

ON THE TREATMENT OF RADIAL PALSY BY TENDON TRANSPLANTATION

BY

KAJ RØJEL

The treatment of a traumatic radial paralysis which shows no evidence of spontaneous recovery is, in the first instance, operation on the nerve, that is to say, either neurolysis or nerve suture after resection of the scar tissue between the nerve ends.

If these operations are ineffective, or if they cannot be used, either because of the extent of the lesion, or because of complications, e.g. suppuration, there still remains a means of improving the function of the hand, namely, transplantation of the less important flexors of the forearm to some of the paralysed extensors.

The various components of a radial paralysis contribute unequally to the total disability, which is frequently severe.

The palmar flexion and loss of active dorsiflexion, at the wrist, make the hand useless for writing and other finer actions which require either a neutral position or a slight dorsiflexion at the wrist, and also weaken the grip, since the long flexors cannot act with full power.

The adduction and opposition of the thumb can interfere with the flexion of the 2nd and 3rd digits, and the loss of active extension and abduction of the thumb make it difficult or impossible to open the hand for gripping.

The loss of active extension of the metacarpo-phalangeal joints of digits 2-5 also reduces the ability of the hand to open, and of the fingers to assume the position necessary for the action of the long finger flexors. However, this lack of

active extension at the metacarpo-phalangeal joints is partly compensated by the extension of the inter-phalangeal joints by the interossei and the lumbricals.

The pronation position of the forearm is of less importance to the function, both because most of the functions of the hand are performed in pronation, and because the paralysis of the supinator can be partly compensated by the biceps; and many patients learn to supinate the hand and forearm by a special twist.

Similarly, the triceps paralysis is usually of less importance because most of the functions of the hand are carried out below the level of the shoulder, and the absent triceps function can be replaced by the action of gravity in extending the forearm. In addition, the triceps is paralysed in only 10-20 % of radial paralyses (3), which are usually caused by lesions of the nerve distal to the origins of the branches to the triceps.

From this it follows that in transplantation for radial paralysis the chief aims are to obtain dorsiflexion of the wrist, extension of the metacarpo-phalangeal joints of digits 2-5, and abduction and extension of the thumb.

Tendon transplantation for radial paralysis was first performed by *Franke* in 1898 (2); the first transplantation in Scandinavia was performed by *Cappelen* in Norway in 1899 (1). During and after the first world war the operation was much used, especially in Germany, and its value was shown in the works of *Gessner & Riedel* (3), *Perthes* (6), *Mayer* (5) and others.

The various techniques which have been used will not be described in detail here, but their common principles will be discussed. These are:

- 1) Transplantation of the flexor carpi ulnaris to the extensor digitorum communis. This aims to give active dorsiflexion of the wrist and extension of the fingers.

- 2) Transplantation of the flexor carpi radialis or the palmaris longus to the oblique tendons of the thumb. This aims to restore the powers of abduction and extension of the thumb.

3) Arthrodesis of the wrist in dorsiflexion, or

4) Tenodesis of the wrist, one or more of the paralysed extensor tendons being fixed to the bones of the forearm with the wrist in dorsiflexion. By this means palmarflexion is lost, while further dorsiflexion is not prevented.

Sudeck (7) recommends suturing the tendons of the extensor digitorum communis to the dorsal carpal ligament with the wrist in dorsiflexion, or joining the extensor tendons together above the wrist, so that the suture site cannot pass under the dorsal carpal ligament. In both cases palmarflexion of the wrist is lost; but the latter method does not prejudice the possibility of active dorsiflexion—in the event of later recovery of the nerve's function or tendon transplantation.

5) Others, including some Americans, have proposed transplanting the pronator teres to the radial extensors of the wrist, in order to give them active function and to reduce the tendency to pronation of the forearm. This method does not seem to have been much used.

The following is the technique used in the Orthopaedic Hospital in Århus:

Through a 15-20 cm. long incision running up from the wrist along the middle of the dorsal surface of the forearm, the bundle of tendons of extensor digitorum communis, and the tendons of extensor pollicis longus, extensor pollicis brevis and abductor pollicis longus are isolated. The tendons of the radial extensors of the wrist are also isolated, if they are to be used for activating the oblique muscles of the thumb, or for tenodesis.

Next, two 15-20 cms. long incisions are made along the ulnar and radial borders of the forearm running proximally from the pisiform and the styloid process of the radius. Through these incisions the flexor carpi ulnaris and flexor carpi radialis are isolated, and later their tendons are divided as far distally as possible.

Muscle fibres of the former arise from the ulna almost down to the wrist-joint, so that it is necessary to cut some of these fibres in order to mobilise a sufficiently long belly,

which should measure 12-14 cms. Isolation of a sufficiently long muscle belly of the flexor carpi radialis presents no similar difficulties.

A blunt instrument is now passed subcutaneously, under the bridges of skin between the three incisions, to make subcutaneous tunnels running from the proximal ends of the two border incisions obliquely distally to the distal end of the middle incision. The two flexors of the wrist are passed through these tunnels, and the border incisions are closed.

With the wrist held in 40° dorsiflexion and the fingers extended, the tendon of the flexor carpi ulnaris is passed obliquely distally and radially across the tendons of the extensor communis digitorum and sutured to each one. In the same way the tendon of the flexor carpi radialis is sutured to the tendons of all three, or perhaps only two, of the oblique muscles of the thumb, with the thumb held in abduction and extension. The midline incision is then closed.

When the plaster is removed, between 4 and 5 weeks later, the patient cannot oppose the thumb, nor flex the fingers. These movements are usually quickly recovered with active exercises.

In a number of cases variations of this standard technique have been used, and these will be briefly mentioned here:

In the 6 cases in which the flexor carpi radialis was used for activating the oblique muscles of the thumb (Cases No. 1, 2, 3, 4, 5, 6, and 9) it was in only 2 cases (nos. 4 and 9) transplanted to all three; in the other 4 it was transplanted to only the extensor pollicis longus and abductor pollicis longus.

In 1 case (no. 8) the palmaris longus was used instead of the flexor carpi radialis and it was sutured to the extensor pollicis brevis and the abductor pollicis longus.

In the remaining cases (Nos. 3, 7 and 10), the dorsiflexors of the wrist were not paralysed and the abduction of the thumb was obtained in the following ways: in no. 3 by transplanting the extensor carpi radialis brevis into the extensor pollicis longus; in no. 7 by transplanting one of the radial extensors of the wrist to the extensor pollicis longus and the

other to the abductor pollicis longus; and finally in no. 10 by transplanting the extensor carpi radialis longus into all the oblique muscles of the thumb.

In these last 3 cases it was possible to transplant to the oblique muscles of the thumb through the dorsal incision, so that it was not necessary to make the radial incision.

In all 10 cases the transplantation to the extensor digitorum communis was by the method already mentioned, using the flexor carpi ulnaris.

Finally, tenodesis of the wrist was done in nos. 1 and 2, using the tendon of one of the radial extensors of the wrist, first cutting it and then suturing it to the periosteum on the dorsal surface of the radius.

This material from the Orthopaedic Hospital in Århus consists of 10 patients, who, since 1937, have been operated on by the method described above. Their case histories and follow-up examinations will be briefly described here.

No. 1. J. 1883. A girl aged 15 years. 5 years previously a blow on the L. arm without fracture. Typical complete isolated paralysis of the radial nerve below the branches to the triceps. Operation 13.7.37, 5 years after the paralysis: 1) flexor carpi ulnaris to extensor digitorum communis, 2) flexor carpi radialis to extensor pollicis longus and abductor pollicis longus, 3) tenodesis. Follow-up, 11 years after operation: 20° ulnar deviation of the wrist. Active movements of the wrist with clenched hand: 30° dorsiflexion, 80° palmarflexion, with extended fingers: 5° dorsiflexion, 50° palmarflexion. The transplanted flexor carpi ulnaris and the site of the suture between it and the extensor communis digitorum, henceforth called only "suture site", cannot be felt. Digits 2-5 have normal active and passive movements of all joints, and the hand is clenched normally. The hand grip is weak. No excursion registered on the dynamometer, and the wrist goes into 80° plantarflexion and 30° ulnar deviation, but if the hand is supported in slight dorsiflexion 10 kg. can be registered. No difference between the sound and operated sides with "finger crooking". The thumb: abduction 40°, flexion 35°, extension — 20° (i.e. the carpo-metacarpal joint lacks 20° of extension in the same plane as the fingers), normal flexion and extension in the metacarpophalangeal and interphalangeal joints, normal opposition with the tip against the root of the little finger. At this examination the patient was aged 26 years, married, looked after her home and in addition had a sewing establishment where she worked without any difficulty. She was

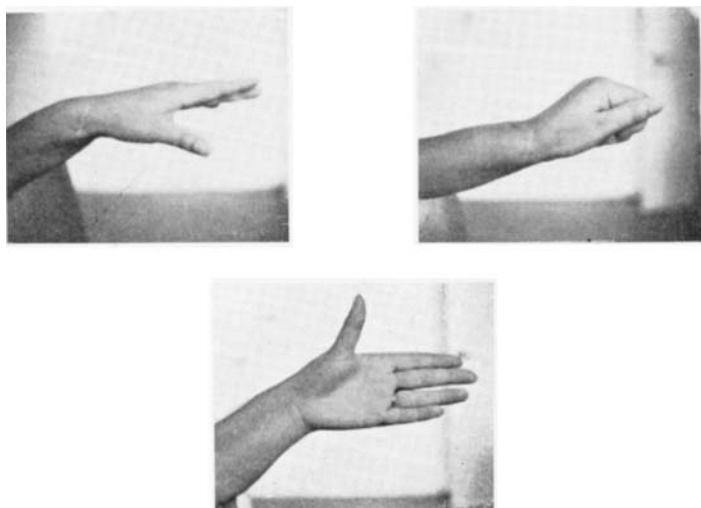


Fig. 1.

well satisfied with the results of the operation. No. 1 photographed 22.6.48.

No. 2. *J. 2155*. (1937). Boy, aged 15 years. Typical complete isolated radial paralysis below the branches to the triceps after operation for osteomyelitis of the R. humerus a year previously. Sequestrum discharged while in this hospital. Operation 9.8.47. 1 year after the paralysis: 1) flexor carpi ulnaris to extensor communis digitorum and extensor indicis; 2) flexor carpi radialis to extensor pollicis longus and abductor pollicis longus; 3) tenodesies of the wrist. Follow-up 11 years after operation: Marked atrophy of the muscles on the dorsal and radial sides of the forearm. Active movements in the wrist with fist clenched: 45° d.f./ 50° p.f., and with extended fingers: 20° d.f./ 80° p.f. Definite contraction of flexor carpi ulnaris and movement of the suture site. No side deviation at the wrist. Normal active movements in all joints of digits 2-5. The hand is clenched normally. Power on the dynamometer 1 kg., the hand going into 80° palmarflexion. If the hand is supported in slight dorsiflexion the power is 12 kg. No difference of "finger-crooking" power between the two hands. The thumb: carpo-metacarpal joint has 30° abduction, 45° flexion, $\div 10^{\circ}$ extension, and normal opposition, with the tip of the finger against the root of the little finger. Normal active movement in the metacarpophalangeal and interphalangeal joints. The patient is a builder's carpenter and manages all the work involved without any difficulty. He is well-pleased with the result of the operation. No. 2 photographed 21.7.48.

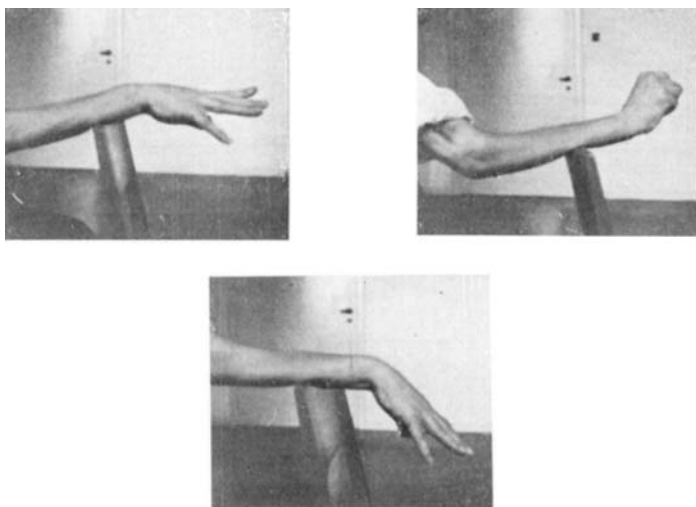
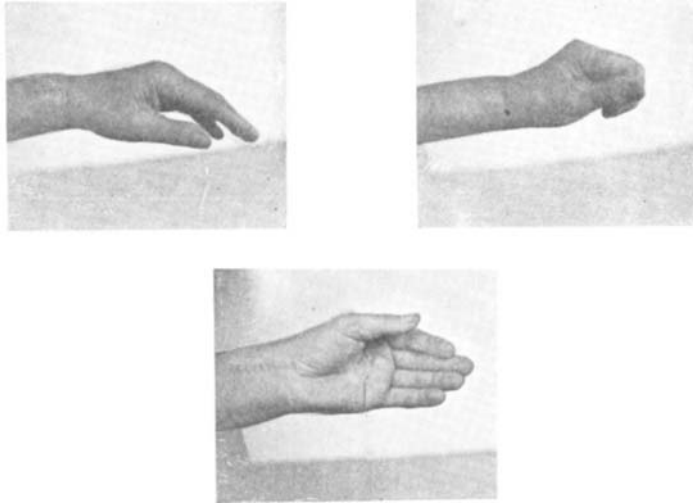


Fig. 2.

No. 3. J. 10372. (1941). Boy, aged 12 years. Injured 5 months previously in the belt of a threshing-machine. Multiple fractures of the R. arm, with a Volkmann's paralysis, which made the limb almost useless. Fracture of the L. forearm with paralysis of extensor communis digitorum and of the oblique muscles of the thumb, with preservation of the dorsiflexors of the wrist: corresponds to a lesion of the posterior interosseus branch of the radial nerve. Operation 1.3.41. 6 months after the injury: 1) flexor carpi ulnaris to extensor digitorum communis; 2) extensor carpi radialis brevis to extensor pollicis longus. The latter was not divided since the possibility of reinnervation could not be excluded. Follow-up 7 years after operation: No side deviation of the wrist of which the active movements with clenched fist are 60° d.f./50° p.f., and, with extended fingers, 30° d.f./75° p.f. Dynamometer: 52 kg. Normal movement of all digits including the thumb. It was specially noted that tightening of the tendons of extensor pollicis brevis and abductor pollicis longus on abduction suggested activity of these muscles. These 2 muscles were not activated at operation, so they must have been re-innervated post-operatively. This case, in which the hand is by all criteria normal, must therefore be excluded from the operation results.

No. 4. J. 13165. (1942). Man aged 46 years. Typical, complete, isolated paralysis of the radial nerve distal to the triceps branches after a blow on the arm, without fracture, 11 months previously. Operation: 7.9.42, 18 months after the injury, and 7 months after neurolysis without result: 1) flexor carpi ulnaris to extensor digitorum communis; 2) flexor carpi

*Fig. 4.*

radialis to the 3 oblique muscles of the thumb. Follow-up 6 years after transplantation: No side deviation of the wrist. Active wrist movements with clenched fist: 70° d.f./ 15° p.f., and with extended fingers 70° d.f./ 0° p.f. Visible contraction of the flexor carpi ulnaris and movement of the suture site can be felt. The meta-carpophalangeal joints of digits 2-5 are held in the following positions and cannot be actively straightened: 120° , 130° , 120° and 90° ; active flexion to 90° , 100° , 90° and 70° . There is full passive movement of these joints, so restriction of active movement by capsular contracture can be excluded. Normal active movement of the interphalangeal joints of these digits. The hand is clenched normally. The patient has some difficulty in grasping the dynamometer, but when he has done so, without the help of the sound hand, he registers 25 kg. (Sound hand 30 kg.). Same power in the 2 hands with finger-crooking. The thumb: Carpo-metacarpal joint: abduction 20° with simultaneous flexion to 30° , flexion 40° , extension $\div 30^{\circ}$, opposition with the tip against the root of the 4th finger. Normal movements of the meta-carpophalangeal and interphalangeal joints. The patient is a labourer and can do all his work. He has slight difficulty with taking hold of things, e.g. the handle of a shovel, but when he has got hold of it correctly his grip is good and strong. He is very pleased with the result of the operation. Case 4, photographed 19.10.42.

No. 5. *J. 15111*. (1942). Following a coramine injection in the R. forearm 19 months previously, paralysis of the extensor digitorum communis and the oblique muscles of the thumb, but preservation of active

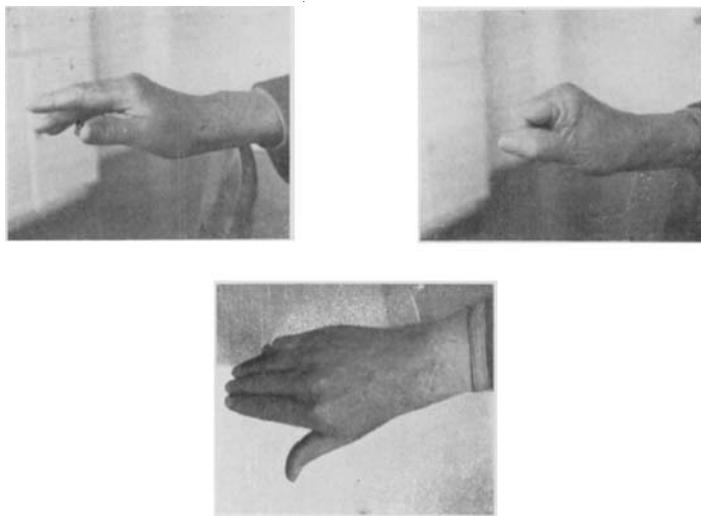
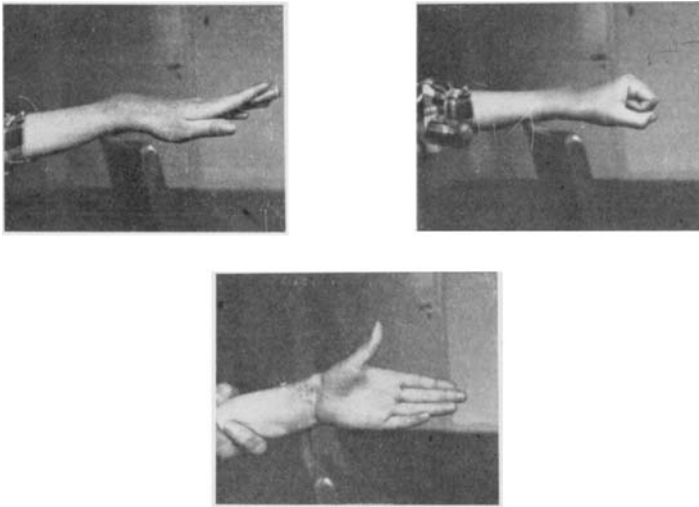


Fig. 5.

dorsiflexion of the wrist. Operation 11.9.42. 19 months after the paralysis: 1) flexor carpi ulnaris to extensor digitorum communis; 2) flexor carpi radialis to extensor pollicis longus and abductor pollicis longus. Follow-up 6 years after operation: Active movement of the wrist with clenched fist: 60° d.f./25° d.f., and with extended fingers: 60° d.f./5° d.f. The suture site could be felt to be mobile. Active movement of metacarpophalangeal joints of digits 2-5: 150-110°, normal active movement of interphalangeal joints. Normal fist. Dynamometer pressure 30 kg. (Sound hand 32 kg.). Equal power of the two hands with finger-crooking. The thumb: Carpo-metacarpal joint movements: abduction 30°, flexion 30°, extension ÷ 20°, opposition with tip of thumb to root of the 4th digital space. Normal movements of the metacarpophalangeal and interphalangeal joints. The patient now works only in an office; he writes without difficulty. Previously he worked as an egg packer and could also do this without difficulty. He is very pleased with the result of the operation. Case No. 5, photographed 15.9.43.

No. 6. *J.* 15524. (1942). Boy, aged 8 years. Extensive laceration of the arm in a road accident 14 months previously. Complete, typical, isolated, radial paralysis distal to the triceps branches. Operation 21.12.42. 15 months after the injury: 1) flexor carpi ulnaris to extensor digitorum communis; 2) flexor carpi radialis to extensor pollicis longus and abductor pollicis longus. Follow-up 5½ years after operation: Active movements in the wrist with clenched fist: 40° d.f./60° p.f., and with fingers extended: 5° d.f./70° p.f. Active contraction of flexor carpi ulnaris is

*Fig. 6.*

felt, with movement of the suture site. Completely normal active movement of all joints of digits 2-5. The hand is clenched normally. Weak power: dynamometry 0 kg., and the hand goes into 70° palmarflexion and 30° ulnar deviation. With the hand supported in slight dorsiflexion the dynamometer records 10 kg. (Sound hand 15 kg.). Equal power in the two hands with finger-crooking. The thumb: completely normal active and passive movements in the carpo-metacarpal, metacarpo-phalangeal and interphalangeal joints. The patient is employed as a boy on a farm and says he can do everything, including milking. Case No. 6, photographed 15.11.43.

No. 8. J. 23156. (1944). Man, aged 23 years. He developed L. radial paralysis distal to the triceps branches 13 months previously, after spraying fruit trees with lead arsenate. Medical treatment had no result. Since he had had a fracture in the elbow region 11 years previously which had left some weakness of the arm the nerve was explored in the neuro-surgical department. This operation also had no result. Operation 2.5.45, 21 months after paralysis: 1) flexor carpi ulnaris to extensor digitorum communis; 2) palmaris longus to abductor pollicis longus and extensor pollicis brevis. Follow-up 3 years after operation: The transplanted flexor carpi ulnaris has changed into a firm fibrous cord without active contraction, and the suture site can be felt firmly fixed during the movements of the wrist. Both the wrist and the metacarpo-phalangeal joints of digits 2-5 can be moved actively, but only in such a way that movement at one at once produces a contrary movement at the other, and

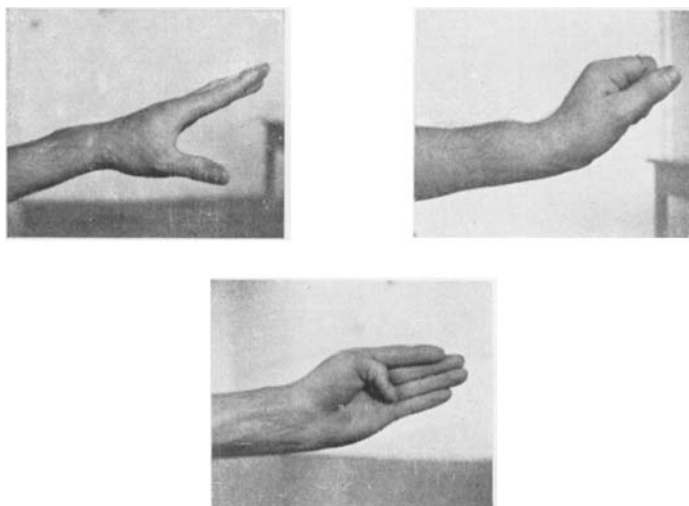


Fig. 8.

isolated active movement of the wrist or the fingers is not possible. When the hand is clenched the wrist goes into 35° dorsiflexion; but this position can only be taken up when the hand is clenched and as long as it is clenched, the wrist can not be moved either actively or passively. When the fingers are extended the wrist flexes to 0° , and remains there so long as the digits remain in this position. These two movements, extension of the fingers and palmar flexion of the wrist, are inseparable, so that one can only be done with the other. The active movements of the metacarpo-phalangeal joints of the fingers are normal with the above reservation, and there is normal movement at the interphalangeal joints. The dynamometer pressure is 16 kg. There is equal power on the 2 sides with finger-crooking. The hand is clenched normally. The thumb's carpo-metacarpal joint: abduction 30° (with simultaneous 30° flexion), flexion 35° , extension $\div 25^\circ$, opposition normal with the tip of the thumb opposite the root of the 5th finger. Metacarpo-phalangeal and interphalangeal joints normal active movements. The patient is a post-man and has no trouble at his work. Case No. 8, photographed 29.6.48.

No. 9. J. 34108. (1946). Man, aged 23 years. Fracture of the lateral condyle of the humerus 6 months previously, with paralysis of the radial nerve below the branches to triceps. Operation 7.10.46. 6 months after the paralysis. Beck's drilling for pseudarthrosis, and tendon transplantation: 1) flexor carpi ulnaris to extensor digitorum communis; 2) flexor carpi radialis to all the oblique muscles of the thumb. Follow-up 2 years after operation: No side deviation at the wrist, which, with the fist

*Fig. 9.*

clenched, has 75° d.f. and 20° p.f., and with the digits extended as far as possible, 80° d.f./35° p.f.: contraction of flexor carpi ulnaris and movement of the suture site is felt. Digits 2-5 are held in 90° flexion at the metacarpo-phalangeal joints and cannot be actively extended; passive extension is normal. There is normal active movement of the interphalangeal joints. Normal fist-clenching. Dynamometer pressure 10 kg., during which the wrist is flexed to 20°. (Dynamometer pressure of sound hand is 44 kg.). The thumb is abducted, flexed and extended normally; its tip is opposed to the side of the base of the 4th finger. Normal movements of the interphalangeal joints. The patient is fairly satisfied with the result of the operation. He is a country postman and can use the hand well for coarser movements, e.g. holding the bundles of letters, but it is awkward for finer movements. Case No. 9, photographed 10.12.46.

No. 10. J. 40365. (1947). Man, aged 21 years. Puncture lesion of the L. cubital region 3 months earlier, with paralysis of the extensor digitorum communis and the oblique muscles of the thumb, and preservation of dorsiflexion of the wrist. Operation 13.11.47, 3 months after the injury: 1) flexor carpi ulnaris to extensor digitorum communis; 2) extensor carpi radialis longus to the oblique muscles of the thumb. Follow-up 6 months after operation: Active movement of the wrist with fist clenched: 40° d.f./25° d.f., and with extended fingers 60° d.f./5° p.f. during which active contraction of the flexor carpi ulnaris and movement of the suture site can be felt. Active movement of the metacarpo-phalangeal joints of digits 2-5 is 180°/120°, and movements of the other joints are normal. Clenching the fist is practically speaking normal, apart from defective flexion in the metacarpo-phalangeal joints which makes the finger tips reach rather more distally than normally. Dynamometer pressure 15 kg. (Sound hand 30 kg.). Equal power of the two hands with finger-crooking. The thumb: carpo-metocarpal joint: abduction 45°, flexion 45°, extension ÷ 20°, opposition with the tip against the base of the 4th digital space. Normal movement in the metacarpo-phalangeal and interphalangeal joints. The patient is a labourer in the country and can do all work, including milking with a little difficulty. Case No. 10, photographed 25.2.48.

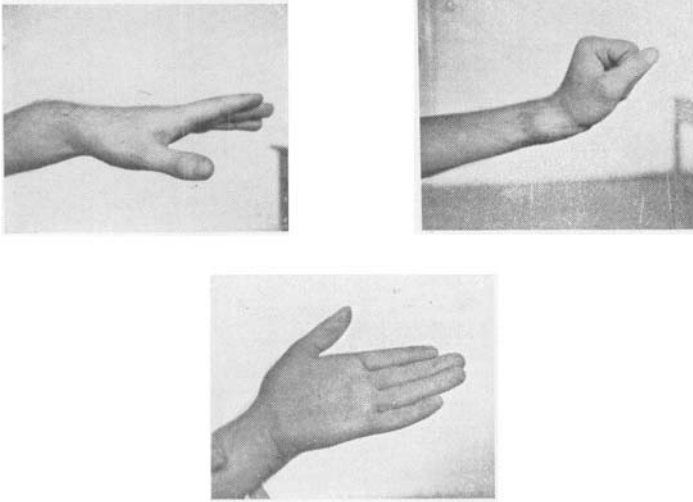


Fig. 10.

DISCUSSION

The indications for operation, and the possibility of post-operative recovery of the nerve function. The indications for tendon transplantation were quite clear in cases nos. 1, 2, 4, 5, 6 and 8; the interval after the occurrence of the paralysis was 1 to 5 years without any sign of spontaneous improvement. Operation on the injured nerve was also contraindicated in nos. 2 and 6 for local reasons, osteomyelitis in the former, and extensive scarring in the latter. In 2 other cases, nos. 4 and 8, the nerve had been operated earlier without result.

In these cases it is evident that recovery of the nerve's function could not have occurred after the transplantation, and it must be accepted that the good results were due to the transplantation, and not to later reinnervation.

This is not the case with the remaining 3 cases, nos. 3, 9 and 10. Case no. 9 had a tendon transplantation 6 months after the injury as the Beck's drilling for pseudarthrosis was done at that time, and cases nos. 3 and 10, in which the signs pointed to a lesion of the posterior interosseous nerve, were operated on respectively 6 and 3 months after the injury.

In view of the good results of tendon transplantation, which may probably be compared with those after operation on the nerve, and of the probable reduction in contractures and disuse atrophy of the non-paralysed muscles with early tendon transplantation, the wider indications by which the last 3 cases were operated cannot be condemned, although spontaneous recovery of the nerve's function could not be excluded at the time of operation.

In these 3 cases the theoretical possibility of reinnervation after the tendon operations makes it impossible to assess the results of the operation. Evidence of postoperative regeneration was found in case no. 3, as already described, and this patient has been excluded. In cases nos. 9 and 10 the results were the same, or a little less good, than those found in the other cases, so that little falsification results from their inclusion included in the assessment of the results of the tendon transplantations.

Follow-up examinations. Table 1 shows the results of follow-up examination of the wrist and digits 2-5. The down columns show the patients, first the 6 with radial paralyses, and then the 3 with posterior interosseous paralyses. The horizontal rows show the most important examinations.

The active movements of the wrist with, respectively, flexed and, as far as possible, extended fingers, is shown in the two first horizontal rows with a Y-shaped figure, whose stem corresponds with the forearm, and whose arms show the range of movements at the wrist. The stippled horizontal line gives the neutral position between dorsiflexion above and palmarflexion below. The figures on the arms of the Y show the degrees of deviation from 0°.

The active movement of the metacarpo-phalangeal joints is similarly shown in the 3rd horizontal row by a T-shaped figure, of which the left arm represents the line of the mid-hand, and the right arm and the stem the proximal phalanx in extension and flexion respectively. The figures on the right arm and the stem give the angles made by the basal phalanx with the palm in maximum extension and flexion. The normal

TABLE 1.

		TRUE RADIAL NERVE PARALYSES						POSTERIOR INTEROSSEOUS NERVE PARALYSES		
		1	2	4	6	8	9	3	5	10
RANGE OF ACTIVE MOVEMENT OF THE WRIST WITH CLENCHED HAND	D									
	P									
RANGE OF ACTIVE MOVEMENT OF THE WRIST WITH MAXIMAL EXTENSION OF THE FINGERS	D									
	P									
RANGE OF ACTIVE MOVEMENT OF THE METACARPO-PHALANGEAL JOINTS										
RANGE OF ACTIVE MOVEMENT OF THE OTHER FINGERJOINTS		NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
FIST-CLENCHING		NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL
DYNAMOMETER PRESSURE IN KG. (POWER OF SOUND HAND IN BRACKETS)		0	1	26 (30)	0 (15)	16	10 (44)	52	30	15 (30)
PALMARFLEXION OF WRIST DURING DYNAMOMETRY										
DYNAMOMETER PRESSURE WITH THE WRIST SUPPORTED		10	12		10					
POWER WITH "FINGER-CROOKING"		NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL	NORMAL

position of extension at the metacarpophalangeal joints is thus represented as 180° .

The 3 next horizontal rows require no further explanation than that given in the Table. Under the heading "Palmar flexion of the wrist during the dynamometer test" the angle of forced palmarflexion of the wrist during the test is shown in the way already described. A O indicates that the wrist was not flexed beyond the neutral position.

The last but one horizontal row shows power recorded by the dynamometer in cases where the power was increased by supporting the wrist.

The last horizontal row shows the "crooked finger" power, which will be explained later.

For the function of the thumb, reference should be made to the case histories since it seemed unnecessary to present it in a table.

The Material. Tendon transplantation for radial paralysis has been done in 10 cases since the Hospital was opened. In case no. 8 the paralysis was presumably of toxic origin; in the others it was caused by various traumata. One patient, no. 7, could not be re-examined, and one patient, no. 3, has had to be excluded because of post-operative reinnervation, as al-

ready described. The cases can be divided into 2 groups. In nos. 1, 2, 4, 6, 8 and 9 all of the muscles innervated by the radial nerve in the forearm were paralysed, including the extensors of the wrist. In 5 of these cases, that is, all but no. 8, both the history and examination pointed to a lesion of the arm as the cause of the damage to the nerve. For this group I have not been able to find any better description than "true radial paralysis".

The remaining 2 cases, nos. 5 and 10, and the excluded no. 3, showed only paralysis of *extensor digitorum communis* and the oblique muscles of the thumb, with preservation of the function of the radial extensors of the wrist, and therefore of active dorsiflexion of the wrist. These lesions, which correspond to damage of the posterior interosseous nerve are grouped under the term "paralysis of the posterior interosseous". In all the cases the triceps' function was intact.

The follow-up findings will now be presented in cross-section, each function being studied for all the cases.

Movements of the Wrist. Tenodesis was done in cases nos. 1 and 2, and was without effect, since marked palmarflexion of the wrist occurred in both.

All patients showed active dorsi- and palmarflexion at the wrist.

In patient no. 8 a peculiar arrangement occurred, as already described in his case history. The transplanted flexor carpi ulnaris was converted into an inactive fibrous cord, the suture site was fixed, and the movements of the wrist were coupled with contrary "compensatory" movements in the metacarpo-phalangeal joints. Since no active extensors of either the wrist or the metacarpo-phalangeal joints could be found, their active extension could be explained only as an action of the flexors of the digits, possibly in conjunction with the action of the active flexor carpi radialis. Evidently the operation had resulted in a tenodesis of the tendons of the extensors of the digits above the wrist, as is done in Sudeck's operation. Their length from the suture site to their insertion

was constant. When the fist was clenched the part of the tendons which lay on the fingers lengthened; this was only possible if there was a corresponding shortening of the tendons between the metacarpo-phalangeal joints and the suture site; this forced the wrist into dorsiflexion. The same mechanism extended the metacarpo-phalangeal joints, when the wrist was actively palmar-flexed.

The rest of the cases all showed active dorsiflexion of the wrist, with the fingers both tightly flexed, and extended as straight as possible. The interest is here in the other 5 patients (cases nos. 1, 2, 4, 6 and 9) with true radial paralysis, in whom the dorsiflexors of the wrist were paralysed before operation. In them the restoration of active dorsiflexion of the wrist must be due to the action of the transplanted flexor carpi ulnaris, and in several one could feel the active contraction of this muscle and the movement of the suture site.

The range of movement in relation to the neutral position is shown in the two upper rows of the Table. It shows that there were big variations, but the cases can be divided into two well-defined groups.

Group A consists of cases nos. 4, 5, 9 and 10, in whom the palmarflexion was limited to near the neutral position. Case no. 8, whose condition has been discussed above, must be included with these.

Two causes for this reduced palmarflexion were demonstrated by case 8, namely 1) fixation of the suture site, and/or 2) conversion of the transplanted muscle into a fibrous band. These 2 causes do not apply to cases 4, 9, 5 and 10, in whom both the muscle was active and the suture site mobile. In these cases one might think 3) that the transplanted muscle by active contraction prevented palmarflexion of the wrist. This idea must, however, be rejected for two reasons, firstly because it does not explain how, as has been described below, the transplanted muscle then fails to hinder the strong compulsory palmarflexion in the patients in *Group B*, when these contract their finger flexors maximally, and secondly because it seems unlikely that this muscle whose power is said to

be 5 kg. (7) should be able to equal the strong pull of the flexors of the forearm.

I think that the most likely explanation of the reduced palmarflexion is 4) that the suture site lies so far distally on the extensors that it is stopped by the dorsal carpal ligament and the partitions under this ligament, so that palmarflexion is prevented.

Group B includes the rest of the cases: (nos. 1, 2 and 6). Here there is good range of all movements at the wrist. Since it is clear that the suture site cannot pass through the partitions under the dorsal carpal ligament, one must assume that in these cases this site lies so far proximally on the extensors that it either does not at all, or only with strong palmarflexion, come up against the upper border of the dorsal carpal ligament.

Movements of Digits 2-5. In cases nos. 1, 2 and 6 there was normal movement at the metacarpo-phalangeal joints, and in nos. 5 and 10 there was slight but functionally unimportant reduction in the range of movement; the movement of these joints was not affected by the position of the wrist in these cases. Thus the results of the transplantation were in these cases good or satisfactory as far as the active extension of these joints was concerned. Case no. 8 also showed normal active movement of these joints; the particular condition in this case has already been discussed.

Reduction of the range of movement in the metacarpo-phalangeal joints, severe enough to impair the function of the hand, was seen in only 2 cases (nos. 4 and 9) in which the joints were held in marked or maximal palmarflexion and showed little or no active dorsiflexion. In both cases there was good contraction of the transplanted flexor carpi ulnaris, which acted, however, mainly, or exclusively on the wrist, and only slightly or not at all on the fingers. The reason for this is not clear to me.

The movements at the interphalangeal joints were normal, and clenching the fist normal or nearly normal in all the patients.

Dynamometry. The cases divided into the same 2 groups with dynamometry as with flexion of the wrist:

In Group A are cases nos. 4, 8, 9, 5 and 10, in whom the palmarflexion of the wrist was limited; dynamometry showed good or fairly good power. In cases 4 and 5 the power of the operated hand nearly equalled that of the sound hand. The rest of the patients in this group showed powers varying between 25 and 50 % of that of the sound hand—but still quite good power.

In Group B are cases nos. 1, 2 and 6, in which the palmarflexion of the wrist was good; dynamometry showed either 0 or minimal power; the wrist went into maximal palmarflexion at the same time as pressure on the dynamometer was attempted.

The “crooked finger” power was tested by the following method: the examiner and the patient held their metacarpophalangeal joints extended and their interphalangeal joints acutely flexed, and hooked their fingers together homolaterally: by pulling the examiner could compare the power with which the patient flexed the fingers of the operated hand with that of the sound hand. This power depends solely on the flexors of the digits and is not affected, like the dynamometer test, by instability of the wrist. Thus the power of the crooked fingers was a more direct indication of the power of the flexors of the digits than dynamometry.

I found no difference in the crooked finger power between the sound and the operated hands, in any of the patients. Thus the reduced power registered on the dynamometer did not represent a reduction in the power of the flexors of the fingers.

When dynamometry was carried out with the wrist supported, so that the forced palmarflexion was prevented, the patients of Group B registered powers of the same order as those of Group A.

The difference in the dynamometer powers of the two groups was obviously related to the different palmarflexions at the wrist. In Group A, either the suture site was fixed, or

it was blocked by the dorsal carpal ligament, so that palmarflexion was stopped before it could interfere with the maximal power of the flexors of the fingers. The cases in Group B had no such braking mechanism, and since the transplanted flexor carpi ulnaris could not overcome the power of the strong flexors, the wrist was pulled into palmarflexion, whereby the flexors of the digits in their turn lost their full power.

The reduction of dynamometer power in the operated hands in Group A, compared with the sound hands, in spite of no difference in the power of the flexors when the power of the crooked fingers was tested, may perhaps be explained by some of the flexors' power being used to resist the extensors, so that there was a corresponding reduction in their flexing power.

Movements of the Thumb. In all cases the activation of the thumb's abductor had a good result. In most patients the abduction of the thumb was normal or, since it was at the same time slightly flexed, nearly normal. Nearly all the patients had 20° to 30° limitation of extension at the carpometacarpal joint, but this did not interfere with function. In all cases, opposition was normal or nearly normal.

CONCLUSION

A comparison of the results of operation in the two groups, A and B, shows that the former has the advantage. The patients of Group A have a strong grip of their working tools, etc., and the reduced movement at the wrist is unimportant. It must be mentioned that the 2 patients who have loss of extension of the metacarpo-phalangeal joints which interferes with function, belong to this group, but there is no obvious causal relation between this loss of extension and the reduced palmarflexion of the wrist. The good palmarflexion of the wrist in the cases of Group B is of no advantage, and the weakened power of the hand is a disadvantage.

Thus the conclusion to which the study leads us is that at operation one must aim to produce a restricting arrange-

ment to limit palmarflexion of the wrist. Probably it will be best to do a tenodesis using the paralysed extensors of the wrist. Since cases nos. 1 and 2 have shown that suture of the tendons to the periosteum of the forearm bones does not hold, the method recommended by *Perthes* (6), in which the tendons are passed through bore-holes made in the bones, and fixed on the opposite side should be used. If one does not wish to do a tenodesis, the suture site, where the tendon of the flexor carpi ulnaris is sutured to the tendons of extensor digitorum communis, should be as far distal as possible, so that the suture site will prevent marked palmarflexion of the wrist as it comes up against the dorsal carpal ligament.

S U M M A R Y

The method used for tendon transplantation in cases of radial paralysis at the Orthopaedic Hospital in Århus is described. The flexor carpi ulnaris is transplanted to the extensor communis digitorum, and abduction and extension of the thumb is obtained by transplantation of flexor carpi radialis or, in some cases of palmaris longus, to its oblique muscles. In cases in which the extensors of the wrist are not paralysed, these can be used to extend and abduct the thumb.

The material consists of 8 patients. 2 of them had paralysis of the extensor digitorum communis and oblique muscles of the thumb, with preservation of the function of the extensors of the wrist. These have been termed "posterior interosseous paralyses". The 6 remaining cases all had paralyses of all the muscles innervated by the radial nerve in the forearm. They have been termed "radial paralyses".

The findings at the follow-up examinations are shown in Table 1. Case 8 had no action in the transplanted flexor carpi ulnaris, and in this patient the active movements at the wrist and metacarpal joints were assumed to be by the flexors of the fingers. All the other patients had good function of the transplanted flexor carpi ulnaris.

Patients nos. 4 and 9 lacked active extension at the meta-

carpo-phalangeal joints, which impaired the function of the hand. In the other patients active movements of the meta-carpo-phalangeal joints were normal, or nearly normal. All the patients had normal movements of the interphalangeal joints, and could make a normal, or nearly normal, fist.

If the movement at the wrist and the power of the hand is considered the cases fall into 2 groups: *Group A* contains patients nos. 4, 8, 9, 5 and 10, who all showed good power when tested with a dynamometer, and limitation of palmarflexion at the wrist, probably because the suture site between the flexor carpi ulnaris and the extensor communis digitorum was so far distal on the extensor tendons that its movement was restricted by the dorsal carpal ligament. *Group B* contained patients nos. 1, 2 and 6, who showed good palmarflexion of the wrist and minimal power on dynamometry, the wrist being forced into palmarflexion.

Movements of the thumb were nearly normal, and, from the functional point of view, wholly satisfactory.

The operation results have on the whole been good, and the patients have generally been well satisfied. It is possible that the results can be improved if one tries to produce a firm tenodesis of the tendons of the extensors of the wrist, which, it seems, should be attached after passing them through drill-holes in the radius and ulna.

RESUME

Description d'une technique appliquée à l'Hôpital Orthopédique d'Aarhus (Danemark) pour la transplantation des tendons dans les parésies radiales: L'extenseur commun des doigts est activé par la transplantation du fléchisseur cubital antérieur. L'extension et l'abduction du pouce est activée au moyen du grand palmaire ou, dans un cas, du petit palmaire. Dans les cas où les extenseurs du poignet ne sont pas parétiques, ceux-ci peuvent être utilisés pour activer l'extension et l'abduction du pouce.

Les observations portent sur 8 malades; chez deux d'entre

eux, il y avait parésie de l'extenseur commun des doigts et des extenseurs du pouce, tandis que les extenseurs du poignet fonctionnaient normalement. L'auteur les désigne comme des « paralysies profondes ». Chez les autres 6 malades, il y avait parésie de tous les muscles de l'avant-bras innervés par le nerf radial. Elles sont indiquées comme des « paralysies radiales proprement dites ».

Le résultat constaté lors des examens complémentaires ressort du schéma No. 1. Chez le malades No. 8, on ne trouva aucune fonction du fléchisseur cubital antérieur transplanté. Les mouvements actifs du poignet et des articulations métacarpo-phalangiennes des doigts sont supposés être dus uniquement, chez ce malade, aux fléchisseurs des doigts. Chez tous les autres patients, on constata une bonne fonction du fléchisseur antérieur transplanté.

Chez les malades Nos. 4 et 9, on constata l'absence d'extension active de l'articulation métacarpo-phalangienne des doigts. Chez les autres malades la mobilité de cette articulation était normale ou presque normale. Chez tous les malades, la mobilité des articulations inter-phalangiennes était normale et ils pouvaient tous fermer la main normalement ou presque normalement.

Par rapport à la mobilité du poignet et aux forces de la main, ces observations peuvent être divisées en deux groupes: *Groupe A*, comprenant les malades Nos 4, 8, 9, 5 et 10 chez lesquels on constata aux mensurations du dynamomètre que les forces étaient bonnes, mais qu'il y avait restriction de la flexion palmaire du poignet, probablement parce que la suture entre le fléchisseur cubital antérieur et l'extenseur commun des doigts était placée si loin distalement sur les tendons de l'extenseur commun des doigts qu'elle touchait le ligament cubital dorsal. *Groupe B*, comprenant les malades Nos. 1, 2 et 6, chez lesquels le pouvoir de flexion palmaire était fort et la pression minimale à l'examen du dynamomètre, au cours duquel le poignet est forcé en flexion palmaire.

La mobilité du pouce était presque normale et en tout cas absolument satisfaisante au point de vue fonctionnel.

Dans l'ensemble les résultats de l'opération ont été bons et les malades s'en trouvaient généralement très satisfaits. Il est possible que l'on puisse améliorer encore les résultats en pratiquant une tenodèse solide des tendons des extenseurs du poignet qu'il convient probablement d'attacher sur les os de l'avant-bras en les faisant passer par des trous perforés dans ces os.

ZUSAMMENFASSUNG

Es wird eine Beschreibung der am Orthopädischen Krankenhaus zu Aarhus angewandten Technik der Sehnentransplantation bei Radialisparese gegeben: Der Extensor digitorum communis wird durch eine Transplantation des Flexor carpi ulnaris aktiviert. Die Extension und Abduktion des Daumens wird mit Hilfe des Flexor carpi radialis oder in einem vereinzeltten Falle des Palmaris longus aktiviert. In den Fällen, bei denen die Extensoren des Handgelenks nicht paretisch sind, können diese zur Aktivierung der Extension und Abduktion des Daumens verwendet werden.

Das Material umfasst 8 Patienten; zwei von ihnen zeigten eine Parese des Extensor digitorum communis und des langen Abductors und der Extensoren des Daumens bei Bewahrung der Funktion der Extensoren des Handgelenks. Sie werden als „Profunduslähmungen“ bezeichnet. Bei den übrigen 6 Patienten bestand eine Parese sämtlicher, vom Radialis innervierten Muskeln des Unterarms. Sie werden als „eigentliche Radialislähmungen“ bezeichnet.

Das Ergebnis der Nachuntersuchungen geht aus Schema 1 hervor. Bei Pat. Nr. 8 wurde keine Funktion des transplantierten Flexor carpi ulnaris gefunden. Es wird angenommen, dass die aktiven Bewegungen im Handgelenk und in den Basalgliedern der Finger bei diesem Patienten ausschliesslich eine Funktion der Flexoren der Finger sind. Bei allen anderen Patt. fand man eine gute Funktion des transplantierten Flexor carpi ulnaris.

Die Patt. Nr. 4 und 9 zeigten einen bedeutenden und funk-

tionshemmenden Mangel in der aktiven Extension der Basalgelenke der Finger. Bei den übrigen Patt. war die Beweglichkeit der Basalgelenke normal oder fast normal. Sämtliche Patt. zeigten eine normale Beweglichkeit des Mittel- und Nagelgliedes und eine normale oder fast normale Faustbildung.

Hinsichtlich der Beweglichkeit des Handgelenks und der Kraft der Hand lässt sich das Material in zwei Gruppen einteilen: *Gruppe A*, bestehend aus den Patt. Nr. 4, 8, 9, 5 und 10, zeigte gute Kraft bei Dynamometermessung und eine Einschränkung der Volarflexion des Handgelenks, wahrscheinlich weil die Suturstelle zwischen dem Flexor carpi ulnaris und dem Extensor digitorum communis so weit distal an den Sehnen des Extensor digitorum communis angebracht war, dass sie an das Ligamentum carpi dorsale anstiess. *Gruppe B*, bestehend aus den Patt. Nr. 1, 2 und 6, zeigte eine gute Fähigkeit zur Volarflexion und minimalen Druck bei der Dynamometeruntersuchung; hierbei wurde das Handgelenk zwangsmässig stark volarflektiert.

Die Beweglichkeit des Daumens wurde fast normal und unter allen Umständen funktionell völlig befriedigend befunden.

Die Operationsresultate waren im grossen und ganzen gut, und die Patt. waren im allgemeinen recht zufrieden. Möglicherweise lassen sich die Ergebnisse noch dadurch weiter verbessern, dass man versucht, an den Sehnen der Handgelenksexpressoren eine solide Tenodese vorzunehmen, die vermutlich an den Unterarmknochen befestigt werden müssen, wobei man sie durch Bohrlöcher führt, die in diesen Knochen anzulegen wären.

LITERATURE

1. *Cappelen*: Norsk Mag. f. Lægevidenskaben 1899, s. 1043.
2. *Franke*: Arch. f. klin. Chir. 1898: 57, 763.
3. *Gessner & Riedel*: Münch. med. Wschr. 1917, I, 817.
4. *LeRoy & Abbot*: J. nerv. & ment. Dis. 1944: 99, 466.
5. *Mayer*: Dtsch. med. Wschr. 1920: 46, 152.
6. *Perthes*: Zbl. f. Chir. 1917: s. 717.
7. *Sudeck*: Der Chirurg 1943: 15, 665.

DISCUSSION

Langenskiöld, F., Helsingfors: As a result of the war in Finland there have been a great number of cases of paralysis of the radial nerve, which could not be cured by suturing the nerve. In these cases *Perthes'* operation, which was the subject of the last lecture, was the treatment of choice, and many of the results obtained have recently been reported by *Saikk*u in a supplement to the *Acta Chirurgica Scandinavica*. In contrast to the lecture, however, we have found that to obtain a good grip it is necessary to secure dorsiflexion of the wrist either by fixing the extensor tendons of the wrist to the radius and ulna, as suggested by *Perthes*, or by transplanting the pronator teres to these tendons by *Jones'* method. There is an exception to this rule: that is, in a paralysis affecting the left hand of a violinist.