might have had such an anastomosis. To form a personal opinion of this anastomosis, 9 hands were dissected and studied with special reference to the ulnar nerve. A Riche-Cannieu anastomosis was found in 3 of them. The conjugation undoubtedly connected the deep motor ulnar branch with the motor branch of the median nerve. In a fourth specimen there was a double innervation of the adductor pollicis muscle: it received nerve fibres from the ulnar as well as from the median nerve. This supports Foerster's (1929) opinion that the anastomosis is of motor type. The number of specimens dissected was not large enough to allow any conclusions on the frequency of the Riche-Cannieu anastomosis. Nor could it be decided whether the anastomosis passes from the ulnar to the median nerve or in the opposite direction. Many of the problems bearing on the Riche-Cannieu anastomosis must therefore abide further research.

It is known (Bunnell 1956) that certain grips are stronger when the wrist is in slight dorsal extension — "position of function". Measurements of the strength of the *pinching grip*, *palmar adduction of the thumb* and *radial abduction of the index finger* were therefore made with the wrist joint in different degrees of volar flexion and dorsal extension. With the exception of the hyperextended position the strength of the pinching grip did not vary with the angle of the wrist. This was so both in the control series and in the group with ulnar nerve block. The strength of the pinching grip can therefore be measured regardless of the angulation of the wrist joint within the limits of 30° volar flexion and 50° dorsal extension.

Concerning the strength of *palmar adduction of the thumb* in ulnar nerve paralysis, it decreased as volar flexion approached its maximum. This was because of the radial shift of the extensor pollicis longus tendon on increasing volar flexion of the wrist joint. This phenomenon is analysed below in connection with the discussion of substituent muscles in ulnar paralysis and palmar adduction of the thumb.

The values found for *radial abduction of the index finger in ulnar nerve paralysis* tended to decrease with increasing volar flexion of the wrist joint. This might have been due to a reduction of the strength of the long extensors in this position of the wrist joint.

The values found for the pinching grip and palmar adduction of the thumb thus lend no support to the widely accepted view that the hand

is strongest when the wrist is in slight dorsal extension. It should, however, be borne in mind that this refers to grasping of larger objects with long flexors of the hand. Therefore the values obtained in the present investigation cannot be used to illustrate the question under discussion.

The *strength of adduction in the second interspace* varies with the flexion of the MP joints. In the flexed position ($=120^\circ$) the strength is greater both in normal conditions and in high ulnar nerve block. This is partly because of the decreased strength of the long extensors and partly because of additional adduction by the long flexors.

In ulnar nerve paralysis the *strength of adduction in the fourth interspace* is nil. This is because of paralysis of the 3rd volar interosseus. Long flexors of the little finger can obviously not substitute any adducting force. The pull in ulnar direction by the long extensors when the MP joint is in extended position also deserves mentioning.

Ulnar abduction of the little finger is stronger when MP joint V is extended than when it is flexed ($=120^\circ$), for then it is nil. This can presumably be explained by a weakening of the long extensors when the MP joint V is flexed, and by tightening of the collateral ligaments. This applies to normals and to subjects with ulnar nerve paralysis, where also the short abductor and the short flexor are functionless.

The investigation included a picking-up test (Moberg 1958), and the time required by the subjects to perform the test was recorded. The results clearly showed that a person with ulnar nerve paralysis has great difficulties to perform precision movements in the dark or when he must do something with his hand without being able to see what he is doing, *e.g.* screwing nuts and bolts in positions hidden from view. The picking-up test is not used consequently before on time and during standardised conditions. The values obtained in the author's control series could therefore be used as a sort of normal values for male and female persons between 18 and 30 years under the conditions used.

Perusal of the literature failed to reveal any analysis of palmar adduction movement of the thumb, *i.e.*, the position of the axis of movement, extrinsic muscles that can substitute the adduction of the thumb in ulnar nerve paralysis, and variation, if any, in the strength of the palmar adduction of the thumb with increasing volar flexion of the wrist joint in ulnar nerve paralysis. For this purpose 14 specimens, fresh enough to allow adduction movements, were dissected. The CMC joint I was also dissected with special reference to the ligament apparatus. Analysis of these preparations and of roentgenograms and electromyograms of volunteers and of patients with ulnar nerve paralysis revealed that on palmar adduction of the thumb the base of the first metacarpal glided in radial direction in the CMC joint I both in normal conditions and in ulnar nerve

paralysis. The axis of movement thus lies *not in* the joint but *distal* to it. Studies with ulnar nerve block in patients with rupture of the extensor pollicis longus tendon and on others with lesions of the flexor pollicis longus tendon clearly revealed that the extensor pollicis longus and not the flexor pollicis longus is the adductor substituent of the thumb in ulnar nerve paralysis and thereby confirmed the opinion of Fick (1845), Duchenne (1867), Babinski and Froment (1918), Boyes (1935), Kaplan (1965) and Bunnell (1956) and disproved the view of inter alia Villiger-Ludwig (1946), Wartenberg (1953), v. Lanz-Wachsmuth (1959), Bowden and Napier (1961) and Mc Farlane (1962) that the flexor pollicis longus is the adductor substitute in ulnar nerve paralysis. Finally, it was found that strength of the adduction exerted by the extensor pollicis longus in ulnar nerve paralysis decreases to practically nil as volar flexion of the wrist joint approaches maximum. This is because in maximum volar flexion the tendon of extensor pollicis longus shifts radially on or past the axis of movement. This was also shown by cineradiography after injection of barium contrast into the tendon sheath of the extensor pollicis longus in a patient with ulnar nerve paralysis.

The onset and disappearance of the ulnar nerve block was studied on the motor side and on the sensory side. Thus Wartenberg's sign and Sunderland's sign (motor paralysis) occurred earlier than loss of sensibility in the distal volar part of the little finger. Motor function returned sooner than full sensibility.

Concerning the area of sensory loss after high ulnar block, the findings in the present investigation were not entirely in accord with common anatomical textbooks. This was the case regarding the dorsal and ulnar part of the long finger, where none of 32 blocked and specially investigated subjects had sensory loss. In anatomical text books e.g. Villiger and Ludwig (1946) and v. Lanz-Wachsmuth (1959) sensory loss in ulnar nerve paralysis also involves the dorsal and ulnar part of the long finger.

An important question is whether intraneural blocks with 1 % Carbo-cain® without adrenalin is followed by any sequelae. A nerve block is useful in the investigation of ulnar nerve paralysis and has been used to evaluate local anesthetics (Dhunér, Edshage and Wilhelm 1960, Albért and Löfström 1961). In the present investigation all 41 volunteers subjected to intraneural blocks were re-examined 6 days after injection of the local anesthetic. Only one complained of pain at the site of injection some weeks after the nerve block but at re-examination some weeks later both the conduction velocity of the ulnar nerve and electromyographic studies of muscles governed by the nerve appeared to be normal, besides which the pain had disappeared. In all 41 subjects except in some females the strength of the muscles studied was the same before, as 6 days after, the intra-

neural block. These few females were re-examined 6 months later and then the strength of the muscles was the same as before the block. It may therefore be concluded that intraneural block with a fine needle in the ulnar nerve at a level just above the sulcus nervi ulnaris with a reasonable amount of 1 % Carbocain® without adrenalin will cause no sequelae.

Eleven patients with post-traumatic ulnar nerve paralysis were investigated. The examination included measurements with the dynamometer but not always under standardised conditions. Although the ages of these patients varied widely as well as the level of the lesions, the values obtained were fairly similar to those recorded in the ulnar nerve block group. This means that artificially induced ulnar nerve paralysis by intraneural injection of a suitable local anesthetic in volunteers can be used with advantage in the elucidation of clinical ulnar nerve paralysis.

Summary

1. The ulnar nerve is the most frequently injured nerve in the upper extremity.
2. A special dynamometer was constructed to measure the strength of certain grips and muscles governed by the ulnar nerve.
3. Normal values were calculated from measurements made with the dynamometer in a control group consisting of 100 healthy volunteers under standardised conditions.
4. These values were used as reference in the evaluation of the residual capacity of some functions of the hand in ulnar nerve paralysis. The paralysis was induced with a local anesthetic (1 % Carbocain® without adrenalin) injected intraneurally into the nerve in 40 volunteers.
5. A special electromyographic technique, never used before for this purpose, was applied to check that the ulnar block was complete.
6. The residual strength of the pinching grip and of palmar adduction of the thumb was 17—20 % of the normal, which is lower than what is widely believed.
7. In 6 of the 40 subjects a Martin-Gruber anastomosis in the forearm was demonstrated or suspected. The possible existence of this anastomosis must be borne in mind in the investigation of peripheral nerve injuries in the arm or hand.
8. Measurement of the pinching grip with the dynamometer can be performed with the wrist between 30° of flexion and 50° of extension without influencing the accuracy of the method both in normal conditions and in ulnar nerve paralysis.
9. In ulnar nerve paralysis palmar adduction of the thumb is low or nil when the wrist joint is in maximum volar flexion. This is due to the radial shift of the extensor pollicis longus tendon towards the radial side during volar flexion of the wrist joint.
10. In ulnar nerve paralysis the substituent muscle in the adduction movement of the thumb is the extensor pollicis longus muscle and not the flexor pollicis longus muscle.
11. The axis of movement in the palmar adduction of the thumb lies not in the carpometacarpal joint I but distally to it.

12. A picking-up test according to Moberg (1958) was used and timed to determine the residual capacity of some grip functions of the hand in ulnar nerve paralysis. The results showed that the working capacity of the hand when hidden from view is severely impaired in ulnar nerve paralysis.
13. Intraneural block with a reasonable amount of 1 % Carbocain® without adrenalin at the level of the elbow is not followed by any sequelae.
14. The residual capacity of some hand functions in patients with post-traumatic ulnar nerve paralysis was about the same as in experimentally induced ulnar nerve paralysis in healthy volunteers.

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References

- Albért, J. and Löfström, B.: Bilateral ulnar nerve blocks for the evaluation of local anaesthetic agents. *Acta anaesth scand* 1961, 5, 99—105.
- André-Thomas, T.: Le tonus du poignet dans la paralysie du nerf cubital. *Paris méd* 1917, 25, 473—476.
- Asmussen, E., Heebøll-Nielsen, K., Molbech, S. V.: Methods for evaluation of muscle strength. *Communications from the testing and observation institute of the Danish national association for infantile paralysis*, 1959, 5.
- Asmussen, E. and Heebøll-Nielsen, K.: Isometric muscle strength of adult men and women. *Communications from the testing and observation institute of the Danish national association for infantile paralysis*, 1961, 11.
- Babinski, J. and Froment, J.: Les signes objectifs de la paralysie de l'adducteur du pouce. *Rev Neurol*, 1918, 1, 484—487.
- Barthold, G.: Die handchirurgische Bedeutung und Diagnostik des ulnaren Canalis carpi. *Zbl Chir*, 1960, 17, 696—703.
- Bateman, J. E.: *Trauma to nerves in limbs*. W. B. Saunders Co., Philadelphia and London 1962.
- Beasley, W. C.: Instrumentation and equipment for quantitative clinical muscle testing. *Arch Physiol Med*, 1956, 37, 604—621.
- Beasley, W. C.: Quantitative muscle testing: Principles and applications to research and clinical services. *Arch Physiol Med*, 1961, 42, 398—425.
- Bechtol, C. O.: The use of dynamometer with adjustable hand spacings. Grip test. *J Bone Joint Surg*, 1954, 36 A, 820—824, 832.
- af Björkesten, G.: Position of fingers and function deficiency in ulnar paralysis. *Acta chir scand*, 1946, 93, 99—110.
- af Björkesten, G.: Suture of war injuries to peripheral nerves. Clinical studies of results. *Acta chir scand*, 1947, suppl 119.
- Bodechtel, G., Krautzunk, K. and Kazmeier, F.: *Grundriss der traumatischen peripheren Nervenschädigungen*. Mit Berücksichtigung der Berufskrankheiten. (Vom neurologischen Standpunkt aus gesehen.) Georg Thieme, Stuttgart, 1951, 2 Aufl.
- Bonica, J. J.: *Clinical applications of diagnostic and therapeutic nerve blocks*. Charles C. Thomas, Springfield, Illinois, 1959.
- Borchardt, M. and Wjasmanski, H.: Der Nervus medianus. *Beitr Klin Chir* (Bruns), 1917, 107, 553—582.
- Bowden, R. E. M. and Napier, J. R.: The assessment of hand function after peripheral nerve injuries. *J Bone Joint Surg*, 1961, 43 B, 481—492.
- Boyes, J. H.: Rupture of tendons. Report of four cases of latent rupture of the tendon of the extensor pollicis longus. *West J Surg Obstet Gynec*, 1935, 43, 442—445.

- Boyes, J. H.: Bunnell's surgery of the hand. *J. B. Lippincott Co.*, Philadelphia, 1964.
- Braithwaite, F., Channell, G. D., Moore, F. T. and Whillis, J.: Applied anatomy of the lumbrical and interosseus muscles of the hand. *Guy's Hosp Rep*, 1948, 97, 185—195.
- Brahme, L.: A new constructed ergodynamometer and its clinical use. *Acta med scand*, 1936, 89, 268—282.
- Brash, J. C.: *Neurovascular hila of limb muscles*. E. S. Livingstone Ltd, Edinburgh and London, 1955.
- Broman, T.: Can a refined method be of importance in clinical investigations of sensibility? *Nord Med*, 1945, 27, 1801—1804 (Swedish).
- Brooks, H. St. J.: Variations in the nerve supply of the flexor brevis pollicis muscle. *J Anat Physiol*, 1886, 20, 641—644.
- Brooks, H. St. J.: Variations in the nerve supply of the lumbrical muscles in the hand and foot, with some observations on the innervation of the perforating flexors. *J Anat Physiol*, 1887, 21, 575—585.
- Bruner, J. M.: Tendon transfer to restore abduction of the index finger using extensor pollicis brevis. *Plast reconstr Surg*, 1948, 3, 197—201.
- Bunnell, S.: *Surgery of the hand*. J. B. Lippincott Co., Philadelphia, 1956, 3rd Ed.
- Calder, F. W. G.: Effects of division of the ulnar nerve. *Lancet*, 1832/33, I, 489—490.
- Cannieu, J. M. A.: Recherches sur l'innervation de l'éminence thénar par le cubital. *J Méd Bordeaux*, 1896, 377—379.
- Cannieu, J. M. A.: Note sur une anastomose entre la branche profonde du cubital et le median. *Bull Soc d'Anat Physiol Bordeaux*, 1897, 18, 339—340.
- Chase, R. N., Brandom-Macomber, W. and Wang, M. K.: Hand Surgery: An appraisal of peripheral nerve block. *Plast reconstr Surg*, 1959, 24, 255—261.
- Chusid, J. G. and McDonald, J. J.: Correlative neuroanatomy and functional neurology. *Lange Med Publ, los Altos, California*, 1962, 11th Ed.
- Cliffton, E. E.: Unusual innervation of the intrinsic muscles of the hand by median and ulnar nerve. *Surgery*, 1948, 23, 12—31.
- Collins, V. J.: *Fundamentals of nerve blocking*. Henry Kimpton, London, 1960.
- Curtis, F.: Recherches anatomiques sur l'anastomose du médian et du cubital à l'avant-bras. *Intern Mschr Anat Physiol*, 1886, 3, 309—324.
- Day, M. H. and Napier, J. R.: The two heads of flexor pollicis brevis. *J Anat*, 1961, 95, 123—130.
- De Lorme, T. L. and Watkins, A. L.: *Progressive resistance exercise*. Appleton-Century-Crofts, Inc New York, 1951.
- Dhunér, K. G., Edshage, S. and Wilhelm, A.: Ninhydrin test — an objective method for testing local anaesthetic drugs. *Acta Anaest Scand*, 1960, 4, 189—198.
- Dole, V. P. and Thaysen, J. H.: Variation in the functional power of human sweat glands. *J Exp Med*, 1953, 98, 129—144.
- Duchenne, G. B. A.: *Physiology of motion*. Transl. and Ed. by Kaplan, E. B. (Physiologie des Mouvements démontrée à l'aide de l'expérimentation électrique et de l'observation clinique et applicable à l'étude des paralysies et des dégénérationes (1867)). W. B. Saunders Co., Philadelphia and London, 1959.
- Ebskov, B. and Bonde Petersen, F.: A new dynamometer for measuring the isometric strength in human finger flexors. *Acta Orthop Scand*, 1963, 33, 176—181.
- Egawa, T.: Electromyographic studies on finger motion. *J Osaka Univ Med School*, 1959, 11, 1739—1758 (Japanese).

- Eyler, D. and Markee, J.: The anatomy and function of the intrinsic musculature of the fingers. *J Bone Joint Surg*, 1954, 36 A, 1—9.
- Fay, T.: Thumb as clinical aid in diagnosis. *J Amer med Ass*, 1954, 155, 729—732.
- Feindel, W. and Stratford, J.: The role of the cubital tunnel in tardy ulnar palsy. *Canad J Surg*, 1958, 1, 287—300.
- Fenton, R. L. and Lapidus, P. W.: An anatomical study of the abductor pollicis longus and extensor pollicis longus and brevis. *Bull Hosp Joint Dis*, 1953, 14, 138—143.
- Fick, L.: *Physiologische Anatomie des Menschen*. Verlag von Christian Ernst Kollman, Leipzig 1845: 1.
- Flemming, W.: Über der flexor brevis pollicis und hallucis des Menschen. *Anat Anz*, 1887, 68.
- Foerster, O.: Die Symptomatologie der Schussverletzungen der peripheren Nerven. In M. Lewandowsky: *Handbuch der Neurologie*. Julius Springer, Berlin, 1929, 2, 975—1508.
- Foerster, O.: Spezielle Anatomie und Physiologie der peripheren Nerven. In M. Lewandowsky: *Handbuch der Neurologie*. Julius Springer, Berlin, 1929, 2, 786—838.
- Foerster, O.: Spezielle Physiologie und spezielle funktionelle Pathologie der quergestreiften Muskeln. In Bumke, O. and Foerster, O.: *Handbuch der Neurologie*. Julius Springer, Berlin, 1937, 3, 1—639.
- Forsell, G.: Über die Bewegungen im Handgelenke des Menschen. Eine röntgenographische Studie. *Skand Arch Physiol*, 1902, 12, 168—258.
- Frank, F.: (1892) as quoted by Collins, V. J. 1960.
- Frohse, F. and Fränkel, M.: *Die Muskeln des menschlichen Armes*. G. Fischer, Jena 1908.
- Froment, J.: La paralysie de l'adducteur du pouce et le signe de la préhension. *Rev Neurol*, 1914—1915, 1236—1240.
- Gassel, M. M.: Sources of error in motor nerve conduction studies. *Neurology*, 1964, 14, 825—835.
- Gedda, K.-O.: Studies on Bennett's fracture. Anatomy, roentgenology and therapy. *Acta Chir Scand*, 1954, Suppl. 193.
- Gehwolf, S.: Weitere Fälle von Plexusbildung in der Hohlhand. *Anat Anz*, 1921, 54, 435—440.
- Goldman, E.: Über des Fehlen von Funktionsstörungen nach des Resektion von peripheren Nerven. *Beitr klin Chir*, 1906, 51, 183—193.
- Goldner, J. L.: Function of the hand following peripheral nerve injuries. *Amer Acad Orthop Surg Instr Course Lectures*, 1953, 10, 268.
- Goldner, J. L. and Jones, W. B.: *Anomalous innervation of the forearm and hand*. 21st Annual Meeting Amer Soc Surg Hand, Chicago 1966.
- Gruber, W.: Über die Verbindung des Nervus medianus mit dem Nervus ulnaris am Unterarme des Menschen und der Säugethiere. *Arch Anat Physiol Med Leipzig*, 1870, 37, 501—522.
- Guyon, F.: Note sur une disposition anatomique propre à la face antérieure de la région du poignet et non encore décrite. *Bull Soc Anat*, Paris 1861, 36, 184—186.
- Haines, R. W.: The mechanism of rotation at the first carpometacarpal joint. *J Anat*, 1944, 78—79, 44—46.
- Halstead, W. S.: (1884) as quoted by Collins, V. J. 1960.

- Haymaker, W. and Woodhall, B.: *Peripheral nerve injuries*. Principles of diagnosis. W. B. Saunders Co., Philadelphia and London 1953.
- Head, H. and Sherren, J.: The consequences of injury to the peripheral nerves of man. In Head: *Studies in neurology*. Oxford University Press, London, 1920.
- Hellebrandt, F. A., Kelso, L. E. A. and Eubank, R. N.: New devices for disability evaluation. *Arch phys Med*, 1950, 31, 201—212.
- Henle, J.: *Handbuch der systematischen Anatomie des Menschen*. Friedrich Vieweg und Sohn, Braunschweig, 1868.
- Hepburn, D.: The comparative anatomy of the muscles and nerves of the superior and inferior extremities of the antropoid apes. *J Anat and Physiol*, 1892, 26, 149—186.
- Hettinger, T.: *Isometrisches Muskeltraining*. George Thieme, Stuttgart, 1964.
- Highet, W. B.: Procaine nerve block in investigation of peripheral nerve injuries. *J Neurol Psychiat*, 1942, 5, 101—116.
- Highet, W. B.: Innervation and function of the thenar muscles. *Lancet*, 1943, 1, 227—230.
- Hilgenfeldt, C.: *Operativer Daumenersatz*. Ferd. Enke, Stuttgart, 1950.
- Hirasawa, K.: Untersuchungen über das periphere Nervensystem, Plexus brachialis und die Nerven der oberen Extremität. *Arb Anat Inst Kaiserlichen Univ Kyoto*, 1931, A: 2, 135—140.
- Hirschlaff-Hjortsjö, C.-H.: Über "Autoanastomosen" im peripheren cerebrä spinalen Nervensystem. *Anat Anz*, 1938, 87, 161—192.
- Hjortsjö, C.-H.: *Rörelseapparaten*. Gleerups, Lund, 1959.
- Hjortsjö, C.-H.: Motion and movements. *Acta Universitatis Lundensis Sectio II* No. 4, 1964.
- Hodes, R., Larrabee, M. G. and German, W.: The human electromyogram in response to nerve stimulation and the conduction velocity of motor axons. *Arch Neurol and Psychiat*, 1948, 60, 340—365.
- Hunsicker, P. A. and Donelly, R. J.: Instruments to measure strength. *Res Quart*, 1955, 26, 408—420.
- Jeanne, M.: La déformation du pouce dans la paralysie cubitale. *Bull mém Soc Chir Paris*, 1915, 41, 703—719.
- Jones, F. Wood: *The principles of anatomy as seen in the hand*. Baillière, Tindall and Cox, London 1949. 2nd Ed. (Reprint).
- Kaplan, E. B.: Variation of the ulnar nerve at the wrist. *Bull Hosp Joint Dis*, 1963, 24, 85—88.
- Kaplan, E. B.: *Functional and surgical anatomy of the hand*. J. B. Lippincott Co., Philadelphia, 1965, 2nd Ed.
- Kendall, H. O. and Kendall, F. P.: *Muscles. Testing and function*. Williams and Wilkins Co., Baltimore, 1949.
- Landsmeer, J. M. F.: Anatomical and functional investigations on the articulation of the human fingers. *Acta anat*, 1955, suppl. 24.
- Landsmeer, J. M. F.: The coordination of finger—joint motions. *J Bone Joint Surg*, 1963, 45 A, 1654—1662.
- v. Lanz T. and Wachsmuth, W.: *Praktische anatomie*. Arm. Springer, Berlin, 1959, 1: 3.
- Lewey, F. H., Kuhn, W. G. and Juditski, J. T.: A standardized method for assessing the strength of hand and foot muscles. *Surg Gynec Obstet*, 1947, 85, 785—793.
- Linell, E. A.: The distribution of nerves in the upper limb with reference to variabilities and their clinical significance. *J Anat*, 1921, 55, 91—97.

- Lipscomb, P. R.: Stenosing tenosynovitis at radial styloid process (Quervain's Disease). *Ann Surg*, 1951, 134, 110—115.
- Littler, J. W.: *Median and ulnar nerve injuries*. Wiederherstellungschir u Traum 1952, 1, 227—240.
- Lovett, R. W. and Martin, E. G.: The spring balance muscle test. *Amer J orthop Surg*, 1916, 14, 415—424.
- McFarlane, R. M.: Observations on the functional anatomy of the intrinsic muscles of the thumb. *J Bone Joint Surg*, 1962, 44 A, 1073—1088.
- Mannerfelt, L.: Studies of ulnar nerve injuries by means of a new special ergometer. *Acta orthop scand*, 1961, 31, 194—196.
- Mannerfelt, L.: Evaluation of functional sensation of skin grafts in the hand area. *Brit J plast Surg*, 1962, 25, 136—154.
- Mannerfelt, L.: Studies on an anastomosis between the median and ulnar nerves in the forearm. *Acta Universitatis Lundensis Sectio II* No. 6, 1964.
- Mannerfelt, L.: Analysis of pinching grip in normal conditions and in ulnar nerve paralysis. To be published.
- Marinacci, A. A.: Diagnosis of all median hand. *Electromyography*, 1964, 4, 85—93.
- Martin, R.: *Tal om Nervers allmänna Egenskaper i Människans kropp*. L. Salvius, Stockholm 1763.
- Martin, E. G.: Tests of muscular efficiency. *Physiol Rev*, 1921, 1, 454—475.
- Masse, L.: Contribution à l'étude de l'action des interosseux. *J Méd Bordeaux*, 1916, 46, 198—200.
- Matson, D. D.: Early neurolysis in the treatment of injury of peripheral nerves due to faulty injection of antibiotics. *New Engl J Med*, 1950, 242, 973—975.
- Minor, V.: Ein neues Verfahren zu der Klinischen Untersuchung der Schweissabsonderung. *Dtsch Z Nervenheilk*, 1928, 101, 302—308.
- Moberg, E.: Några handkirurgiska hjälpmedel. *Nord Med*, 1948, 40, 2328—2329.
- Moberg, E.: Objective methods for determining the functional value of sensibility in the hand. *J Bone Joint Surg*, 1958, 40 B, 454—476.
- Moberg, E.: Criticism and study of methods for examining sensibility in the hand. *Neurology*, 1962, 12, 8—19.
- Moberg, E.: Aspects of sensation in reconstructive surgery of the upper extremity. *J Bone Joint Surg*, 1964, 46 A, 817—825.
- Mondry, F.: Beitrag zur operativen Behandlung des Wackeldaumes. *Zbl Chir*, 1940, 67, 1532—1535.
- Monrad-Krohn, G. H.: *Clinical examination of the nervous system*. Lewis Co., Ltd, London 1948, 9th Ed.
- Moore, D. C.: *Regional block*. Charles C. Thomas, Springfield, Illinois, 1961, 3rd Ed.
- Moritz, U.: Electromyographic studies in adult rheumatoid arthritis. *Acta rheum scand*, 1963, suppl 6.
- Mumenthaler, M.: *Die Ulnarisparese*. G. Thieme, Stuttgart, 1951.
- Mumenthaler, M. and Schliack, H.: *Lesionen peripherer Nerven*. G. Thieme, Stuttgart, 1965.
- Murphey, F., Kirklin, J. W. and Finlayson, A. I.: Anomalous innervation of intrinsic muscles of hand. *Surg Gynec Obstet*, 1946, 83, 15—23.
- Napier, J. R.: The form and function of the carpometacarpal joint of the thumb. *J Anat*, 1955, 89, 362—369.
- Newman, L. B.: A new device for measuring muscle strength. The myometer. *Arch phys Med*, 1949, 30, 234—237.
- Nicholson, O. R. and Seddon, H. J.: Nerve repair in civil practice. *Brit med J*, 1957, 2, 1065—1071.

- Pitres, A. and Testut, L.: *Les nerfs en schemas*. Doin, Paris 1925.
- Pollock, L. J.: Supplementary muscle movements in peripheral nerve lesions. *Arch Neurol Psychiat*, 1919, 2, 518—531.
- de Quervain, F.: Über das Wesen und die Behandlung der stenosierender Tendonvaginits am Processus styloideus radii. *Münch med Wschr*, 1912, 59, 5—6.
- Ranschburg, P.: "Über die Anastomosen der oberen Extremität des Menschen mit Rücksicht auf ihre neurologische und Nerven chirurgische Bedeutung." *Zbl Neurol*, 1917, 13, 521—534.
- Regnier, J. B.: *Considérations sur la force musculaire, suivies de la description et de l'exposition chalcographique d'un nouvel instrument pour mesurer cette force*. Diss. Paris 1807.
- Remak, E.: Zur vicariierenden Function peripherer Nerven des Menschen. *Berlin klin Wschr*, 1874, 48—49, 601—604, 615—619.
- Riche, P.: Le nerf cubital et les muscles de l'éminence thénar. *Bull mém Soc anat Paris*, 1897, 5, 251—252.
- Rowntree, T.: Anomalous innervation of the hand muscles. *J Bone Joint Surg*, 1949, 31 B, 505—510.
- Rud, J.: Local anesthetics. An electrophysiological investigation of local anesthesia of peripheral nerves, with special reference to xylocaine. *Acta physiol scand*, 1961, suppl. 178.
- Saikku, L. A.: Tendon transplantation for radial paralysis. *Acta chir scand*, 1947, suppl 132.
- Salter, N. and Darcus, H. D.: The effect of the degree of elbow flexion on the maximum torques developed in pronation and supination of the right hand. *J Anat*, 1952, 86, 197—202.
- Spourigitis, J.: Sur un rameau musculaire très rare fourni par le nerf cubital. *Bull mém Soc Anat*, Paris 1895, 9, 410.
- Ssokolow, P. A.: *Anastomosen zwischen dem N. medianus und ulnaris am Vorderarm und der Hand*. Iswjetija Donsk. Univers. 5, 1925 (cit. in Anat Bericht, 1926, 5).
- Stack, G. H.: Muscle function in the fingers. *J Bone Joint Surg*, 1962, 44 B, 899—909.
- Stein, A. H. Jr.: Variations of the tendons of insertion of the abductor pollicis longus and the extensor pollicis brevis. *Anat Rec*, 1951, 110, 49—55.
- Stener, B.: Displacement of the ruptured ulnar collateral ligament of the metacarpophalangeal joint of the thumb. A clinical and anatomical study. *J Bone Joint Surg*, 1962, 44 B, 869—879.
- Stopford, J. S. B.: The variation in distribution of the cutaneous nerves of the hand and digits. *J Anat*, 1918, 53, 14—25.
- Strandell, G.: Posttraumatic rupture of the extensor pollicis longus tendon. Pathogenesis and treatment. *Acta chir scand*, 1955, 109, 81—96.
- Strandell, G.: Total rupture of the ulnar collateral ligament of the metacarpophalangeal joint of the thumb. *Acta chir scand*, 1959, 118, 72—80.
- Sunderland, S.: The significance of hypothenar elevation in movements of opposition of the thumb. *Aust NZ J Surg*, 1944, 13, 155—156.
- Sunderland, S.: *The intraneural topography of the radial, median and ulnar nerves*. Brain 1945, 68, 243—299.
- Sunderland, S. and Hughes, E. S. R.: Metrical and non-metrical features of muscular branches of ulnar nerve. *J comp Neurol*, 1946, 85, 113—123.
- Tornvall, G.: Assessment of physical capabilities. *Acta physiol scand*, 1963, suppl 201.

- Tubiana, R. and Valentin, P.: The anatomy of the extensor apparatus of the fingers. *Surg Clin N Amer*, 1964, 44, 897—906.
- Turner, W.: Further examples of variation in the arrangement of the nerves of the human body. *J Anat Physiol*, 1874, 8, 297—299.
- Valone, J. A.: Paralysis of the ulnar nerve and management of its deformity. With suggestion for temporary partial blockage during recovery. *J Neurosurg*, 1953, 10, 138—144.
- Villiger, E. and Ludwig, E.: *Die periphere Innervation*. Schwabe und Co., Basel 1946.
- Wainerdi, H. R.: Simple ergometers for measuring the strength of the hand grip. *J Amer med Ass*, 1950, 144, 619—620.
- Wartenberg, R.: A sign of ulnar palsy. *J Amer med Ass*, 1939, 112, 1688.
- Wartenberg, R.: *Diagnostic test in neurology — a selection for office use*. Monogr. The Year book publishers, Inc., Chicago 1953.
- Whipple, G. M.: *Manual of mental and physical tests*. Warwick and York, Inc., Baltimore, 1914, 2d Ed.
- Wiberg, G.: Quervains tendovaginit som olycksfallspåföljd. *Nord Med*, 1941, 10, 1929—1933.
- Woodhall, B.: Peripheral nerve injuries: basic data from peripheral nerve registry concerning 7,050 nerve sutures and 67 nerve grafts. *J Neurosurg*, 1947, 4, 146—163.
- Wright, V.: Factors influencing diurnal variation of strength of grip. *Res Quart*, 1959, 30, 110—116.
- Zachary, R. B.: Results of nerve suture in peripheral nerve injuries. In H. J. Seddon (Ed): *Peripheral nerve injuries*. Med. res. council special report series No. 282, 354—388. Her Majesty's Stationery Office, London 1954.
- Zadig, A.: Objektiv muskeltestning. *Sjukgymnasten*, 1962, 20, 5—11.
- Zancolli, E. A.: Claw-hand caused by paralysis of the intrinsic muscles. *J Bone Joint Surg*, 1957, 39 A, 1076—1080.
- Zoth, O.: Ergographie und Ergometrie. In *Handbuch der biologischen Arbeitsmethoden*. Herausgeg. E. Abderhalden 1936, 5 A, 171—244.
- Önne, L.: Recovery of sensibility and sudomotor activity in the hand after nerve suture. *Acta chir scand*, 1962, Suppl 300.

Tables

Table 30. Mean values pinching grip
group ♂ I—V

Position of wrist joint		+70°			+50°			+30°			±0°			—30°		
Sex	Day	N	M	s	N	M	s	N	M	s	N	M	s	N	M	s
♂	1	5	156	46	5	181	49	5	195	35	5	203	47	5	210	41
	7 A	5	164	30	5	208	20	5	214	24	5	229	49	5	221	34
	7 B	5	37	6	5	30	8	5	34	6	5	35	5	5	35	10
	13	5	161	28	5	230	39	5	257	28	5	254	26	5	263	38

Table 31. Mean values palmar adduction of thumb
group ♂ I—V

Position of wrist joint		+50°			+30°			±0°			—30°			—50°		
Sex	Day	N	M	s	N	M	s	N	M	s	N	M	s	N	M	s
♂	1	5	118	27	5	129	22	5	130	33	5	131	42	5	126	37
	7 A	5	127	23	5	136	47	5	144	45	5	152	51	5	144	43
	7 B	5	36	9	5	30	9	5	36	5	5	27	13	5	23	18
	13	5	131	28	5	144	32	5	150	35	5	147	33	5	141	38

Table 32. Mean values radial abduction of index finger
group ♂ I—V

Position of wrist joint		+30°			±0°			—30°		
Sex	Day	N	M	s	N	M	s	N	M	s
♂	1	5	176	27	5	192	33	5	167	33
	7 A	5	214	24	5	215	28	5	196	22
	7 B	5	51	21	5	44	14	5	32	8
	13	5	210	31	5	222	32	5	204	27

Table 33. Mean values adduction in second interspace group ♂ I—V

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	5	89	19	5	121	30
	7 A	5	105	28	5	148	29
	7 B	5	20	8	5	31	10
	13	5	124	29	5	152	27

Table 34. Mean values adduction in fourth interspace group ♂ I—V

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	5	80	28	5	104	29
	7 A	5	64	14	5	105	12
	7 B	5	0	0	5	0	0
	13	5	58	18	5	103	7

Table 35. Mean values ulnar abduction of little finger group ♂ I—V

MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	5	93	17	5	84	13
	7 A	5	94	23	5	84	11
	7 B	5	16	9	5	0	0
	13	5	100	16	5	97	14

Table 36. Mean values pinching grip
groups ♂ 1—25 and ♀ 1—10

Position of wrist joint		+70°			+50°			+30°			±0°			—30°		
Sex	Day	N	M	s	N	M	s	N	M	s	N	M	s	N	M	s
♂	1	15	162	33	15	230	56	17	233	57	15	241	53	15	225	49
	7 A	15	156	35	15	231	42	17	235	45	15	220	50	15	211	46
	7 B	15	31	12	15	34	11	17	39	12	15	39	15	15	37	13
	13	15	150	29	15	228	39	17	242	46	15	233	47	15	225	50
♀	1	9	123	39	9	164	39	9	171	36	9	171	35	9	163	30
	7 A	9	109	33	9	159	26	9	175	28	9	166	27	9	161	40
	7 B	9	29	11	9	30	9	9	30	11	9	29	7	9	30	8
	13	9	97	33	9	148	26	9	172	37	9	157	26	9	146	27

Table 37 Mean values palmar adduction of thumb
groups ♂ 1—25 and ♀ 1—10

Position of wrist joint		+50°			+30°			±0°			—30°			—50°		
Sex	Day	N	M	s	N	M	s	N	M	s	N	M	s	N	M	s
♂	1	16	121	31	16	135	31	18	141	31	16	139	37	16	125	35
	7 A	16	123	32	16	142	44	18	152	39	16	147	42	16	133	36
	7 B	16	30	13	16	26	6	18	27	9	16	22	11	16	17	11
	13	16	120	31	16	130	33	18	144	34	16	137	38	16	129	35
♀	1	9	98	26	9	107	29	9	109	26	9	110	27	9	102	27
	7 A	9	102	20	9	113	25	9	113	27	9	116	30	9	109	26
	7 B	9	28	13	9	26	11	9	25	12	9	26	11	9	23	11
	13	9	94	24	9	107	25	9	114	21	9	107	26	9	96	19

Table 38. Mean values radial abduction of index finger groups ♂ 1—25 and ♀ 1—10

Position of wrist joint		+30°			±0°			—30°		
Sex	Day	N	M	s	N	M	s	N	M	s
♂	1	16	252	34	18	245	40	16	213	38
	7 A	16	234	23	18	238	33	16	211	27
	7 B	16	34	20	18	34	17	16	25	15
	13	16	242	34	18	247	35	16	225	28
♀	1	9	187	35	9	186	38	9	168	23
	7 A	9	189	31	9	196	35	9	181	34
	7 B	9	28	8	9	25	9	9	23	11
	13	9	177	42	9	190	40	9	181	41

Table 39. Mean values adduction in second interspace groups ♂ 1—25 and ♀ 1—10

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	15	94	19	15	138	28
	7 A	15	104	24	15	144	35
	7 B	15	28	12	15	43	13
	13	15	109	15	15	150	32
♀	1	9	91	13	9	116	19
	7 A	9	92	10	9	121	17
	7 B	9	22	9	9	33	17
	13	9	85	17	9	112	21

Table 40. Mean values adduction in fourth interspace groups ♂ 1—25 and ♀ 1—10

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	16	66	22	16	97	23
	7 A	16	61	13	16	93	15
	7 B	16	0	0	16	0	0
	13	16	67	17	16	97	14
♀	1	9	52	22	9	78	21
	7 A	9	56	18	9	78	16
	7 B	9	0	0	9	0	0
	13	9	49	18	9	81	13

Table 41. Mean values ulnar abduction of little finger groups ♂ 1—25 and ♀ 1—10

Position of MP joint		180°			120°		
Sex	Day	N	M	s	N	M	s
♂	1	16	101	19	16	88	19
	7 A	16	99	21	16	85	18
	7 B	16	14	10	16	0	0
	13	16	102	17	16	93	17
♀	1	9	83	9	9	73	11
	7 A	9	82	13	9	70	16
	7 B	9	9	6	9	0	0
	13	9	80	12	9	71	28