TENDON GRAFTS FOR FLEXOR TENDON INJURIES
IN THE FINGERS AND THUMB

A Study of Technique and Results

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The object of this work is to report the results obtained in a consecutive series of 149 cases of flexor tendon grafting in the fingers and thumb, and to study the lessons which failure and success have taught. The first graft was performed in 1942 and the period under review includes the year 1954. No case has been omitted except where an adequate late assessment has been impossible, or for some special reason which will be stated. Three groups of tendon divisions are considered: 1) flexor digitorum profundus beyond the distal palmar crease; 2) flexor digitorum profundus and sublimis in the same region; and 3) flexor pollicis longus beyond the wrist joint.

It is unsatisfactory to classify results as good, fair and poor because these terms convey little meaning. A method is needed which is accurate without containing excessive detail and which can be readily understood. In 1950 Boyes published a critical evaluation of the results obtained in 138 cases of flexor grafts in the fingers and thumb. At the Berne meeting of the Société Internationale de Chirurgie Orthopédique et de Traumatologie in 1954 a small group of surgeons studying these problems agreed to adopt Boyes's method of classification of results:

(a) Flexor tendon action in a finger is recorded by measuring the distance by which the pulp of the finger tip fails to reach the distal crease of the palm (Fig. 1).

Boyes however was not concerned with the restoration of profundus action alone in the presence of a normal sublimis tendon, and in this special group an additional measurement is necessary which calls for an explanation. The disability caused by loss of active flexion of the terminal phalanx is most noticeable in the index and middle fingers because these fingers take part in the thumb-finger grip. Controlled terminal flexion of these fingers is of importance to all individuals, but it is of special significance in all four fingers to those who need precision action. Replacement of the profundus tendon by free grafting will restore a useful flexion range to the terminal joint in most cases, but this range of movement tends to diminish as the finger is flexed into the hand.
Measurement of the finger tip to distal crease deficiency gives only a partial picture of the functional result, and it is instructive also to record the actual range of terminal interphalangeal joint movement when the finger is semiflexed (Fig. 2).

(b) Flexor tendon action in the thumb is estimated by the range of active movement of the interphalangeal joint (Fig. 3).

Following Boyes's method, the angle is expressed as a percentage of the passive range.

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\text{Percentage of joint movement} = \frac{\text{voluntary flexion}}{\text{passive flexion}} \times 100.
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The actual joint range is also presented as a check against this method of assessment.

**SELECTION OF CASES**

**Flexor digitorum profundus**—Operative treatment was restricted to those fingers in which passive movement was good and in which sensation of the finger tip was satisfactory, or could be restored by digital nerve suture. Arthrodesis was advised when these conditions were not satisfied. The total number of fingers operated upon was twenty-eight, of which six could not be traced. At least four of these cases are known to have been good so that their rejection from the series does not materially affect the conclusions.

**Flexor digitorum profundus and sublitis**—The operative indications in this group were less uniform. Grafting was not advised for tendon divisions in a single finger when the passive range was poor or when there was an irreparable complete nerve lesion. It was, and still is, considered that the better treatment in these cases is amputation. The index finger is an exception to this general rule and has always been considered a special case on account of the important thumb-index pinch. In the severely damaged hand with multiple flexor tendon divisions or loss of several digits, grafting has been performed under less favourable conditions on the grounds that even a small return of voluntary flexion would benefit the hand.

The total number of fingers treated was 109. It was not possible to trace sixteen cases but of this number at least half are known to have been satisfactory. A further three cases have been excluded because the fingers were in a poor condition and were in fact unsuitable for operation. There remain ninety fingers in which the end-results are known; in this group were eleven fingers in which grafting operations had been previously performed and had failed.

**Flexor pollicis longus**—Flexion of the interphalangeal joint of the thumb is essential for a good pinch grip. The normal range of flexion varies between 80 and 90 degrees, but an active range of 30 or 40 degrees is adequate for most purposes. The indications for grafting can therefore be less stringent than for the fingers; a moderate restriction of passive range does not contra-indicate operation.

The total number of cases was thirty-seven, all of which have been traced and are included in the series.

**OPERATIVE TECHNIQUE**

**Exposure**—Exposure has in all cases been made by a mid-lateral incision throughout the full length of the finger, the incision being deepened to the fibrous tendon sheath, passing posterior to the vessels and nerve. The palm has been opened by incisions placed in the appropriate crease lines. During the past few years a wider and more satisfactory exposure has been made by combining the finger and palm incisions and raising a large flap (Figs. 4 and 5). This incision owes its development to the influence of Rank and Wakefield (1952), although they prefer to carry the finger flap anterior to the neurovascular bundle. The middle and ring fingers do not so easily lend themselves to flap exposure and as a rule the limited approach is still employed. It is possible, however, by choosing suitable skin lines to link the two incisions, and by so doing the difficult area at the base of the finger can be fully exposed.
Figure 4—Incision for exposure of the index finger and palm. The two incisions may be joined. Figure 5—Incisions for exposure of the thumb, palm and forearm. The proximal incision for removal of palmaris longus is also shown.

The thumb exposure requires three incisions—a mid-lateral incision on the radial side of the thumb, an incision the full length of the thenar crease and an angled incision above the wrist (Fig. 6). This approach has been used in all cases and has proved most satisfactory. It has occasionally been necessary to place the thumb incision on the ulnar side when the digital nerve on this side required repair. Figures 7, 8 and 9 show the exposure of the index finger, the little finger and the thumb.

Source of the graft—The grafts have been taken from palmaris longus, extensor digitorum longus to the fourth toe, and plantaris. Sublimis tendon was used in one case only before it was thought that a more slender graft would become revascularised more rapidly. It is interesting to note however that Kyle and Eyre-Brook (1954) have recently expressed their preference for sublimis. Flexor carpi ulnaris was used once for a special reason: the result was effective but some bow-stringing occurred owing to the difficulty of preserving satisfactory pulleys around the bulky tendon. In any case there is no need to sacrifice this important muscle.

On four occasions an elongation of the flexor pollicis longus at its musculo-tendinous junction was performed and the tendon advanced to its insertion. The elongation is limited to one and a half inches and this restricts its use to tendon divisions in the distal part of the thumb. Theoretically the method is attractive, as it is probable that the blood supply of the tendon is not completely lost. The results in the four cases, although reasonable, did not reach the standard achieved by free grafting and the method was not continued. Elongation of the flexor digitorum profundus was used on one occasion and was successful, but this also has a limited application and is not recommended.
The palmaris longus tendon, present in approximately 90 per cent of individuals, is usually of good quality and convenient size. Its length is only just sufficient and it cannot be used if extra length is needed for passing the graft through a tunnel in the terminal phalanx. It is the tendon of choice for the thumb because a wrist incision is part of the thumb exposure. Palmaris longus was originally removed by open dissection as it was thought essential to remove a plentiful covering of paratenon with the tendon. This method was abandoned when it was found that sufficient paratenon came away with the tendon when a limited exposure was made. The long forearm scar is unsightly in contrast with the two small scars which become almost invisible (Fig. 6).

The long extensor tendon of a toe is removed by open dissection, for it is difficult to extract it through small incisions (Fig. 10). It is of good quality and of ample length. Because of the short extensor muscle its loss does not seriously affect a toe, except for the little toe which does not possess a second extensor muscle. The skin wound may heal slowly unless complete haemostasis is secured and a careful skin suture performed. These tendons are the obvious choice when several grafts are required.

Plantaris, a very variable tendon, has its special value which deserves to be more widely known. It has the advantage of being thin and is the longest tendon in the body. It is the tendon of choice for the replacement of profundus in the presence of a normal sublimis because its slender character allows it to slip easily through the thecal canal leaving the sublimis undisturbed. Its presence cannot be determined until an exposure is made, but if it is absent no harm has been done and a toe extensor can be used. Two small incisions are needed, one at the medial side of the tendo Achillis and the other placed three finger breadths behind the medial border of the tibia in the mid-calf (Fig. 11). The tendon lies between the gastrocnemius and the soleus muscles.
Apart from the special indications, the relative merits of these three tendons are difficult to assess and the choice is probably not one of great importance.

**Suture of the graft**—The suture material has been single-strand stainless steel wire (0.0046 of an inch) in all except three early cases in which ophthalmic silk was used. The wire has not been removed except in cases where a Bunnell withdrawal suture (Bunnell 1944) was used for the terminal fixation. In no case has any harm resulted from the permanent presence of the wire. The needles, which are swaged to the wire, are one inch long and are made in a very thin bayonet shape. They are constructed from a steel which will bend before it will break; this feature makes it possible to bend the needle into a suitable shape to negotiate awkward corners.

The proximal suture has been performed by the well known Bunnell end-to-end stitch which is ideal when the tendons are of equal size, or by a particular form of interlacing stitch which is more suitable when tendon and graft are of different cross-sections (Fig. 12). As the majority of the grafts in this series were of the latter type, it became standard practice to use the interlacing suture. This junction has always been sited well proximal in the palm and the suture area has been covered by sewing lumbricalis muscle around it. In the case of the thumb, the suture is placed proximal to the wrist joint and covered by muscle if the graft is sufficiently long (Fig. 13).

Several methods of distal suture have been used—suture to the remaining tag of tendon, the Bunnell withdrawal suture, and looping the graft through a transverse hole in the terminal phalanx (Fig. 14). The first method was given up as it was thought to be less secure and more difficult to perform neatly. The Bunnell suture is a very neat and effective method and has been used when early movements have not been encouraged; it is the method of choice in children. Fixation of the graft through a transverse hole in the phalanx is also a tidy procedure and is, in my opinion, the most secure of all methods. The tunnel must be made in precisely the correct position through the broadest part of the bone. If it is placed too far dorsally there is a danger of injury to the nail root. The tendon is sutured to itself distal to the joint in order to avoid adhesions in front of the joint (Fig. 15).

**Tension of the graft**—It is said that a tendon graft tends to shrink and that allowance should be made in judging the length of the graft. I am not convinced of the practical significance of this observation but there can be little doubt of another more important consideration. The muscle of the divided tendon shortens as it adapts itself to the inevitable retraction. It is not unreasonable to assume...
that the muscle will return to normal or near normal length with the return of active use after a successful grafting operation, provided the period between injury and operation is not too long. It follows, therefore, that the tension under which the graft is placed should be a little greater than that which would appear to be normal at the time of operation. Normal tension under anaesthesia can easily be gauged by comparison with the other fingers, the index finger being flexed least and the little finger flexed most.

In all the cases reported here the proximal suture has been performed first and the tension adjusted at the distal suture, the finger finally lying in a slightly more flexed position than would appear correct (Fig. 8). The same principle has been applied to the thumb (Fig. 9). It has been found in practice that a digit has rarely been put up too tight, but the opposite error has been made on several occasions. It is interesting to note that even in patients in whom there has been a long interval between injury and operation, it has rarely been found necessary to use another muscle as a motor. In 129 cases the average delay amounted to five and a half months; in the remaining twenty cases the delay varied between eighteen months and twenty-four years, and there were nine cases in which the interval was over three years. Contrary to expectations, there was no appreciable difference in the results of the short and long interval cases. One graft for profundus division with a four and a half years interval regained 30 degrees active range of the terminal interphalangeal joint. A graft for profundus and sublimis division after three years delay obtained a range of movement from full extension to half an inch from the distal palmar crease. A thumb graft regained 80 degrees range after four years (Fig. 16), and another obtained 70 degrees after ten years delay.
The result obtained by a tendon graft to replace flexor pollicis longus, showing extension and flexion. The operation was performed four years after injury and these photographs were taken four months later. The flexion range is 40 degrees, which increased to 80 degrees eighteen months after operation. This is the same hand as is shown in Figure 9.

Treatment of the fibrous sheaths—The flexor tendons pass through a fibro-osseous canal in the fingers which holds the tendons against the flexor surface of the three finger joints. This fibrous tunnel or thecal sheath is lined by a synovial membrane which suspends the tendons in a mesentery. The theca is strengthened over the middle of the proximal and middle phalanges by transverse bands—the digital vaginal ligaments. It is our custom to remove the entire thecal sheath except for the vaginal ligaments, which are carefully retained as slings. When the theca has been severely damaged, or is so scarred that it needs to be completely removed (Fig. 17), it is necessary to form new slings to prevent bow-stringing of the graft (Fig. 18). These slings or pulleys may be constructed from a short length of graft.

Figure 17—Exposure of middle finger showing a previous failed graft. No thecal sheath remains. Figure 18—The same case, showing the new graft in place and the reconstructed tendon slings.
The majority of injuries occurred in patients aged between sixteen and thirty years.

TENOLYSIS

The return of active movement after tendon grafting is often slow and much patience is needed. In those cases in which the flexion range ceases to improve after six to nine months and remains obstinately less than the passive movement, it is probable that the tendon flow is limited by adhesions. It is in these cases that a considerable improvement can sometimes be obtained by tenolysis, and failure changed to success.

The operation is extensive and needs to be performed with meticulous care. It is indeed a more difficult procedure than a tendon graft. A complete exposure is essential, for the full length of the graft must be freed from all its adhesions by gentle sharp dissection. Care is taken to preserve the pulleys, and, if this proves to be impossible, new pulleys must be
TENDON GRAFTS FOR FLEXOR PROFUNDUS ONLY

RESULTS IN ALL TRACED CASES

FIG. 20

The results obtained in all traced cases (twenty-two of a total number of twenty-eight), showing the distance by which the finger tip failed to reach the distal palmar crease. Note the influence of splintage and early movements.

constituted. The operation is not completed until it is clearly established that the finger will flex to the full passive range by pulling upon the proximal end of the graft.

Active movements are encouraged after a few days. During the past year cortisone has been given for ten to fourteen days after operation in an effort to limit adhesion formation (Carstam 1953). The number of cases so treated is yet too small to enable a fair judgment to be made, but the improved results suggest that cortisone may be beneficial.

Tenolysis has not been universally successful, but in no instance has the function been decreased and in several cases there has been a marked improvement.

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RESULTS

IN ALTRACED CASES

ALL TRACED CASES (22)
SPLINTED 3 WEEKS (9)
EARLY MOVEMENTS (13)

SHOWING THE GENERAL RESULTS AND THE INFLUENCE OF SPLINTAGE AND EARLY MOVEMENTS

FIG. 21

The results obtained in all traced cases, showing the range of active movement in the distal interphalangeal joint when the finger is semiflexed. Note the influence of splintage and early movements.

RESULTS

Flexor profundus—The results are shown as graphs. The percentage of cases (individual digits) is plotted on the vertical axis. The horizontal axis shows: 1) the distance by which the finger tip fails to reach the distal palmar crease (Fig. 20); and 2) the active flexion of the terminal interphalangeal joint when the finger is semiflexed (Fig. 21). A reading of the first graph shows, for instance, that in 50 per cent of cases the finger tip reached to half an inch or less of the distal crease, and in 14 per cent of cases the tip touched the crease. The second graph shows that 86 per cent of cases obtained 30 degrees of active flexion and 9 per cent attained 70 degrees.
The result obtained from a plantaris graft to replace the divided flexor profundus tendon of the index finger. Flexor sublimis was uninjured and was not disturbed. A digital nerve suture was performed at the same time. Terminal fixation was by a tunnel in the phalanx. Splintage was maintained for three weeks. The finger tip reaches to within half an inch of the distal palmar crease.

Fig. 22

The result obtained by a toe extensor graft to replace a divided flexor profundus tendon of the little finger. Flexor sublimis was uninjured and was not disturbed. Terminal fixation was by a withdrawal suture. Splintage for three weeks. The finger tip reaches the distal palmar crease.

Fig. 23
The results obtained in all traced cases (ninety of a total number of 109), except for three cases which have been deliberately excluded because the fingers were in poor pre-operative condition. Two cases had complete nerve lesions and one had a previously failed graft with severe contracture. Note the influence of splintage and early movements.

Extension was full in all cases except four, in which there were flexion contractures at the terminal interphalangeal joints of 5, 5, 10 and 20 degrees.

There were three failures. In two instances the flexion range was very poor and for one of these patients an arthrodesis was performed; the other patient expressed herself as satisfied with the result. The third case failed owing to rupture of the graft at two weeks; the operation was repeated and 30 degrees of active flexion were obtained.

There were no complications and in no instance was a finger made worse by operation. This fact is of particular importance in this group, since an operation of this magnitude for a comparatively minor disability would stand condemned if it led to disaster.
The result obtained from a plantaris graft to replace divided flexor sublimis and profundus tendons of the middle finger. Terminal fixation was by a tunnel in the phalanx. Early movements. The finger tip reaches to within three-quarters of an inch of the distal palmar crease.

The result obtained by a palmaris graft to replace divided flexor sublimis and profundus tendons of the middle finger. Terminal fixation was by a withdrawal suture. Splintage for three weeks. The finger tip reaches to within a third of an inch of the distal palmar crease.

The general inference to be drawn from these results is that replacement of profundus in the presence of a normal sublimis is justifiable if the state of the finger is satisfactory. It should be explained to the patient that there is a good expectation of restoring a reasonable flexion range, but that only if he is very fortunate will he recover full joint movement when the finger is fully flexed (Figs. 22 and 23).
Flexor profundus and sublimis—The results are presented in a similar manner showing the
distance by which the finger tip fails to reach the distal palmar crease (Fig. 24). In this series
of ninety grafts nearly 70 per cent of the fingers could reach to within one inch or less of the
distal palmar crease, but only 9 per cent regained perfect flexion. There were twenty-nine
cases (32 per cent) in which there was a flexion contracture at the proximal interphalangeal
joint of over 5 degrees, and of these, twelve suffered from a contracture of 30 degrees or more.
A flexion deformity of 30 degrees is not a troublesome disability although it may detract
from the appearance of the hand when it occurs in the middle or ring finger. A deformity
of more than 30 degrees cannot be regarded with complacency, although all these patients
expressed themselves well satisfied with the functional improvement they had obtained.
Contractures of this degree are disquieting. The reason for their development is obscure,
for although some occurred in fingers already somewhat contracted, or in patients with
multiple finger injuries, a few occurred in fingers which were in a perfect pre-operative state.

![Fig. 27](image)

The result obtained by a toe extensor graft to replace divided flexor sublimis and profundus tendons of the
middle, ring and little fingers at one operation. The pre-operative (a) and post-operative (b) and (c) conditions
are illustrated. Terminal fixation was by a tunnel in the phalanx. Splintage for three weeks. The finger tips
reach to one and three-quarters, one and a half and one inch from the distal palmar crease. There is a flexion
contracture of 20 degrees at the proximal interphalangeal joints.

Flexion contractures (eight cases) occurred more often when early movements were given;
only four splinted cases developed contractures of over 30 degrees.

There were nine complete failures, six of which were due to adhesions and three to
rupture of the graft without undue violence. One rupture occurred in a patient who had
suffered from an original attrition rupture of his flexor tendon due to an arthritis of the wrist
joint and it is probable that the same cause was responsible for the graft rupture. The three
cases of rupture occurred in patients who had commenced gentle movements one week after
operation. Two of the failures due to adhesions happened in patients who were treated by
early movements and four in whom splintage was maintained for three weeks.

There were no complications apart from one instance of mild sepsis near the finger tip
which rapidly responded to treatment. The final result was satisfactory.
The results obtained in all cases, showing the percentage of active joint movement in relation to passive movement. Note the influence of splintage and of early movement.

It seems reasonable to conclude that a satisfactory functional result may be expected in approximately 70 to 80 per cent of patients in whom the pre-operative state of the finger is good (Figs. 25 to 27).

Flexor pollicis longus—The results are shown in three graphs depicting: 1) the percentage of active joint movement in relation to passive movement (Fig. 28); 2) the active joint range measured in degrees (Fig. 29); and 3) the influence of the graft source upon the result (Fig. 30).

The general inference is that there is a high measure of success (Figs. 31 and 32). Eighty-five per cent attained 30 degrees of joint movement and 21 per cent reached 70 degrees (Fig. 29).
In only one case did the graft fail—this was due to rupture two months later owing to unexpected severe strain. The patient was lifting a heavy suitcase from a railway carriage rack when it slipped and caught his thumb. The operation was repeated and he gained 45 degrees of active flexion.

Influence of the graft source—Palmaris longus and the toe extensor have been most frequently used and the results obtained from these grafts are compared. The thumb has been chosen as the conditions have been more uniform than in the finger. It will be seen that there is no essential difference in value, which confirms the impression gained during the years that the choice may be made for convenience and for the reasons already stated.

Influence of the after-treatment—It has been my opinion that gentle active movement commenced within a few days or a week of the operation gave more impressive results than were obtained
if splintage for three weeks was used (Pulvertaf 1948). It was therefore with great personal interest that these results were analysed. In each of the three series the influence of splintage and early movements has been compared (Figs. 21, 24 and 28), and it came as a surprise to find that there was very little difference (Figs. 33 and 34). It is noteworthy that Iselin (1955) has expressed the same opinion.

When splintage is employed it would seem wiser to hold the finger or thumb in considerable flexion. It is easier to overcome adhesions in flexion during the first few weeks following the release of splintage than to improve the flexion range. The judicious use of elastic traction will assist the return of extension, but there is no effective way of improving flexion apart from the patient's own active use.
The result obtained from a palmaris graft to replace a divided flexor pollicis longus. Terminal fixation was by a withdrawal suture. Splintage for three weeks. The interphalangeal joint range was 84 degrees.

The result obtained by: 1) a palmaris graft to replace a divided flexor pollicis longus; 2) a short graft in the palm to bridge flexor profundus of the index finger, and local removal of the divided sublimis; 3) suture of the median nerve, all at one operation. The pre-operative (a) and post-operative (b) and (c) conditions are illustrated. Terminal fixation was by a withdrawal suture. Splintage for three weeks. The interphalangeal joint range is 55 degrees. The index finger has a complete range of movement.
The result obtained from a toe extensor graft to replace divided flexor sublimis and profundus of the little finger. Terminal fixation was by suture to tendon. Splintage for three weeks. Extension, semiflexion and full flexion are illustrated. The finger tip reaches the distal palmar crease.

FIG. 34
The result obtained from a toe extensor graft to replace divided flexor sublimis and profundus of the little finger. Terminal fixation was by suture to tendon. Early movements. Extension, semiflexion and full flexion are illustrated. The finger tip reaches the distal palmar crease.

SUMMARY

1. A series of 149 consecutive cases of flexor tendon grafting in the fingers and thumb is reviewed and the results are analysed. A description of the technique which has evolved from this experience is given.
2. Replacement of a divided flexor digitorum profundus in the presence of an intact sublimis tendon restored a useful range of movement in 80 per cent of cases.
3. Replacement of both flexor digitorum profundus and sublimis gave good results in 70 to 80 per cent of cases.
4. Replacement of a divided flexor pollicis longus tendon gave good results in 85 per cent of cases.
5. The particular tendon used for the graft did not materially influence the result, but there are special indications for the use of the different tendons.
6. The choice of splintage or of early movement after operation does not appear to have a significant bearing upon the result.

7. The most important factor in determining the result is probably a precise and gentle surgical technique and complete haemostasis. Minor differences in method are of little importance. The failures in this series were due more to faulty performance of the operation than to any other single factor.

I would like to thank the many surgeons who have helped me with these cases, with special mention of Douglas Reid and Konstantin Velaskakis. I am much indebted also to Miss Peggy Coupland and to Mr J. S. Fayers, both of the Derbyshire Royal Infirmary, for their able assistance with the secretarial and with the photographic work.

Figures 7, 22 and 33 are reproduced from the Proceedings of the Sixth Congress of the International Society of Orthopaedic Surgery and Traumatology.

REFERENCES


