THE PLASTIC REPLACEMENT

OF SEVERED

FLEXOR TENDONS OF THE FINGERS

BY

THEODORE LEONARD SARKIN M.B. Ch.M.

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INTRODUCTION.

The calamity of a severed flexor tendon of the finger is due not only to the fact that the treatment is prolonged and complicated but a significantly large percentage of cases fail ever again to recover a usefully functioning finger.

The difficulty of the problem and the poorness of the results are due to many factors, but essentially the key to success lies in the total avoidance of adhesions between the tendon and the relatively firm fibrous flexor tunnel, through which the tendon passes in its journey through the digits.

Free tendon grafting, the technique most commonly performed today, in repairing this type of injury, is an attempt to transfer the site of suture from the areas of the firm fibrous tunnels to the areas of loose paratenon, where the adhesions loose their importance and no longer limit the excursion of the tendon to the same degree.

The technique of free tendon grafting however requires skill, experience and great care, whilst even in the most experienced hands, results are by no means satisfactory.

The investigation which lead to this thesis was begun with the object of developing a simple yet generally acceptable method of treating severed flexor tendons within the digital theca. Any such technique, to be satisfactory, has to fulfil certain requirements.

1. It must be simple and should require little skill and no experience.

2. Post operative rehabilitation to normal must be short and simple.

3. The results in almost all cases should be an almost complete return to normal.

4. The results obtained should endure for the life time of the patient.

A technique fulfilling these conditions has gradually been developed. Commencing with animal experiments and operations, performed on rabbits, a clinical technique has been devised whereby a severed flexor tendon within the digital theca is functionally replaced by a plastic "tendon."

This thesis is an account of the developement of this technique together with animal and other experiments presented as evidence of the safety and success of the method.

Twenty clinical cases in whom the method has been clinically performed are presented in detail, together with full post operative notes and measurements of the digital movements as they recovered.

CHAPTER I.

THE FLEXOR TENDONS OF THE FINGERS.

Introduction:

The history and developement of our knowledge of the physiology and pathology of the tendons is presented. Commencing with Galen, who in about 160 A.D., described tendons as a mixture of nerve and ligament, and strongly warned against tendon suture, our knowledge is traced up to modern times, when as recently as 1932, Mason and Shearon for the first time, described the full processes of tendon repair.

The Anatomy of the Flexor Tendons of the Digits.

The anatomy and histology of the flexor tendons and their surrounding sheaths and paratenon are described.

The tendon sheath.

The function of the sheath and how this is dependent on its architecture is described, together with its mesotenon, epitenon, endotenon and paratenon.

The entrance of the tendon into the sheath is traced and the two mechanisms, the plica simplex and the plica duplicata, upon which the glide of the tendon through the sheath is dependent, are described.

The Structure of the Tendon.

The histological structure of the tendon is described in detail, as are the musculo-tendonous junction and the tendon's insertion into the bone.

The Blood Supply of the Tendon.

The blood supply to the flexor tendons of the hand is described, together with a detailed plan of the intra-tendinous vascular pattern of supply and drainage, in both synovial and non-synovial regions.

The Lymphatic drainage of the Tendons of the Digits.

The lymphatic drainage of the tendon, in both synovial and non-synovial regions, is described together with the intra-tendinous pattern of lymphatic channels as far as they are known.

The Embryology of the Tendons.

The embryology of the flexor tendons of the fingers is described as far as it is known.

The Mechanics of Muscle Contraction of Tension.

Isometric contractions and the "all or none" law of muscular contraction are explained, together with the general mechanics of muscular contraction and its degree of efficiency.

The Co-ordination of Muscular Action.

The functional role of muscles in performing actions is described, and it is pointed out that not only are the prime movers important but the antagonists, the fixation muscles and the synergistic muscles are as important.

The Physiological motions of Tendons.

The angle of the approach of a tendon to its insertion is of importance since upon this depends whether the pull of the tendon will produce movement at the adjoining joint or simply increase it's stability.

The factors influencing the angles of approach in the fingers are described.

The Normal Tension of a Tendon.

The normal tension of a tendon is discussed. The accepted views, according to Mayer, are presented, together with a reasoned hypothesis, that our ideas of the normal tension of a tendon may be falacious.

The Mechanism of Tendon Glide.

The mechanism enabling a tendon to glide easily in areas of both paratenon and sheath are described, together with the details of the mechanisms of both the plica simplex and the plica reduplicata, which form the entrance and exit of the sheath.

The Amplitude of Excursion of a Tendon.

The importance of the amplitude of a tendon's excursion is discussed.

The Mechanics of the Movements of the Fingers and Thumb.

The movements, normally possible, of the fingers and thumb are discussed in detail, together with the mechanisms, as far as they are known, which influence and control these movements.

Muscle Balance in the Hand.

The position of rest of the hand, due to a balance between the long extensors, the long flexors and the intrinsic muscles of the hand is described, together with their importance with regard to the efficiency of the hand.

The "balance" of individual digits is also discussed, as acting on three main areas.

1. The base of the distal phalanx.
2. The base of the middle phalanx.
3. The base of the proximal phalanx.

The part played by the lumbrical muscles in the actions of the digits is also discussed.

The Pathology of tendons after Injury.

The changes which occur in a tendon after it is severed are described, and the differences in these changes depending upon whether the tendon is severed in an area surrounded by sheath or paratenon is pointed out. The importance of whether or not infection follows the severence of the tendon is also stressed.

The process of healing of a tendon.

The processes, occuring in and around a tendon during the process of healing, are followed in chronological order, from immediately after the severence of the tendon, to the stage, more than four weeks later, when it again approaches the normal.

The Strength of the Tendon during the Process of Healing.

The strength of the tendon during the various stages of healing, throughout the four weeks, is followed and described.

The Effect of function on Tendon healing.

Function has a three fold effect upon the process of tendon repair. Firstly it causes an increase in tissue reaction and proliferation. Secondly it affects the intratendinous pattern of fibres, causing them to lie longitudinally rather than haphazardly, and thirdly it results in the tendon, after the twenty-first day, continuing to gain in strength.

The process of repair in tendon grafts.

It is pointed out that a free tendon graft, initially depends for nutrition upon the surrounding lymph and tissue juices. A graft therefore tends to undergo a patchy necrosis which later undergoes a process of "creeping replacement" and revascularisation. These processes, and the effect of infection as a complication, are described in detail.

The healing of preserved homografts.

The comparison between preserved homografts and fresh autografts is made, and it is pointed out that functionally the results with preserved homografts are not as satisfactory.

CHAPTER II.

TENDON REPAIR.

Introduction:

The practical difficulties facing the surgeon are presented, and the various methods being used today are discussed, together with their advantages and disadvantages.

The History of the Developement of these contemporary methods.

The history of the treatment of severed tendons is presented, from the time of Galen to modern times.

An Evaluation of the Results of the Contemporary Methods of Treating Severed Tendons within the Digital Theca.

A critical evaluation of the methods of tendon suturing and free tendon grafting, for severed flexor tendons within the digital theca, is presented.

The methods of assessing results are critised, and the fact that the published results are from highly experienced, skilled and enthusiastic centres, is stressed.

CHAPTER III.

THE DEVELOPEMENT OF THE PLASTIC REPLACEMENT TECHNIQUE.

Introduction:

The aims and methods of the investigation are stated. The value of intraperitoneal "nembutal," as an anaesthetic in small animal surgery, is stressed.

The Polythene Plate Technique.

A method of tendon suture, allowing immediate and unprotected use of the tendon is described, in detail. The method has, it is believed, a useful place in the treatment of tendon injuries, apart from those in the hand. The technique for making and sterilising the plates of polythene, is described in detail.

Details of rabbit experiments, in which the technique is used, are described and illustrated. Tabulated results are presented.

Plastic Replacement.

The principle of the functional replacement of a severed tendon by a plastic "tendon" is presented together with its rationale. The questions that such a method raises, are presented. Experimental, clinical and other evidence is brought in answer to these questions.

The results of numerous animal and other experiments are presented in detail and/are tabulated and illustrated, being part of the work performed in developing the final technique of "plastic replacement."

The problems which mainly required elucidation and the developement of special techniques were:

1. Which plastic was the most suitable as an artificial tendon?

2. Would this substance be inert within the body?

3. What technique of fixation of the plastic would be practical?

4. Would the plastic be as strong and as lasting as a tendon?

5. Would the plastic stretch within the body?

6. Would the plastic deteriorate within the body?

CHAPTER IV.

AN ILLUSTRATED TECHNIQUE FOR THE PLASTIC REPLACEMENT OF SEVERED FLEXOR TENDONS IN THE DIGITS.

A fully detailed description of the final technique is presented together with diagramatic and photographic illustrations of the text.

The technique employed in an emergency case at the time of severence, and in a late case after skin healing has occurred, are described separately.

CHAPTER V.

A REPORT ON THE PLASTIC REPLACEMENT TECHNIQUE IN 20 CLINICAL CASES.

Each individual case is presented in detail. History, examination, operative detail and tabulated follow-up notes are presented in each case, together with photographs of pre-operative and post-operative features of many of the cases, and photographic records of the degrees of movements regained.

The series is analysed and discussed, as are individual cases.

APPENDIX.

The future offers vast possibilities that artificial "tendons" open to orthopaedic surgery is suggested. These are mainly the overcoming of paralysis, by leading "tendons" from normal muscles, over long distances, to take over the function of paralysed muscles and tendons.

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I N T R O D U C T I O N.

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INTRODUCTION.

Although an apparently minor injury, a cut which involves the flexor tendons of the fingers within the digital theca is a calamity. The treatment at best is prolonged and complicated, at worst a significant percentage of cases fail ever again to recover a usefully functioning finger.

The area between the distal crease of the palm and the middle creases of the fingers, has been called the "no mans land" of tendon surgery by Bunnel (17), since reconstruction of the flexor tendon mechanisms is most difficult and unsatisfactory in this area.

Results of tendon repair in this critical zone have undoubtedly shown steady improvement over the past thirty years, largely due to the efforts of such workers as Bunnel (18), (19), (20), (21), (22), (23), (24), (25), (26), (27), (28), (29), Meyer (124), (125), (126), (127), (128), (129), Pulvertaft (139), (140), (141) and many others, so that whereas many excellent results can be shown, on the whole, the treatment is still far from satisfactory.

The investigation which developed into this thesis was begun with the idea of developing a method, with a simple technique, which would yet give reasonable surety of re-establishing normal function in a finger which had suffered severence of its flexor tendons. It soon became very apparent, that the key to success in tendon surgery, in the fingers, lay in the avoidance of all adhesions around the tendon.

Normal flexion of the fingers depends on the intact function of two muscle-tendon units, those of the flexor digitorum sublimus and the flexor digitorum profundus. These muscles arise in the forearm and their tendons pass distally through the hand to their insertions in the fingers. The profundus tendons are inserted into the bases of the distal phalanges and their function, as far as the fingers are concerned, is flexion of all the joints of the fingers. The sublimus tendons are inserted into the bases of the middle phalanges and their function, as far as the fingers are concerned, is mainly flexion of the proximal inter-phalangeal joints.

Absence of the sublimus unit in a finger is said to make the final clench of the finger weaker, but in practice, according to Pulvertaft (140) the power for ordinary use is usually unaffected.

Surrounding the muscle-tendon units as far as the metacarpo-phalangeal joints is a loose filmy elastic medium, the paratenon. Beyond this, and as far as the proximal digital crease, the tendons pass through a relatively rigid non-elastic covering or osseo-fibrous flexor tunnel, which is differentiated into areas of lesser and greater thickening, the latter being concentrated over the phalanges to form a pulley system around which the tendons act.

During the movement of full flexion of the fihger, the usual excursion of the profundus tendon through this system is 3.3 cms. in an average man, whilst the sublimus tendon's excursion is 2.8 cms. (125).

When a tendon is divided within it's sheath, the muscle contracts, and the tendon end, in an abortive attempt to re-unite with its opposite end, attaches itself to anything in its neighbourhood. This attachement is further increased by the adhesions which form around the tendon after injury, and which occur even if a meticulous and accurate tendon repair has been performed.

Bunnel (17, 19) in an attempt to reduce these adhesions, advocated an "atraumatic technique" and developed the withdrawal suture, but no matter how meticulous the technique, some adhesions always form.

In areas where the tendon is surrounded by paratenon, these fine adhesions, which develope just as elsewhere, are not of the functional importance which they assume when they occur within the relatively rigid sheaths of the fingers (5), for in this latter situation, they seriously impair the normal excursion of the tendon. It is this fact which has made the flexor tendons of the fingers, between the metacarpo-phalangeal joint and the proximal interphalangeal joint the most difficult situation for tendon repair (90), (99), (150), (156), (162), (163), This area still sets a baffling problem to the restoration of normal function (32), (33), (39), (52), (53), (59), (61).

It is to meet these difficulties that the technique of free tendon grafting was originally devised, in an attempt to transfer the site of suture from the area of the relatively rigid sheath to the areas of loose paratenon.

Free tendon grafting, the technique usually accepted as giving the most consistently satisfactory results, (although primary suture is performed by many surgeons), consists of the replacement of the cut flexor digitorum profundus tendon between the palm of the hand and the distal phalanx with a free tendon graft, (usually taken from the palmaris longus, flexor digitorum sublimus tendon or extensor digitorum tendon to the fourth toe), together with the removal of the flexor digitorum sublimus tendon in this area.

For best results this technique requires skill, experience, and great care, and the display of what Bunnel has described as "atraumatic surgery" (19), (17).

However, an injury of the flexor tendons of the digits is a most common industrial and civilian accident (142), and whilst few tendon injuries result in death, the loss of function causes untold loss to the patient, his family, his employer and society. The hand is such a simple yet immeasurably important functioning unit with so many subtle influences on the ordinary daily mental processes and character that its importance is immeasurable.

In view of the commonness and importance of these injuries the surgical technique for their repair should be simple, safe and yet sure enough for the average practising surgeon to perform with good promise of acceptable results.

This, on the whole, is not the case with free tendon grafting (98), (107), (131). The results obtained are to a large measure in a direct ratio to the skill and experience of the surgeon, and the average practising surgeon, seldom gets the opportunity to gain sufficient skill and experience in this field, so that the majority of surgeons have found that their results with this technique are far from satisfactory, and amputation of the finger is often offered as the quickest and most practicable treatment for a severed flexor tendon within the digital theca.

Failure with free tendon grafting, however, is not always the fault of the surgeon, for even in the most experienced hands, results are not uniformly good (8), (45), (50), (51), (132), (137). Successful cases do indeed give excellent results with almost full function, but as shown by Kyle & Eyrebrook (103), Boyes (11) and others, such results form only a small total of any series, whereas a significantly large percentage of cases suffer a marked and permanent degree of limitation of movements.

The investigation which lead to this thesis was begun with the object of developing a simple yet generally acceptable method of treating severed flexor tendons within the digital theca. The technique, to be satisfactory, had to fulfil certain requirements, which when they were listed, appeared to set an almost unattainable ideal for technique and standard of results. It was felt however, that anything short of this ideal, would always be unsatisfactory. The conditions for an ideal technique with acceptable results are:-

1. The technique should be simple and should require little skill, and no experience.

2. The period of rehabilitation, during which the patient has to be off work, must be minimal and organised physiotherapy should not be essential.

3. The results, in almost all cases must be as near to normal as any patient might require.

4. The result must endure for the life-time of the patient, and allow him to perform hard active digital work, if he so wishes.

The investigation was begun by testing experimental methods and techniques in rabbits. At first the principle adopted, was that if the tendon could be kept moving, adhesions could not form. A method of suture appeared necessary therefore, which would give as strong a junction, immediately after suture, as was necessary to take the unprotected strains which might be thrown upon it.

Such a method of suture was developed. The "polythene plate" method and although this has proved to be a satisfactory method of suture, allowing early function without danger of rupture at the suture line, the principle that movement would prevent adhesions from forming, and maintain normal tendon glide and excursion, has proved entirely unfounded.

The approach to the problem was soon altered therefore. Experiments were commenced, in an attempt to find a satisfactory and safe plastic material to entirely replace the tendon within the danger zone, for it was felt that if an artificial tendon could be made strong enough and lasting enough, it would succeed, since the danger and complications of adhesions around this tendon would at once be removed.

Nylon appeared to be an ideal substance for tendon substitution, and it was therefore tested further. A great deal of experimental work being performed in the early stages, in an attempt to perfect a method of fixation of the nylon into the tendon, in a safe and simple way.

Experimentally the "nylon bypass" technique, as it was called during these experimental days, appeared very promising, but even in the early experiments in the rabbits, upon whom the operation was first practised, early hints of danger began to manifest themselves, for the degree of foreign body reaction and scar formation around the nylon, although apparently insignificant, gradually limited the full movements of the joints and resulted in limitation of passive movements and stiffness.

In early clinical cases, in whom the "nylon bypass" technique was performed, the periarticular fibrosis was even more marked, and although this was not immediately recognised as the problem with which we were contending, it became obvious that the clinical results were not reduplicating the experimental results, and return of function and range of movements were both far slower and less wide than had been hoped for.

For a time the problem appeared insurmountable. Nylon had the required strength but appeared to be acting as an irritant, and no other substance presented itself with the qualities necessary to an artificial tendon.

A series of experiments was therefore commenced in order to "insulate" the nylon by surrounding it with polythene, which is obtainable in the tube form and which is reputed to be inside the body, the most inert plastic substance known. Almost immediately the difference was obvious, foreign body reaction disappeared entirely and periarticular fibrosis no longer developed within a few weeks of the nylon implantation.

The first clinical case was then performed. Immediately the technique was vindicated, for within three days the patient could move his finger through almost a full range of movements and as the days and weeks passed and function was maintained with no fibrous tissue or scar formation occurring, it became obvious that the polythene was adequately performing its function as an "insulator" to the nylon.

Five clinical cases have now been treated with this technique and all have uniformly given the same rapid and excellent results which the idea originally gave promise of. The technique appears therefore to fulfill nearly all the requisites which are laid down for an ideal method.

One condition still remains to be proven. Will the plastic last the life-time of the patient? A great deal of experimental evidence has been amassed which indicates that the plastic and its fixation are adequately permanent, but for the final and only conclusive proof to this question - time alone appears to hold the answer!

CHAPTER ONE.

THE FLEXOR TENDONS OF THE FINGERS

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INTRODUCTION.

The ancients were aware of the approximate uses of the various muscles, for the injuries, which they sustained, during their wars and whilst hunting, revealed to them the essential part played by the muscles.

Galen, in about 160 A.D., described the involuntary muscles and understood the action of antogonistic muscles and muscle tone, and showed that ligation of a motor nerve resulted in paralysis of its muscle. The accepted physiology of this time was that the animal spirits consisted of "nitro-aerial spirit" (oxygen) and that, in the muscle, these met with "salino-sulphureous particles" (combustible material) carried there by the blood, with the result that an "effervescence" in the muscle occurred, causing it to swell or contract. Hence, in exercise, there was deeper breathing, to supply more "nitro-aerial spirit."

Galen even went as far as to suggest the differences in function of tendons, nerves and ligaments, but considered tendons to be a mixture of nerve and ligament, and strongly warned against tendon suture since he considered that suture within nerve substance would be followed by severe pain, twitchings and convulsions (119).

Galen's teachings of the constitution and physiology of tendon function influenced medical practice for nearly sixteen centuries. The confusion between ligament and nerve and the dangers of pricking nerve substance appearing repeatedly in the literature until as late as the middle of the nineteenth century, when Strohmeyer and Dieffenbach popularized the operation of tenotomy for clubfoot and finally ended the centuries old belief of the great sensitivity of tendon. During this period, between the time of Galen in the second century and Mechnen in 1682, little research work was directed towards the elucidation of the actual anatomy or physiology of tendons, although Avicenna, the Arabian physician, in the tenth century probably realised the true situation, for he advocated tendon surgery and practised it.

In 1682 Mechnen, in an attempt to refute the teachings of Galen, performed experiments to test the sensitivity of tendon tissue. He found no evidence that the tendons were sensitive or that their pricking or injury caused pain. The maxim, however, never to pass a needle through a tendon, continued to have a great hold on the medical profession and experiments to determine the sensitivity of tendon tissue continued to be performed up to as late as the middle of the eighteenth century when Albrecht von Hallen conclusively demonstrated that tendons were insensible.

Research work in the meantime was being directed towards an appreciation of the contraction, excitability and general physiology of muscles and tendons. Boerhaares' "Institutiones Medicae" in 1708, the first textbook in physiology, marked the commencement of the formal treatment of the subject. In 1757 von Haller, the dominant physiologist of his time, collected together all the contemporary knowledge in his "Elementa Physiologicae Corporis Humani", but still rejected the idea put forward a few years before by Hauser that the stimulation of the muscle to contraction was electrical in nature via the nerve.

In 1767, Hunter, attempted for the first time experimentally, in dogs, to study the actual process of tendon repair and described the process as akin to the formation of bone callus in the repair of fractures. In 1837, van Ammon, experimenting in a similar way, described the process rather as a regeneration of new tendon, from the tendon stumps, which grew into a formless exudate, which filled the defect between the divided tandon ends. Bouvier and Velpeau, on the other hand, considered that the new tissue owed its origin mainly to the sheath tissue about the tendon.

A period was now entered into during which tendon sutures were widely performed, with varying degrees of success. The experimental work of the period being largely directed towards the actual process of tendon repair. The questions of the value or otherwise, of the exudate between the tendon ends, and the part that the sheath played in tendon regeneration, were warmly contested. Pirogoff, Bouvier, Thierfelder, Boner, Feltz, Dembowski and many of the other well known experimenters of the period, contending that the exudate was the conditio sine qua non for tendon repair, whilst Billroth and Adams asserted that the exudate hindered growth of the scar.

Dembowski, based his conclusions on experiments which he performed, in which he observed that cells in the new tendon contained a dye that he had previously injected into the blood stream. He believed that the new tendon was formed by cells that wandered into the defect from the blood.

A new problem began to intrude itself, from the beginning of the present century, namely the question of the importance of function on the healing of tendons. Barfurth, Solger and Roux noted the importance of stress on the repair of a tendon, and maintained that they were important factors in tendon regeneration. Ribbert however, asserted that function played a minor role and that each tissue had the innate power of reproducing itself. He believed that, regardless of function or tension, tendon proliferation resulted in the production of tendon. Kirschner, in experimental work, found that tendon grafts, whether subjected to function or not, remained alive, at least partly, but tended to lose their orderly parallel structure. Rehn went further and studied the effects of transplantation on all sorts of tissue, grafted into tendon defects. He showed that a tendon graft without function, underwent retrogressive changes and practically disappeared, whilst, if subjected to function and placed under tension, not only did the graft remain viable, but it became incorporated and replaced the lost tissue efficiently.

Clinical experience at this stage was being quoted as demonstrating that the healing power within a synovial sheath was poor, and in 1917 Bier and later Salamon propounded a theory that the synovial fluid contained a hormone which inhibited tendon regeneration.

Wehner, however, in experiments designed to disprove Biers theory, excised the patella in dogs and sutured the patella tendon across the open knee joint where the suture line was constantly bathed in synovial fluid. In spite of this, there was perfect regeneration of the tendon.

Gradually two reasons for the poor healing of tendons in synovial sheaths became accepted, firstly the poor blood supply and poor regenerative power of the tendon itself and secondly the absence of peritendinous tissue around the tendon. Bloch and Bonnet, in a long report on tendon surgery of the hand, before the French Congress of Surgery in 1929 profounded the view that the tendon cells themselves probably played a very minor role in the formation of the regenerated tendon, the repair being mainly dependent upon peritendinous tissue. It was however as recently as 1932 that Mason and Shearon (119) in their classic and detailed experiments on tendon regeneration, described for the first time the full processes of tendon repair.

THE ANATOMY OF THE FLEXOR TENDONS OF THE DIGITS.

(35), (42), (65), (85), (120).

Flexion of the fingers is largely dependent upon the flexor digitorum profundus and sublimus muscles, whilst flexion of the thumb is produced by the flexor pollicis longus muscle.

The Flexor Digitorum Profundus is a long thick muscle, that lies deeply amongst the muscles in the front compartment of the forearm, becoming more superficial medially. Its chief origin is from the upper three-quarters of the medial and anterior surfaces of the ulna, the thick belly becoming a thick tendinous mass which divides into four tendons, one for each finger, only the tendon for the forefinger becoming separate and distinct in the forearm. Leaving the forearm, the tandons all pass through the carpal tunnel into the palm where the flexor tendons diverge, one passing to each finger.

The flexor digitorum sublimus muscle is superficial to the flexor profundus, hence its name, but for the most part it lies deep to the muscles which form the superficial group of the forearm. It is a powerful muscle and arises by two heads, one from the medial epicondyle and the coronoid process, the other by a thin sheet, from the upper half of the anterior border of the radius. Four tendons issue from the fleshy mass and enter the palm under cover of the flexor retinaculum.

The flexor retinaculum is attached to the hamate and pisiform medially and the scaphoid and trapezium laterally. These carpal bones provide four bony prominences, the tuberosity of the scaphoid, the oblique ridge of the trapezium, the pisiform and the hook of the hamate which act as hooks to make the flexor tendons converge as they glide through the narrow channel of the wrist.

The two projections on the ulnar side are more prominent, being more necessary to hold in the tendons, as ulnar flexion is greater than radial flexion. The channel between these prominent bones is oblique, so that when the wrist is in its natural position of ulnar flexion the channel is in line with the forearm.

Behind the flexor retihaculum the flexor tendons become arranged in pairs, those for the little and index fingers lying behind those for the ring and middle fingers.

The flexor pollicis longus muscle lies deeply in the forearm, taking origin chiefly from the upper two-thirds of the front of the radius. The tendon which issues from the fleshy belly passes through the carpal tunnel, turning laterally into the palm. The tendon then passes along the lower margin of the thenar eminence between the flexor pollicis brevis and adductor pollicis muscles to the thumb. It is inserted into the base of the terminal phalanx.

As the flexor tendons of the fingers pass behind the flexor retinaculum they are enveloped in a sheath known as the common flexor sheath which is invaginated by the tendons from the lateral side. (Fig. 1).

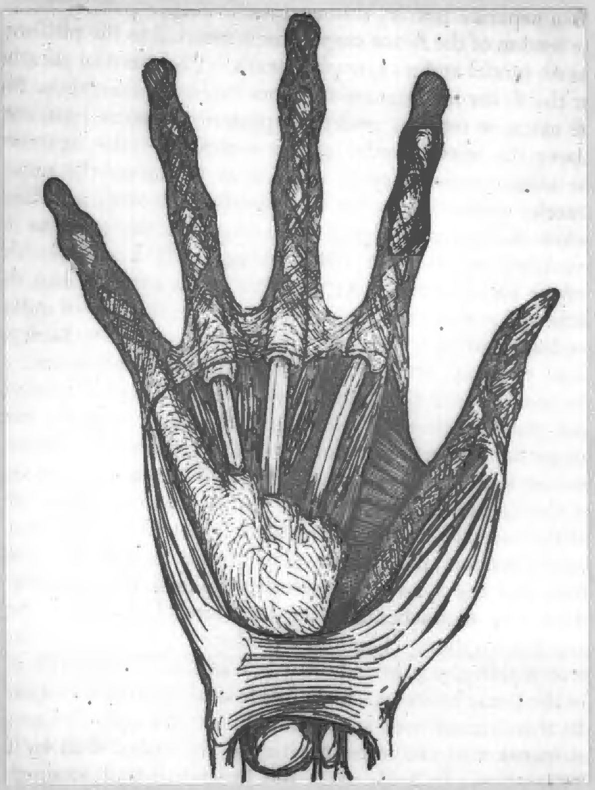

Fig. 1: The synovial sheaths of the flexor tendons of the wrist and digits. (After Poirier).

The common flexor sheath sometimes communicates with the sheath surrounding the flexor pollicis longus tendon, which is commonly called the radial bursa. The sheath lines the "carpal tunnel", a tunnel bounded by the flexor retinaculum and the carpal bones. The sheath greatly facilitates the free play of the tendons through this tunnel, being prolonged as it is both into the forearm for about an inch, and into the palm, on the diverging flexor tendons. The portion ensheathing the tendons to the index, middle and ring fingers ends near the middle of the palm, whilst the portion ensheathing the tendon to the little finger, and the sheath of the flexor pollicis longus tendon are prolonged into their digits as far as the insertion of the tendon into the base of the terminal phalanx. In the terminal part of their course they line the fibrous flexor sheaths. New synovial sheaths form to ensheath the tendons of the index, middle and ring fingers and to line the fibrous flexor sheaths of those digits.

The fibrous flexor sheaths are a part of an osteofibrous canal which lodges the flexor tendons enclosed in a synovial sheath. They are simply the condensed and thickened deep fascia of the front of the digits. Their function is to hold the flexor tendons in contact with the palmar surface of the phalanges and joints, during flexion of the digits. Each fibrous flexor sheath is an elongated plate curved round the front and sides of the flexor tendons. Its edges are attached to the margins of the phalanges, the metacarpo-phalangeal joints and interphalangeal joints, and to the margins of the palmar ligaments of those joints. Its distal end is attached to the palmar surface of the distal phalanx, immediately beyond the insertion of the flexor profundus tendon. At its proximal end it is continous with the palmar aponeurosis.

The flexor sheath consists chiefly of transverse fibres, being very dense opposite the phalanges (6), but thinner and weaker opposite the joints, in order not to interfere with the flexion of those joints.

In the fingers, the fibrous flexor sheaths, lined by synovial membrane, contain the flexor sublimus and profundus tendons. In the thumb, it contains the flexor pollicis longus tendon alone.

The synovial sheaths of the thumb and little finger have been described above. In the index, middle and ring fingers the sheath extends from the middle of the palm, to the insertion of the tendon into the base of the terminal phalanx, but it is not continuous with the common flexor sheath.

Also lined by the synovial membrane, are the vincula tendinum, the fibrous structures carrying blood vessles to the tendons. There are two kinds of vincula, the long and the short. The vincula brevia are triangular in shape and are set into the angle formed by the tendon at its insertion ihto the phalanx. The vincula longa are very slender bands situated nearer the root of the finger.

Into each finger two flexor tendons pass, one from the flexor sublimus and one from the flexor profundus. The tendons pass along the palmar surfaces of the phalanges, and are held in position by the fibrous flexor sheaths. On the palmar surface of the first phalanx, the tendon of the flexor sublimus becomes flattened and folded around the subjacent tendon of the flexor profundus. The sublimus tendon then splits into two parts which pass behind the tendon of the flexor profundus. The reversed edges of the two parts of the sublimus tendon then fuse together and partly decussate; to diverge again before being inserted into the borders of the shaft of the second phalanx. The tendon of the flexor profundus, passes on and through the split sublimus tendon to be inserted into the palmar surface of the base of the terminal phalanx. This arrangement is found in each of the four fingers.

Arising from the radial or adjacent sides of the tendons of the flexor profundus, in the palm, are slender fleshy bellies of the four lumbrical muscles, their delicate tendons passing backwards across the radial sides of the metacarpo-phalangeal joints to be inserted with the inter-osseous muscle into the extensor expansion on the dorsum of the fingers.

The flexor digitorum profundus is supplied by the anterior interosseous branch of the median nerve and by the ulnar nerve. It is a flexor of all the joints of the fingers, as well as of the wrist.

The flexor digitorum sublimus is supplied by the median nerve. It is a flexor of the proximal inter-phalangeal joints, the metacarpo-phalangeal joints and the wrist joints.

The flexor pollicis longus muscle is supplied by the anterior interosseous nerve and it is a flexor of all the joints of the thumb and wrist.

THE TENDON SHEATH AND THE CONNECTIVE-TISSUE STRUCTURES ASSOCIATED WITH THE TENDON.

A tendon sheath is found whenever a tendon at some phase of its motion is forced to turn a corner (125). The object of the sheath is probably to act as a fluid buffer where the tendon would otherwise rub against bone or ligament. It does not give the tendon an increased range of movement, since the tendon glides as freely above the sheath as within it, it simply facilitates the full range of glide. A tendon sheath differs from a bursa only in its degree of developement. The sheath when fully developed, fully encloses the tendon, a bursa protects a relatively small portion of the circumference of a tendon.

Retterer, a French embryologist claimed that the sheaths were not closed at their ends, but that they merged with the connective tissue. Meyer (125) disagreed with this and showed that the sheaths are closed at both ends by a very thin, yet definite lining membrane.

(1) <u>The Wall of the Sheath</u>.

The wall of the sheath is lined with a layer of synovial cells, which are probably modified connective tissue cells, developed from the undifferentiated embryonal connective tissue, which surrounds the foetal tendon. The synovial layer is present in all parts of the sheath, but need not be the only lining of the sheath, however, for between it and the outer fibrous layer of the wall of the sheath, may be interposed fatty areolar tissue. In other parts the synovial layer is the only lining and is firmly adherent to the outer fibrous layer.

(ii) The Mesotenon, Epitenon and Endotenon.

The mesotenon is the delicate connective tissue membrane connecting the tendon with the floor of the sheath, and transmits the blood-vessels. The line along the tendon, into which the mesotenon is inserted, is called the hilus. It is always on the least exposed surface of the tendon to friction. The connective tissue of the mesotenon expands on the surface of the tendon to form the epitenon, and sends connective tissue strands between the tendon bundles to form the endotenon.

The mesotenon when stretched to its maximum width may be as much as 3 to 4 cms., diminishing as it approaches the insertion of the tendon. The mesotenon is continuous with the connective tissue surrounding the tendon above and below the sheath, the mesotenon normally forming numerous folds as it covers the floor of the sheath.

In certain cases the mesotenon may be completely absent, being represented at each end of the sheath by a short membrane, the vincula. Usually in addition there are one or more fine strands connecting the tendon with the sheath, the vincula filiformia. These residual mesotena are usually coupled to one another, on the surface of the tendon corresponding to the hilus, by a thin band of connective tissue in which blood vessels ramify.

(iii) The Paratenon.

Above the sheath the tendon is surrounded by fatty areolar tissue called paratenon, which completely fills all the interstices of the fascial compartment, in which the tendon is situated.

(iv) The Entrance of the Tendon into the Sheath.

The portion of the tendon above the sheath is separated from the deep fascia by paratenon. At the commencement of the sheath, the paratenon becomes continuous with the sheath. The closed end of the sheath is not a simple boundary but consists of a fold, which may reduplicate, to form a superficial and a deep pocket, called a plica reduplicata. If the end of the sheath is a simple boundary, without reduplication, it is called a plica simplex. (Fig. 2) The plica reduplicata is usually found at the upper end of the sheath, whilst the plica simplex is found at the lower end commonly.

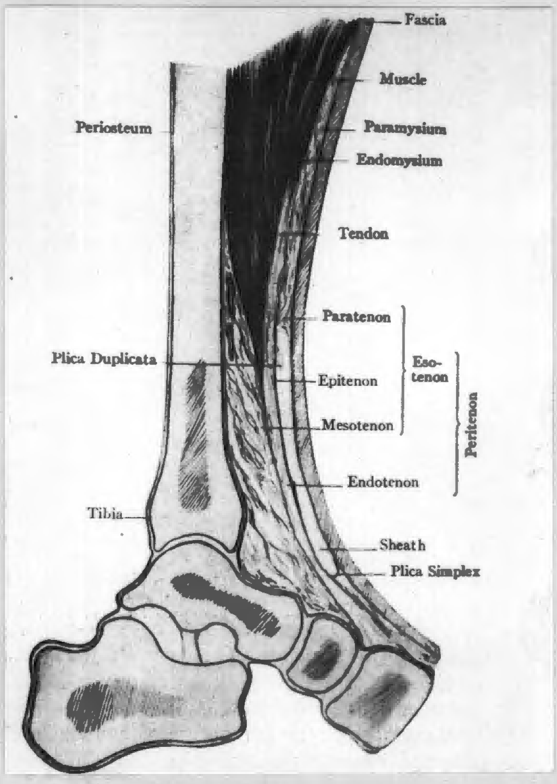

Fig. 2 : A diagrammatic representation of the Tendon and its Mechanism of Glide. (After L. Meyer (125)).

THE STRUCTURE OF THE TENDON.

Tendons are composed almost entirely of white fibrous tissue, which is a true connecting structure developing in response to tensile strains in situations where strength is required without rigidity or elasticity (146).

In white fibrous tissue, as its name implies, the white fibres predominate (146), the matrix being only a cement substance, and comparatively few yellow elastic fibres being seen. The tissue cells are also arranged in a special manner (166).

To the naked eye, tendon has a silvery white glistening appearance. It is devoid of elasticity and has only the very slightest extensibility, but is exceedingly strong so that the application of any external force to a tendon is more likely to fracture the bone to which the tendon is attached than to tear the tendon itself (114), (121), (122).

The fibres in a tendon run parallel with each other, whilst the cells which are often called "tendon-cells" are situated on the surfaces of groups of fibres, and are arranged in single rows, each cell being separated from its neighbours by a narrow line of cement substance. The nucleus is generally situated at one end of the cell, the nucleus of the adjoining cell being in close proximity to it. (Fig. 3 (a)). The tendon cells have winglike processes which pass between the bundles of fibres, giving a stellate appearance in transverse section. (Fig. 3 (b)). In longitudual section, the cell, with its wings, is quadrilateral, and there may be the appearance of a vertical line on the body of the cell owing to the projection of a wing towards the eye of the observer (146).

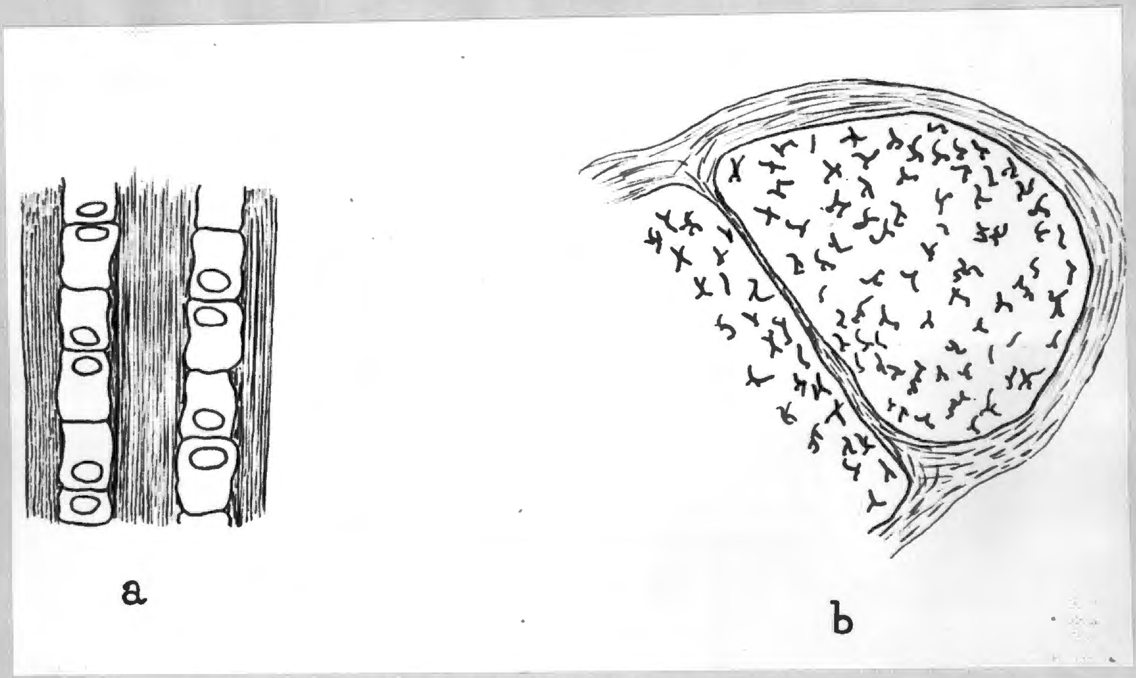

Fig. 3: (a) Chains of tendon cells.
(b) Transversesection through a tendon, showing the winglike processes between the bundles of fibres, from the tendon cells.

White fibrous tissue is composed of collagen, which is regarded as the anhydride of gelatin, and it may be converted almost completely to gelatin when boiled in water.

The tendon itself is composed of separate units or fascicles, each of which is roughly hexagonal in shape and each of which is composed of these closely packed collagen fibres. Between these fascicles lies the interfascicular tissue or endotenon, which not only binds together the fascicles, but also carries the vessels of the tendon (48), and gives to the tendon certain of the properties of a laminated spring, which facilitates internal movement of the tendon.

There is a characteristic limit 0.125 to 0.375 sq. mms. to the cross-sectional area of a fascicle, these limits probably being related to its nutritional requirements.

At the musculo-tendinous junction, a group of muscle fibres enclosed in perimysium, continues into the tendon, to become the tendon fascicle, surrounded by endotenon. Each muscle fibre being continued as a collagen bundle.

At the tendon's insertion the collagen bundles, composing the fascicle, are continued into the bone as the perforating fibres of Sharpey, whilst the endotenon becomes continous with the periosteum.

THE BLOOD SUPPLY OF THE TENDONS OF THE HAND.

(43), (48)

In 1850 Kollicker expressed the opinion that tendons have no blood-supply. In 1872 however, Ludwig and Schweigger-Seidel showed that intratendinous vessels existed, whilst Mayer (125), in 1916, in a much more detailed description, pointed out that tendons may receive blood vessels in 4 regions.

(i) At the musculo-tendinous junction

(ii) At the osteo-tendinous junction

(iii) Through the paratenon surrounding the tendon in extra synovial regions.

(iv) Through mesenteric attachments of vincula, in synovial regions.

In 1946 Edwards (48), showed that the vessels of a tendon are arranged around the collagen bundles of the tendon, and that there is a simple blood-vascular system consisting of a series of longitudinal channels parallel to the collagen bundles, with frequent cross-anastomosis. Each intra-tendinous longitudinal channel being composed of a small arterial vessel accompanied by two small veins.

The blood supply to tendons in non-synovial regions.

In areas where the tendons pass through paratenon, the blood supply to the tendons is via vessels which pass through the loose tissue at frequent intervals (147). The vessels are arranged in curves, so that when the tendon moves, the curves are straightened out. The connecting vessels consist of an artery and two small accompanying veins, with frequent anastomoses between the veins. The diameter of the veins is slightly greater than that of the artery and one of the veins is usually much larger than the other.

At the musculotendonous junction these vessels, on entering, divide into two branches, one branch passes into the muscle, the other into the tendon, whilst a further blood supply to the tendon in this area occurs from vessels which pass into the tendon from the muscle belly.

In the palm, the tendons of the flexor digitorum sublimus and profundus tendons, lie within the palmar bursa, but are still surrounded by a certain amount of loose connective tissue which is continous, both above and below the bursa, with the paratenon. The vessels of supply to the tendon run through this loose connective tissue, making numerous connections with the vessels within the tendon.

These vessels are so arranged as to allow the gliding motion of the tendon to occur unhampered. The feeding vessels to the sublimus tendon are formed in arcades, usually three in number, from the most distal of which connections are made with the intratendonous vessels.

Within the digital sheath the arrangement is somewhat different, since the visceral layer of the synovial membrane of the sheath is closely adherent to the tendons, without any intervening loose connective tissue, except in a few sites where function is minimal. Vessels can therefore enter the tendon, within the sheath, at certain sites only. These are:

(a) At the insertion of the tendons. Near the insertion of the sublimus slips, at the proximal interphalangeal joints, are vessels which supply the capsule. From these vessels branches pass distally and proximally, along the slips of the sublimus tendon to supply the tendon.

(b) Through certain synovial bands or vincula.

(i) The vinculum brevium is a synovial reflection near the insertion of the profundus tendon into the distal phalanx. Tiny vessels run through the vinculum brevium to supply the tendon.

(ii) The vinculum longum is a synovial reflection near the insertion of the flexor digitorum sublimus tendon, through which tiny vessels run to supply it.

(c) Vessels enter at the points of reflection of the synovial sheaths onto the tendons at the proximal and distal ends of the digital sheaths.

Having reached the tendon, the vessels form a main longitudinal vessel on the dorsum of the tendon, comprising a small artery accompanied by two veins. These vessels are surrounded by a little loose connective tissue deep to the synovial membrane. This dorsal position is one of minimal friction, for it is only in this dorsal position that the synovial membrane is not firmly bound down to the tendon.

From this main longitudinal vessel, branches enter the tendon and once within the tendon are arranged into a definate pattern.

The arteries veins and capilliaries are arranged as longitudinal vessels lying parallel to and between the actual collagen bundles of the tendon. Each arteriole is accompanied by two venules which anastomose at frequent intervals. (Fig. 4). One is usually larger than the other.

This pattern is found in all the flexor tendons of the hand, except in the flexor digitorum profundus tendon, in the region of the proximal and distal interphalangeal joints. In this area the usual longitudinal pattern is

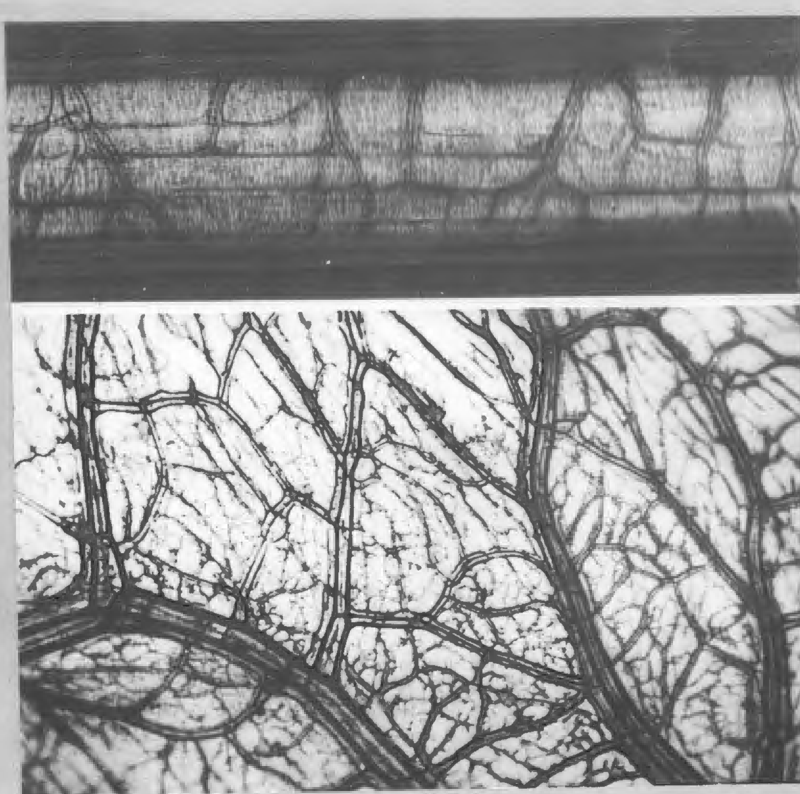

Fig. 4: (a) The arteries and venae comitantes of a tendon.
(b) The arteries and venae comitantes under greater magnification. (From D.A.W. Edwards (48)).

upset and is replaced by vascular loops which pass vertically through the tendon substance. It is probable that this altered arrangement of the vessels is related to the fact that the tendon, in these areas, has to bend to a marked degree during full flexion of the finger. If the vessels were not so arranged, the blood flow at these points might well become obstructed during flexion.

THE LYMPHATIC DRAINAGE OF THE TENDONS OF THE DIGITS.

Apart from blood vessels, the endotenon also carries the lymphatics of the tendon (48). The lymphatic channels follow the same course as the arteries (75) and form a characteristic plexus composed of two or three large vessels, of very irregular bore, with many inter-connections which form a close meshwork surrounding the artery and veins. (Fig. 5)

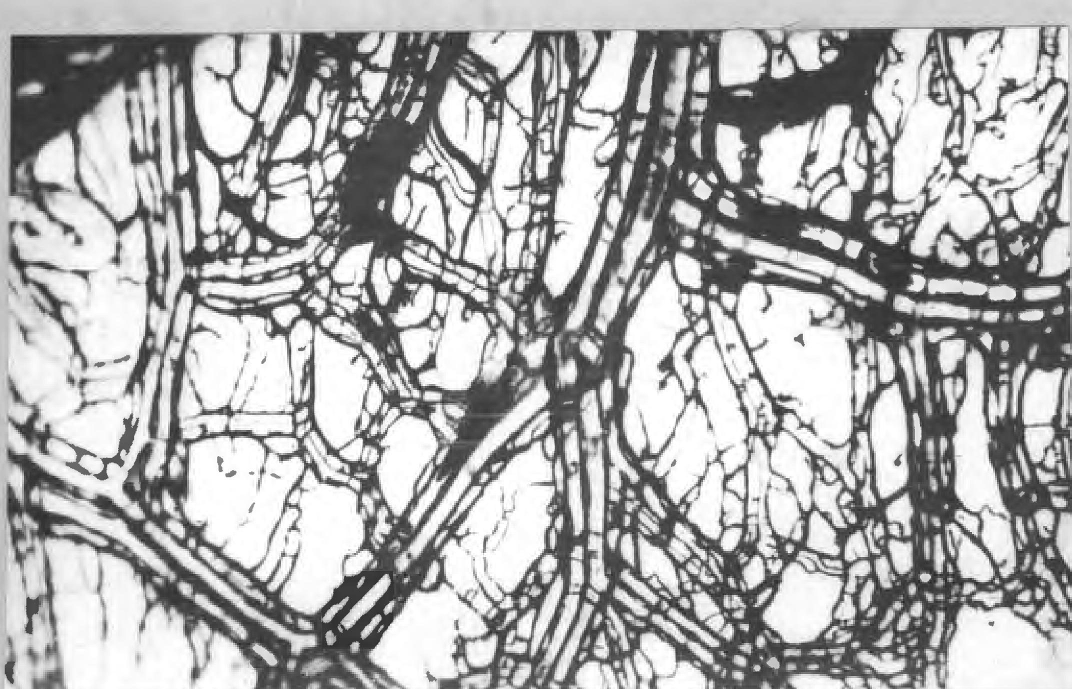

Fig. 5: The lymphatic vessels of the tendon. Note the arrangement of four parallel vessels with clear spaces between, where the artery and venae comitantes are to be found. (After D.A.W. Edwards (48)).

The tributaries of the plexus are short, blindly ending capilliaries, lying in the endotenon and extending only a short distance from the main stem.

Connections of this intra-tendinous lymphatic system with the external lymphatics, are located at four sites:

(a) At the musculo-tendinous junction - Superficial lymphatic vessels drain from the surface of the tendon into the muscle sheath and into the perimysium. It is doubtful whether there are any deeper lymph vessels of the tendon draining into the perimysium in this area.

(b) At the osseo-tendinous junction. Relatively large lymph vessels, communicate with the deeper channels of the tendon, in this area, but there is no definite demonstration of deeper lymphatics.

(c) Where the tendon has no synovial sheath - In this area the drainage is into vessels which run alongside the arterial channels.

(d) Where the tendon lies within the synovial sheath - The lymphatic drainage is into the mesotenon, where there are usually four lymphatics accompanying the artery. They are of larger bore than the artery and their lumen is irregular, and they acquire valves, just shortly before entering the mesotenon. Within a few centimetres of the mesotenon the four lymphatics fuse to form a single vessel which may become double again for short distances, eventually joining the general lymphatic drainage of the area.

THE MECHANICS OF MUSCLE CONTRACTION AND TENSION.

For an understanding of the normal movements and mechanics of the hand, some knowledge of the muscles initiating and stabilising these movements is necessary, for muscles can both cause and prevent movement. When a muscle fibre is stimulated, it develops within itself a state of tension, and its subsequent behaviour depends on conditions external to it. If there is no resistance, the fibre contracts and causes movement, if there is resistance which it is unable to overcome, movement is absent or minimal and the contraction is said to be "isometric." The former process is used in making movement, the latter in maintaining posture. Individual fibres however follow the "all or none" law and therefore the power exerted by a contracting muscle is proportionate to the number of fibres in action (143). For the maintenance of posture, the number of fibres in use simultaneously is small and there is a continual change of contracting fibres which reduces fatigue to a minimum.

Individual muscle fibres, when isolated, are able to shorten to as much as thirty to forty per cent of their uncontracted length. Since, however, muscles are attached to rigid bones, the actual total amount of shortening of a muscle is usually only a small percentage of the distance between its origin and insertion, and therefore a long muscle often does not have a greater length of excursion than a short muscle. This means therefore that a short muscle belly, with a long tendon to its insertion, may produce as much actual excursion as a longer muscle would, and is therefore a much more efficient arrangement, since muscle has a high metabolic requirement whilst the white fibrous tissue of tendon has a low metabolic requirement.

THE CO-ORDINATION OF MUSCULAR ACTIONS TO GIVE EFFECTIVE MOVEMENT.

The actions of muscles are often calculated from the relationship of their "line of pull" to the axes of the movements of the joints over which they pass, and theoretically a muscle is capable of acting on every joint over which it passes.

It is movements, however, and not individual muscles which are represented in the cerebral cortex. Therefore the action of a muscle does not necessarily depend upon the mechanics of its attachments (63).

In normal motion, any particular movement requires a co-ordinated combination of muscles to carry out that movement. No muscle can be omitted nor can one be added voluntarily (152).

In this co-ordinated group of muscles responsible for a single planned movement, there are subgroups of muscles each of which plays a functional role in the provision of the final total effect.

(a) There are one or more muscles primarily responsible for the main component of the movement - the muscle is called the prime mover.

(b) The muscles, which on contraction would cause exactly the opposite movment to to those of the prime mover, must of necessity relax during the contraction of the prime movers. These muscles are called the antagonists.

(c) For the prime mover to act with full effect one of its attachements (usually the origin) must be fixed. Certain muscles by contracting fix this origin and are therefore essential components in obtaining the final total effective movement planned. These muscles are therefore called fixation muscles.

(d) There is still a further group of muscles essential to a co-ordinated movement. Many muscles pass over several joints before reaching their insertion. If special muscles did not tense, to prevent these intermediate joints from moving, unnecessary and hampering movements would occur. These special muscles are called synergistic muscles.

For example, in the planned co-ordinated movement of clenching the fist, the prime movers are the flexors of the fingers, the flexor and adductor of the thumb and the opponens pollicis muscle. Since these same flexors would also act on the wrist joint and hamper the movement of clenching the fist, the extensors contract to steady the wrist and obviate this hampering and undesirable associated movement. In this action therefore the extensor muscles are the synergistic muscles.

It is apparent therefore that the efficient performance of any movement depends on the proper co-ordination of prime movers, antagonists, fixation and synergic muscles. This co-ordination is ensured by the manifold connections which exist within the central nervous system.

THE PHYSIOLOGY OF MOTION OF THE TENDONS' AND MUSCLES.

Angles of Approach and Leverage.

The muscles of the limbs are with few exceptions, inserted immediately distal to the joint on which they exert their principal action. This arrangement results in a loss of mechanical advantage, but what is lost in power is made up in speed (89).

For example, rapid movements of the hand can be produced by a relatively short contraction of the Brachialis muscle, which is inserted into the coronoid process of the ulna. When the Brachialis muscle contracts, its insertion moves round an arc of a circle with a very short radius, but in the same period of time the hand is moved round the corresponding arc of a circle whose radius is the length of the forearm. This results in a rapid and wide range of movement.

In any movement, in order that the tendon of the prime mover may move a joint, it must fulfil two requirements. Firstly there must be sufficient length of lever arm between the insertion of the tendon and the centre of motion of the joint, and secondly the angle between the line ofpull of the tendon and the axis of the part to be moved must be at least in the neighbourhood of 20 to 30 degrees. (Fig. 6).

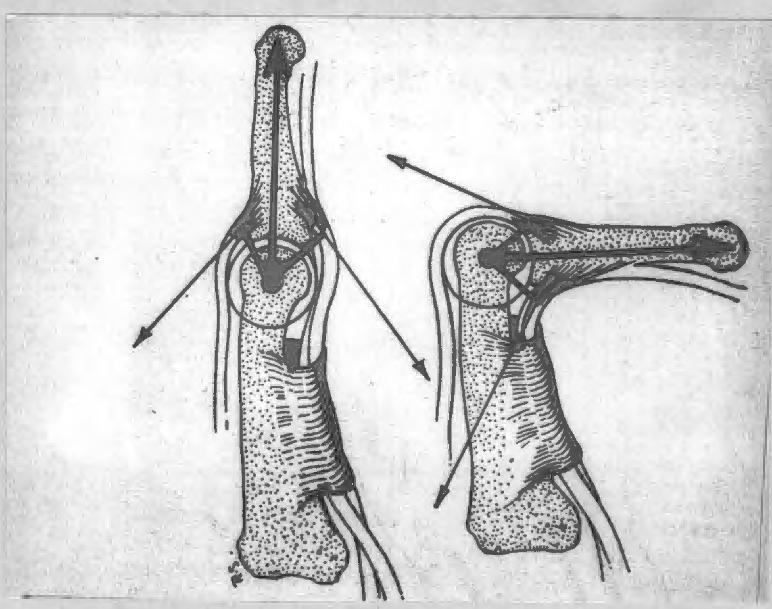

Fig. 6: Mechanics of a finger joint showing the circle and center of movement, and the angles of approach of the tendons in both extension and flexion.

The greater the angle, the greater the movement the tendon produces, and conversely, the less the angle the less movement it produces, but the greater its stabilizing effect on the joint. Mathematically, the force of these two tendon actions, flexion and stabilization, is proportional to sine and cosine of the angle of approach.

As flexion continues, the angle of approach rapidly increases and the tendon gains in rotating effect but looses in stabilizing effect, until the stage is reached where the angle of pull is a right angle, and the whole force is expended on rotation and none is expended on stability.

The flexors of the fingers illustrate the above principles clearly and are good examples of tendons with an average angle of approach.

Factors increasing the angle of approach of the flexor tendons of the hand are firstly that at the distal end of each long bone in the hand is a definite expansion, which serves the useful function of deviating the tendon, just prior to its insertion, and thus increasing the angle of approach. The angle of approach of the flexor digitorum profundus tendon is further increased and regulated by the loop which the flexor digitorum sublimus tendon makes as it straddles it. The pulleys which bow the profundus tendon dorsal-ward as it passes the shafts of the metacarpals and phalanges also increase the angle of approach of the tendon since they force it to undulate volarward at a sharper angle than it would otherwise need to do to pass over the projecting proximal bone, articular cartilage and capsule, at the joints.

The pulleys in the digits, and the retinaculum at the wrist, also prevent the tendons from bowing across the joints on strong flexion, which would destroy the efficiency of the tendon's action by causing too much slack.

THE NORMAL TENSION OF A TENDON.

There are two definitions or methods of measuring the tension in a tendon. The first is clinical. When relaxed every joint assumes a normal and accepted physiological position of rest. If there is undue tension in any tendon acting on the joint, or undue slack either from paralysis of the muscle or functional or true lengthening of the tendon, this position of rest is disturbed. This gives a method of assessing tendon tension. The second method of stating the tension in a tendon is based upon the experimental observations of L. Meyer (125) namely, that when the origin and insertion of a muscle are separated, the tension in the tendon gradually rises so that eventually it is impossible purely by traction to approximate the tendon to its insertion. Conversely when the origin and insertion are approximated, the tendon ends contact without tension eventually. Therefore when origin is approximated to insertion the tendon is without any tension.

It will be seen that neither of these difinitions or measurements makes any attempt at exactitude, a task which in fact is impossible. Are there in fact normal limits to the tension of a tendon? It is obvious that since the muscle has the properties of an elastic body, increases in tension of the tendon, due for example to shortening, or decreases in tension of the tendon due to lengthening of the tendon, will to some degree be compensated for by muscle relaxation or contraction. Whether, however, this compensatory ability of the muscle is limited to set boundaries, is still disputable.

Is there in actual fact a state of "tight tendons" or "lax tendons", which are beyond the degree of physiological compensation by the muscle (67). Can the muscle not, in time, always undergo adaptive lengthening or shortening, if given the opportunity and if physiological, and not pathological processes are present such as muscle fibrosis or paralysis.) ? meaning

The possibility that "tight" and "lax" tendons are in fact much less well defined entities, and can be physiological, is of great importance, when problems of tendon suture, tendon graft and tendon replacement are considered.

The further possibility that one or other of these usually accepted abnormalities of tendon tension might well be physiologically acceptable to the muscle must also be considered. For example, is it not possible that laxity of tendon can always be "taken up" and compensated for by muscle adaptation even if tendon "shortening" cannot be, or vice versa.

In fact the usually accepted ideas of tendon tension are not necessarily substantiated and some of the results of tendon replacement which will be presented later tend to show that the usually accepted ideas of the tension under which grafts should be inserted might possibly be erroneous (86). This is a possible contributing cause to the great length of time which recovery of full function takes even in successful cases of free tendon grafts in the digits.

THE MECHANISM OF TENDON GLIDE.

In areas where the tendon has no sheath it is surrounded by paratenon, which is adherent to both the tendon and the deep fascia covering the tendon. The glide of the tendon is permitted by the peculiar elasticity of the paratenon which allows its two adherent surfaces to glide together and apart.

The tendon does not glide through the paratenon but merely drags the loose elastic tissue first in one direction and then in the other. The deeper part of the tissue, which is adherent to the tendon moves with the tendon, the peripheral part which is adherent to the fascia, does not move.

As the tendon approaches its insertion, less glide is necessary and it is found therefore, as might be expected, that the width of the mesotenon gradually narrows towards the insertion, the width of the mesotenon being a ratio of the degree of glide possible and necessary.

In the areas where the tendon turns around corners during its course, it is covered with a sheath. In the sheath the glide of the tendon depends on the slack available at either end of the sheath, and this area of slack can be arranged in two possible designs forming prepuce-like, invaginating, concentric folds or plicae. (Fig. 7).

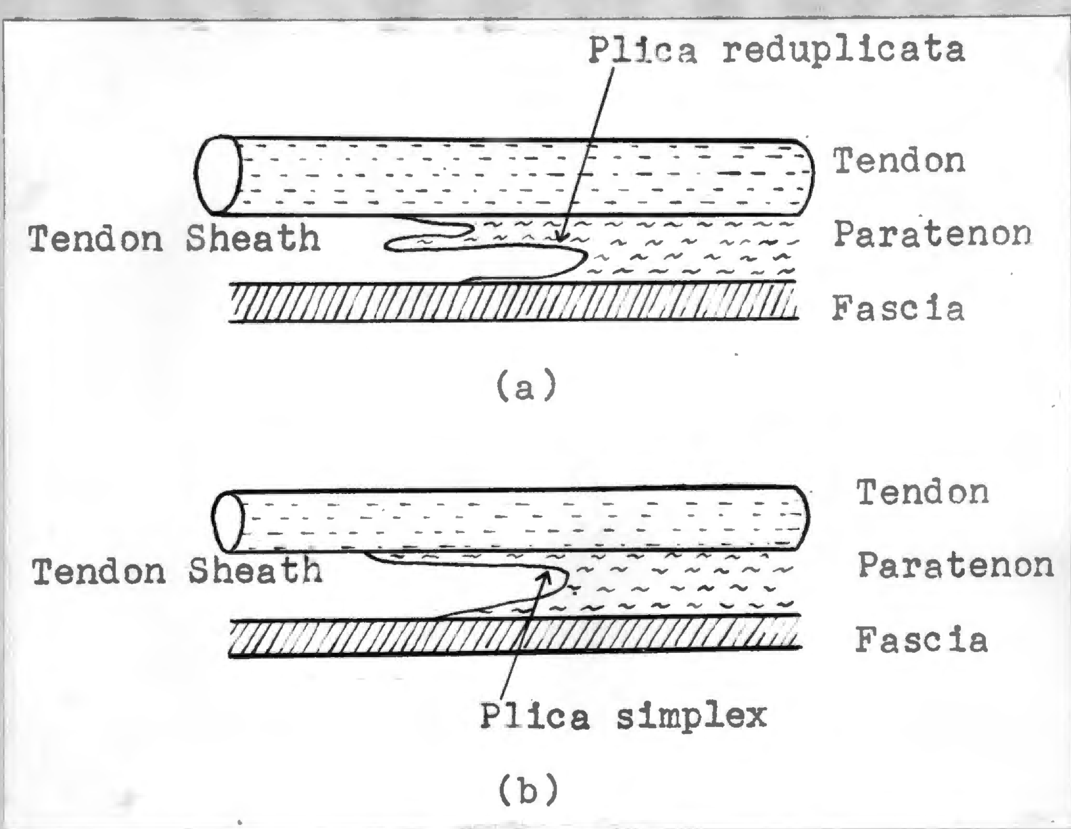

Fig. 7: The mechanism of tendon glide.

(a) Where the slack at the end of the sheath is arranged into two pouches it is known as a plicae reduplicata. As the muscle contracts and the tendon begins to glide, the pouches at the end of the sheath invaginate so that the superficial pouch, which at the stage of muscular relaxation, is the deeper of the two, gradually becomes shallower at the expense of the deep pouch. During muscular relaxation the reverse occurs.

(b) Where a plica simplex is present, the end of the sheath has a single pouch, which simply becomes deeper as the muscle contracts and therefore allows the tendon to glide unhampered. The plicae are zig-zag in sagittal section, and pull out straight when the tendon is pulled in either direction.

The amplitude of excursion is the same through the sheath as through the paratenon, the sheath simply permits the tendon to glide around corners on a thin film of synovial fluid between two smooth synovial lined surfaces.

THE EMBRYOLOGICAL DEVELOPEMENT OF THE FLEXOR TENDONS OF THE FINGERS.

Actual differentiation of joints and of muscular and tendinous structures is not sufficiently evident in early embryos to analyse them, but embryos of about 40 millimeters, corresponding to the age of nine weeks, begin to show some tendinous pattern.

A common cell mass appears on the volar side of the developing phalanx, from which the flexor tendons differentiate simultaneously into flexor sublimus and flexor profundus tendons (138) and the flexor tendon sheath. There is no outgrowth of tendons from corresponding muscles. The differentiation into various muscle groups and tendons occurs independently at each level. In other words, muscles and tendons differentiate in situ. An individual muscle unit does not develope from a certain myotome, with the tendon subsequently moving towards its point of attachement (87).

Simultaneously with this developement of the flexor tensons the dorsal extensor apparatus is developing, and the extensor tendons become united by fibres to the tunnel of the flexor tendons, and also to the metacarpo-phalangeal and proximal inter-phalangeal joints.

Once the ventral cell mass has differentiated into tendons and tendon sheath, the tendons differentiate further into the flexor profundus and sublimus tendons medially and the flexor pollicis longus tendon laterally (2).

Each of these tendon groups subsequently invaginates the tendon sheath, from the side, so that the sheath eventually surrounds the tendon resulting in the adult configuration (88).

The separation of the so-called radial bursa or sheath of the flexor pollicis longus is, however, not always complete from the common flexor sheath of the flexor sublimus and profundus tendons.

THE AMPLITUDE OF EXCURSION OF A TENDON.

The amplitude of excursion of a tendon is the maximum distance the tendon has to glide in order to produce the fullest range of joint movements normally dependent upon it.

If the amplitude of excursion of a tendon is limited, as it usually is after tendon repair, it means that the tendon can move a few joints individually fairly well, but is unable to move all the joints at once through their full range of movements. Thus repaired tendons, to have full function, must have a normal full amplitude of excursion.

Bunnel (17) in fresh cadavers measured the amplitudes of excursion of the various tendons of the forearm, hand and fingers. He determined not only the total amplitudes of excursion of these various tendons, but also the amplitudes of excursion of each tendon necessary to produce each individual joint movement. The following is a table of total tendon excursions required to produce full joint movements.

	Flexor Profundus	Flexor Sublimus
Index Finger	50 mms.	53 mms.
Middle Finger	85 mms.	88 mms.
Ring Finger	76 mms.	65 mms.
Little Finger	70 mms	60 mms.

Thumb (Flexor Pollicis Longus) : 52 mms.

The following are averages:

Flexors of the fingers: $2\frac{3}{4}$ inches.

Flexor of the thumb: $2\frac{1}{4}$ inches.

THE MECHANICS OF THE MOVEMENTS OF THE FINGERS AND THUMB.

It is probably true that next only to his brain, man owes more to his fingers and hand, than to any other factor, for his superiority over all other forms of life.

A clear concept of the mechanics of the hand is essential therefore (109) before one can presume to attempt any repair of this beautifully balanced mechanism (36), let alone replace part of its mechanism.

Yet, when all our knowledge is added up, we still know so little of some of its functions, that if a working model of the hand were to be constructed, we would be unable to fit in the actions and forces of many of its muscles and tendons.

(a) The Fingers:- The joints of the digits are sliding joints, and therefore in flexion the phalanx distal to the joint slides so that its end articulates with the volar surface of the phalanx proximal to the joint. The proximal finger joints flex 90 to 100°; the middle 110 to 130°; and the distal joint 45 to 90°.

When the joints are thus fully flexed, the grasp on an object is very firm, since when they are fully flexed there is no lateral movement at these joints. This stability on flexion is associated with two factors. Firstly the shape of the metacarpal heads, which are wider on their palmar aspect than on the dorsal, and therefore when the finger is flexed the flat ends of the proximal phalanges are firmly braced against a wide base, and secondly the collateral ligaments are loose when the finger is extended but are taut when the finger is flexed. Their tautness limits the lateral movement.

All digits when fully flexed should normally be able to touch their bases, and all should normally be able to circumduct.

A fact easily tested is that if any finger is held in extension, the adjoining fingers cannot be fully flexed voluntarily, but can be passively. This is so since the tendons of the flexor digitorum profundus muscle all originate from a common tendon and only separate and interdigitate in the palm. Similarly, the extensor digitorum tendons all originate from a common tendon which also interdigitates over the dorsum of the hand, therefore again, if any finger is held in full flexion, the adjoining fingers cannot be fully extended voluntarily, but can be passively.

(b) The Thumb:- The tip of the thumb, in circumduction, describes an irregular but complete curve from the base of the little finger across the volar surfaces of the ring and middle fingers to the middle crease of the index finger. If circumduction is continued, the thumb then passes, slightly posteriorly, to the plane of the palm, but soon afterwards passes well forward in opposition and finally arrives back at its starting point.

The thumb has a wide variety of movements for grasping. With the index finger the thumb can form a round O, whilst with the little finger it forms an ellipse. It has such a wide range of movements that it can touch almost all points of the hand.

In maximum flexion and adduction, it reaches the ulna border of the palm at the base of the little finger. In extension it reaches to an inch behind the plane of the dorsum of the hand, and it can spread to a right angle with the radial border of the hand. In many people the distal joint, and in some, even the proximal joint, can hyper-extend.

In opposition the tip of the thumb reaches a position, three inches in front of the base of the long finger with the nail nearly parallel to the palm, but when the thumb is at the side of the hand, the nail is at a right angle to the palm.

From habit, flexion of the thumb and flexion of the index finger are associated together, and moving one generally results in a movement of the other.

These individual and analysed movements together enable the thumb to be moved in a great variety of directions and to a markedly varying degree, whilst the area of the hand which can be touched by the thumb is very great, being the distal part of the palm, the volar and radial surfaces of the length of each of the fingers, the radial half of the dorsum of all the fingers and the ulna half of the index and long fingers.

MUSCLE BALANCE IN THE HAND.

The motion of a normal hand is the result of simultaneous actions of many muscles. This was well described and explained as early as 1867 by Duchenne of Boulogne, and even earlier by other workers.

When no special movement or position is intentionally assumed, these muscles all maintain a resting tone which causes the hand, wrist and forearm to take up a characteristic posture known as the "position of function", which is due to a resting "balance" between the three main sets of muscles acting on the hand, the long extensors, the long flexors, and the intrinsic muscles of the hand. (Fig. 8).

Fig. 8: The hand, in its position of rest. The three main sets of muscles, extensors, flexors and intrinsic muscles are all in a state of balance.

In practice these joints assume the midposition of their range of motion. The forearm being halfway between pronation and supination; the wrist in about 20 degrees of dorsiflexion and 10 degrees of ulna flexion; the fingers slightly flexed in each of their joints, the index finger being flexed least and the little finger most; the thumb forward from the hand in partial opposition and its joints partially flexed. The severance of the tendons of any of these three main sets of muscles results in a characteristic deformity in each case. (Fig. 9 & 10).

According to Bunnel (17, 28), in this functioning or balanced position all the muscles are mechanically set for their most efficient action. The muscles being arranged into functional groups consisting mainly of an extensor apparatus, a flexor apparatus and an abductor-adductor auxiliary.

The flexor apparatus, consists of two flexor tendons, the sublimus and the profundus, both of which are enclosed in a narrow tunnel intimately connected with the periosteum of the phalanges and the volar portion of the metacarpo-phalangeal and inter-phalangeal joints.

The adductor-abductor auxiliary, is a dependent of the extensor apparatus, with the addition of the lateral

Fig. 9: The characteristic attitude which the hand assumes on flexion, when the profundus tendons to the index, middle and fing fingers have been severed.

Fig. 10: The little and ring fingers, here illustrate the characteristic lack of flexion which they assume, when their sublimus and profundus tendons are severed.

insertions of the interossei into the bases of the proximal phalanges.

In the co-ordinated activity of the entire finger, there are three areas of balance.

1. Acting on the base of the distal phalanx, two forces are in balance:-

   (a) The fused lateral bands of extensor apparatus dorsally.

   (b) The flexor digitorum profundus volarly.

2. Acting on the base of the middle phalanx, two forces are in balance:-

   (a) The middle band of the extensor digitorum dorsally.

   (b) The flexor digitorum sublimus volarly.

3. Acting on the base of the proximal phalanx, two forces are in balance:-

   (a) The extensor digitorum dorsally

   (b) The interossei and limbricals volarly (and the long flexors).

The lumbrical muscle is usually described as either a flexor of the metacarpo-phalangeal joint or as a flexor of this joint and an extensor of the two distal joints of the finger. Its position between the extensor apparatus and the profundus, theoretically places it in a position of an immediate co-ordinator between these two systems. It is not known definately whether the lumbricals contract when the flexor profundus contracts, or whether they act simultaneously with the interossei and the extensor digitorum.

In ordinary activity extension of the fingers, requires speed, whilst flexion requires force. It is possible therefore that, if the lumbricals contract during rapid extension of the fingers, they pull the flexor profundus tendon distally more rapidly, and expedite extension of the distal phalanx. On the other hand, if the lumbrical contracts in flexion, it may produce better stabilization of the distal phalanx, by producing tension on the distal portion of the extensor apparatus, thus effecting a far more forceful action.

The muscles, acting on the digits, are however, not only arranged in balanced antogonistic pairs in more or less opposite directions, but are arranged somewhat around the joints, so that by a co-ordination of their actions, movements in any plane and even in circumduction, as occurs in the proximal joints of the fingers and thumb is possible. The joints of the digits themselves move in one plane only however.

Many muscles, varying from seven to eight in the fingers, to ten in the thumb, by acting and co-ordinating together, produce the many possible movements of the digits. The muscles acting on the thumb consist of four long muscles and six short ones which together require branches from the radial, median and ulnar nerves which produce roughly extension, flexion and adduction, respectively. The long abduductor and the thenar muscles control the base of the thumb, whilst the three other long muscles act more distally.

The long extensor of the thumb's action primarily, is to pinch the thumb against the border of the hand, to draw it to a plane behind the hand, and to extend both its distal two joints.

The abductor pollicis longus on the other hand, acts mainly as a stqbilizer against the antogonists which keep the carpo-metacarpal joint in extension, and the thenar eminence from being pulled forward into the palm when the thumb flexes. All these muscles, at rest, are in a state of balance.

Muscle balance in the hand, wrist and forearm, has a further effect on movement, for if one joint is moved, it has the automatic effect of moving the adjoining joints, both proximal and distal to it, especially when the same muscles span all these joints. For example when the wrist is dorsiflexed, the long flexor tendons become tense and automatically flex the digits, whilst if the wrist is palmar flexed, the long extansor tendons automatically extend the digits.

THE PATHOLOGY OF TENDONS AFTER INJURY.

When a tendon is severed, the changes which occur vary to some extent depending on whether the tendon, in the area of severence, lies in a sheath or is surrounded by paratenon (49). The final pathological changes and their severity depends further on whether infection follows the severence or not.

(a) The Severence of a tendon within a sheath:

The tendon ends lie loose in the sheath, and make no effort to proliferate, after a time becoming smoothly rounded over. Tendon retraction is greater in the sheath than in paratenon, the muscle contracting the distance of the amplitude of motion of the tendon or about half the length of the muscle belly. If infection follows severence, the tendon however does become adherent and shows attempts at proliferation and attachment at its ends.

Infection, if it occurs, is far more serious if it occurs within a tendon sheath, since the tendon tends to rapidly undergo necrosis in part or in whole and later sloughs to be replaced by cicatrix. If infection occurs in the firm tunnels, within the digits, or under the annular ligament at the wrist, it is even of more serious significance, for when infected the tendon swells and is held so firmly that it becomes ischaemic and consequently undergoes necrosis and sloughs. Later, it is replaced by a contracting cicatrix which becomes attaches to the surrounding tissues and draws the finger into flexion. The tendon sheath at the same time proliferates greatly, and also attaches itself to the surrounding tissues, and later on contracting adds a firm fibrous cord to the tight flexion contracture of the finger.

(b) <u>Severance of a tendon within paratenon</u>:

When a tendon is severed within paratenon, the ends of the tendon and the surrounding paratenon proliferate in an attempt to reattach themselves. The tendon end attempts to reach out and join its opposite end by sending out a pseudopodium, which may be an inch or two long and may sometimes be considerably thicker than the tendon itself. This is an attempt at a natural cure, for if the two ends of a severed tendon grow towards each other and touch each other, they fuse and eventually reestablish the continuity of the tendon.

The pseudopodium formation seems to occur in a ratio to the extent of the paratenon, but even in the palm of the hand, where there is only a thin slippery layer of paratenon, a thick translucent jelly like tube with walls one to two millimeters thick, may extend out as a pseudopodium.

If infection follows the severance of the tendon, proliferation of the paratenon and of the tendon ends are both increased, and cicatricial attachment is much more marked.

Care must always be taken, in an end to end suture of a small tendon to a large one, that the part of the large end is carefully enclosed (159), for otherwise, these "unsatisfied" fibres, as Bunnel (17) calls them, grow out and firmly attach themselves to the surrounding tissues thereby limiting the excursion of the tendon.

This attachment of the tendon may have far reaching consequences, since if one tendon of a muscle with multiple tendons becomes attached, it holds back the whole muscle and therefore limits the excursion of all the tendons and therefore all the fingers in their movements.

Apart from these complications, all tendons, when severed, tend to undergo degeneration from disuse and adherence to the surrounding tissues. They become thick, yellowish, soft, shreddy and friable from disuse, and whenever a tendon is adherent at one place, it will be found to be adherent from there distally.

The strong tendency for tendons to become adherent to their surrounding tissues, is probably associated with a similar tendency which the joints of the fingers have, to stiffen after trauma, infection, or any process which causes the hand to become swollen or oedoematous with serofibrinous exudate.

This exudate which is rich in protein and fibrin, tends to make the movable parts stick, and later when it is followed by the fibroblastic proliferation which it stimulates, further and more permanent sealing of the tendon and joints occurs.

THE PROCESS OF HEALING OF A TENDON.

The process of healing of tendons has been studied very extensively by Mason and Shearon, (119) experimenting in dogs. They found that the process progresses according to a fairly regular chronological table. A tendon takes approximately five weeks for normal strength and almost normal histological and macroscopic appearance to return to the junction zone after severance. The process of repair in tendon surrounded by paratenon takes place faster than when the tendon is surrounded by a sheath, probably because in paratenon the vascularity from the surrounding tissues is better, whilst the proliferation of the paratenon itself adds strength in the early stages.

The process of tendon healing may be followed weekly:-

First Week:-

Almost immediately after the tendon is severed, a serum clot forms between the two ends. It is a soft, fusiform translucent jellylike substance. Connective tissue cells start growing into this jelly almost at once, coming not from the tendon cells but from the epitenon, tendon sheath, paratenon and endotenon which surround the tendon.

The tendon ends undergo increased vascularity, and connective tissue proliferation causes the distal half inch of each tendon end to become reddened and swollen.

In the meantime, the homogeneous jelly like substance between the tendon ends, becomes converted to a fibroblastic splint as the connective tissue fibres contract. It is still completely devoid of strength however.

At about the fourth or fifth day, the actual tendon cells themselves commence proliferating. The first week is however, characteristically, the week of the fibroblastic splint.

Second Week:-

During the second week the connective tissue ingrowth into the jellylike mass between the tendon ends continues more vigorously. There is marked proliferation of all the elements arising from the tissues surrounding the tendons, and the fusiform mass of junction tissue becomes continuous with the surrounding tissues, which aids the two tendon ends, in their repair process, by increasing their vascularity.

The tendon ends become more swollen, and oedoematous and reddened, and by the eighth day, tendon fibres and cells commence to grow into the jellylike junction substance from the tendon ends. By the end of the second week, these tendon fibres and cell elements, are fairly conspicuous, but until the gap is well bridged by these structures, the junction is weak, and can easily be ruptured. The second week is characteristically one of marked connective tissue proliferation.

Third Week:-

During the third week the junction tissue developes a firmer consistency as the soft oedoematous tissue is replaced by true tendon fibres. The junction is still swollen and vascular, but is less red. Tendon fibres form in increased number across the gap, and increased mitosis of the cells between the fibres can be seen extending into each tendon end for about one centimeter.

Gradually the junction tissue increases in strength, largely due to the formation of the strong tendon collagen fibres which develop in a longitudinal and parallel arrangement in response to the stress of tension, These strong cords of collagen which compose the bulk of the tendon, are the nonvital products of connective tissue cells. The long spindle-shaped cells within the tendon are really flat and ovalshaped canals which pass throughout the tendon and are the vital parts. The function of the longitudinal canals is probably one of lubrication. ? tissue spaces

At the time that the collagen fibres are increasing at the junction between the tendon ends, a cleavage of separation commences between the tendon and the surrounding tissue in the first stage of the loosening of the tendon to re-establish movement.

<u>Fourth Week</u>:-

By the beginning of the fourth week there is good strength at the junction, and although it is not quite equal to normal, it is strong enough to take the strain thrown on it by a functioning tendon and muscle.

During this week the swelling and vascularity gradually decrease and the loosening of the tendon from the surrounding tissue progresses, so that by the end of this week a fair degree of gliding of the tendon becomes possible.

THE STRENGTH OF THE TENDON DURING THE PROCESS OF HEALING.

The strength of the tendon, as already described, varies with the stage of healing (116). At first, immediately after tendon severance, the junction tissue under natural repair has no strength (54, 104). If suture is performed the strength of union in this early stage is the strength of the suture (117).

As vascularity of the tendon ends occurs and they swell, the strength of the tendon drops, so that by the fifth day after severance, the tendon junction is at its weakest stage and is even weaker than immediately after the suture. By the ninth day the initial strength of the tendon is restored, whilst after fourteen days it has gained slightly in strength but is still completely unable to accept any strain.

At the end of the third week there is moderate strength and after four weeks the normal strength of the tendon is restored.

THE EFFECT OF FUNCTION ON THE PROCESS OF TENDON HEALING.

Function appears to have a marked three fold effect upon the process of tendon repair (119). Firstly it results in a marked increase in tissue reaction, proliferation and adhesions, so that the tendon ends become bulbous, and tend to separate from each other.

An immobilised tendon in the early stages shows far less irritative tissue reaction and attachement to its surroundings, so that a tendon which has been immobilised for five weeks gives a better appearance and gives a far greater degree of glide than a tendon which has been mobilised from immediately after suture. In fact functional activity during the first fifteen days is actually detrimental to the degree of excursion ultimately obtained.

The second effect of function is upon the arrangement of the tendon fibres and cells within the tendon and especially within the junction tissue. In response to tension on the tendon, the fibres and cells arrange themselves longitudinally, whereas if the muscle is paralysed the structures lie haphazardly and irregularly.

The third main effect of function on tendon healing results, to some extent, from the effect function has on the arrangement of the tendon fibres, for if the muscle is paralysed, union of the tendon ends is considerably delayed and feeble. Up to the twenty-first day, function does not appear to influence the strength of the junction but beyond this time, a paralysed or immobilised tendon does not increase in strength, whilst an exercised tendon continues to strengthen to normal.

THE PROCESS OF REPAIR IN FREE TENDON GRAFTS.

A free tendon graft at first has no true vascular supply and depends for its nourishment upon the surrounding lymph and tissue juices. The centre of the graft therefore tends to undergo a patchy necrosis since only its surface is nourished.

The process of repair in general is similar to that which occurs after any tendon severance, only the stages lag behind those in a normal tendon by about a week, so that after a month a tendon graft is fairly stong.

Soon after inserting the graft, the surrounding tissues undergo increased vascularity and proliferation and the tendon graft gradually becomes swollen, as vascularity is re-established.

After about eleven days, growing cells can be seen in the graft and eventually the patches of necrosis, which occurred in the centre of the tendon, are substituted by regular tendon cells and fibres. If a large tendon is used, it may be so thick that much of its centre undergoes necrosis, which results in a prolonged seepage from the wound until eventually complete substitution by tendon cells has occurred and healing follows. Tubular grafts of fascia lata act similarly.

As the vascularity and tissue reaction in the graft subsides, its appearance changes from pink and translucent to a normal pearly sheen and it gradually contracts.

A tendon graft will eventually hypertrophy to fulfil the strain placed upon it and will live permanently.

If a tendon graft becomes infected, it usually sloughs, but occasionally, if it survives it undergoes the normal processes of healing and lives on.

THE PROCESS OF HEALING OF PRESERVED HOMOGRAFTS OF TENDON AND FASCIA.

Homografts of tendon and fascia have been successfully used in tendon grafting.

The eventual result is a tendon which looks normal except that it is somewhat yellower.

The preserved graft does not survive as such, however, but after about six weeks, is completely substituted by live tendon tissue, which grows in from the tendon, at each end of the graft.

Microscopically more foreign body reaction occurs, whilst functionally the result is not as satisfactory (66), (100), (161), as it is with live autografts, since many more adhesions usually form.

CHAPTER TWO

TENDON REPAIR.

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CHAPTER II.

TENDON REPAIR.

A cut which involves the flexor tendons of the finger within the digital theca is a calamity, for although it is an apparently minor injury the treatment at best is prolonged and complicated, at worst a significant percentage of cases fail ever again to recover a useful functioning finger.

The technique which is today generally accepted as giving the most consistently satisfactory results is replacement of the cut flexor digitorum profundus tendon from the palm of the hand to the distal phalanx, with a free tendon graft, together with the removal of the flexor digitorum sublimus tendon in this area, since, even if a meticulous and accurate tendon suture is performed, some adhesions always form.

Bunnel (17), (19), ih an attempt to reduce these adhesions, advocated an "atraumatic technique" and developed the withdrawal suture. No matter how meticulous the technique, however, some adhesions always form.

In areas where the tendon is surrounded by paratenoh, these fine adhesions, which develop just as elsewhere, are not of the functional importance which they assume when they occur within the relatively rigid sheaths of the fingers, for in this latter situation, they seriously impair the normal excursion of the tendon. It is this fact which has made the flexor tendons of the finger, between the metacarpo-phalangeal joint and the proximal inter-phalangeal joint the most difficult situation for tendon repair. This area still sets a baffling problem to the restoration of normal function.

It is to meet these difficulties that the technique, of free tendon grafting was devised, in an attempt to transfer the site of suture from the area of the relatively rigid sheath to the areas of loose paratenon.

In many centres, however, surgeons do not practise tendon grafting but perform a suture even in the so-called "no man's land" of tendon repair (10), (148).

The technique is to suture the profundus tendon, after removal of the sublimus tendon, if both are severed, and to suture the profundus tendon to the sublimus tendon if only the profundus is divided. A window of the tendon sheath approximately 1c.m. in length directly over the site of suture is also removed (6).

Bogdonov (10) describes the technique used in the

Soviet Union in all its centres. Essentially, if the flexor tendons of the fingers are severed, even within the digital theca, primary suture is performed, provided that the wound is clean, fresh and that the hand has been at once correctly immobilised in complete flexion. This latter condition is greatly emphasized by Bogdanov.

Delayed suture is practised in the majority of those cases not suitable for primary surgery and only occasionally are grafts performed.

For best results all these techniques require skill, experience, and great care, and the display of what Bunnel has described as "atraumatic Surgery". However, injuries of the flexor tendons of the digits is a most common industrial and civilian accident, and the surgical technique necessary for its repair to be satisfactory, should be straightforward enough for the average practising surgeon to perform with good promise of acceptable results. This, on the whole, is not the case with either free tendon grafting or tendon suturing in this area. The results obtained are to a large measure in a direct ratio to the skill and experience of the surgeon, and the average practising surgeon, seldom gets the opportunity or the material to gain sufficient skill and experience in this field. The majority of surgeons have found therefore that their results with this technique are far from satisfactory, and amputation of the finger is often offered as the quickest and most practical treatment for a divided flexor tendon within the digital theca. However, failure is not always the fault of the surgeon, for even in the most experienced hands, results are not uniformly good. Successful tendon grafts do indeed give excellent results, with almost full function, but as shown by Kyle and Eyrebrook (103), a significant percentage of cases, for no apparent reason, do not give these good results and marked limitation of movement results.

Even apart from these aspects, economically and socially the great length of time required for full rehabilitation back to normal, after free tendon grafting, is a great disadvantage (34). According to Pulvertaft (139) the patient in most cases is able to return to work four months after the operation, whilst recovery continues for up to one year, given the intelligent co-operation and ability of the patient to continue exercises (110), physiotherapy and supervision for this period, whilst if two or more fingers are affected the invalidity periods are usually proportionately longer.

A further extremely common problem in digital tendon surgery, not yet completely answered by free tendon grafting, is the division of a flexor digitorum profundus tendon without associated damage to the sublimus tendon. If the injury is near an intact sublimus tendon, Rank and Wakefield (142) advise that great consideration has to be given to an acceptance of the disability without any attempt at repair, for fear of interfering with the functioning sublimus unit. Sometimes, arthrodesis of the terminal interphalangeal joint is advocated (142) to overcome the serious disability of the absence of the functioning profundus tendon, whilst Pulvertaft (139) advises that if grafting of the profundus tendon is attempted a thin graft should be used, and contrary to the usual practice, the sublimus tendon should not be removed but should be retained, so that if the result does not come up to expectation no harm has been done and the finger still has sublimus action.

THE HISTORY OF THE DEVELOPMENT OF THE CONTEMPORARY METHODS OF TENDON SUTURE.

It is not so many years since the practice of tendon suture was not only not generally accepted, but was indeed vehemently condemned (60), (62). But this should not be surprising, since the very practice of the suturing of wounds in general has had the most eminent of medical men as adversaries. Paracelsus proclaimed that "Nature is horrified at the babarians who sew up wounds, whilst even as recently as the late eighteenth century Louis and Pibrac, two great French Surgeons of their day, raised vehement protest against this practice.

The Arabian surgeons were probably the first to write on the suture of divided tendons, Avicenna put forward the dictum that "every time a tendon is cut or ruptures it should be sutured", Avicenna applied thus to both nerves and tendons, for although Galen had differentiated between the two anatomically, centuries before, this confusion between the two structures lasted until modern times in most surgical writings.

In the seventeenth century, Avicenna's teachings became disseminated by the writings of Roger of Parma, Roland, Lanfrachi of Milan, William of Salicet and others.

William of Salicet wrote "And if the tendons have been cut across and through and through, it does not displease me to bring the two ends into approximation and to stitch them about as is done for the skin and flesh ...... because when Nature finds these structures thus brought into contact by the surgeon, much more lightly and better than she can do by a better uniting ...... the union and cicatrix will be much nicer ...... And although some would have it that the pain caused in the nerve by the needle may be the cause of spasm, this is not true."

A century later Guy de Chauliac used all his great authority to defend this doctrine and attempted to overcome the prejudice then reigning in respect of wounds of nerves and tendons and the means of their cure. He only partially succeeded.

Two centuries later Ambrose Paré, in his book on "Monsters and Prodigious Beings" wrote "Estienne Tessier, master barber surgeon, of Orleans, an honourable man, skill-ful in his art, told me that a short time ago he dressed Charles Vesignel, a Sargeant, of Orleans, for a wound received on the calf of the right leg with complete division of the flexor tendons, so he sutured them ...... the wound healing by first intention."

In Italy, at about the same time, Andre della Croce, and in Bale, Felix Wurtz both defended tendon suture vigorously, but the majority of surgeons of the period continued to accept Galen's precepts in his "Ars parva" that, "A prick of nerve or tendon will induce convulsions."

In fact, the blind paraphrasing of this dictum is well illustrated by the remarks of Jacques Guillemeau a wellknown surgeon of his period who wrote in 1598, "When nerves and tendons are stitched, on account of the pricks made by the needle, pain, swelling, inflamation and convulsions ensue, and often death, on account of the sympathy of the principle and origin which is the brain." Whilst in 1649 Jean Talcon repeated "After tendon suture convulsions ensue, not only because of the great sympathy of the parts, but because the lesion is transmitted to the brain."

This, in general, was an epoch in medicine, where practice followed on preconceived ideas based largely on ancient prejudices.

Periodically however, there appeared in the literature the writings of men who saw further than their times and practised tendon suture with good results and with none of the fearful complications usually prognosticated.

Veslingius in "Observationes Anatomicae, Epistola XV" in 1740, wrote strongly against the generally held prejudices, and even quoted facts and personal cases of suture of the tendo achilles and patella tendon, to support his contention. Whilst Sévern wrote at the same time "In children the union of tendon after suture, is always successful and easier to obtain than in the adult, but the chances of healing in the latter are in reality numerous, (so great are Natures resources), therefore the operation should always be attempted and the practitioner should have no fear of witnessing the developement of inflammation and pain in the area, as these fears are exaggerated."

In 1665, Moinichen in his "Medico-Surgical Observations" published some successful personal cases of tendon suture, whilst Lanzweerde in his appendix to Scultet's "Armamentarium Chirurg", described an experimental operation on the tendo achilles of a dog in which, shortly afterwards, healing had taken place and the animal's movements and walk were perfect, whilst at about the same time further experimental work on the flexor tendons of the dog were reported by Nuck, later quoted by Van der Wiell in "Observat rares de medecine et de chirurgie Vol II." in 1789.

At this stage all experimental work was still performed with the intention of disproving the still generally held views of Galen on the degree of sensitivity of tendons. Meekren, publishing his results in "Observ. med. chirurg LXII", in 1682, showed how he had divided several tendons incompletely, and had crushed the fibres of others with various instruments, all without pain in any instance.

In 1677 Baster, a surgeon of Zeeland, performed three successful cases of tendon suture using silk. One patient, a young peasant of Oosterlandt is said to have "obtained a perfect clinical result at the end of a fortnight after complete division of the long supinator tendon at its attachment to the radius."

At about the same time the literature contains reports of successful clinical cases of tendon suture by a surgeon called Gauthier who sutured two flexor tendons at the wrist and by Boevaert and Maynaert who performed several cases of tendon suture.

La Vauguion, in writing a surgical treatise in 1698, advised suture of the tendon where the wound was recent, whilst Verduc in his "Pathologie Chirurgicale" in 1698, not only advised tendon suture when the wound was fresh, but also in cases where the injury was of long standing. He advised in such cases that "the cutaneous cicatrix be excised, and the ends of the divided tendon be freshened (since they had become callous), and then sutured."

Whilst La Vauguion, in his enthusiasm for the necessity for surgical treatment, went as far as to say that when a tendon was incompletely divided, the surgeon should cut it completely and then suture the two ends, for otherwise, "acute pain, convulsions and sometimes gangrene will ensue." Needless to say it would appear that La Vauguion had himself never performed a tendon suture but only reported cases previously published by others, amongst which are some recorded by E.H. Muller, a wellknown surgeon of the time.

Bienaise, although being convinced that tendon suture was an essential treatment, was still decidedly influenced by the ancient ideas of the danger of pricking a tendon and in one case, in which surprisingly enough, he is said to have obtained a complete recovery, he tied a silk thread around each tendon end and by tying them together maintained apposition. The famous surgeon, Dionius, after seeing results of cases of tendon suture performed by Bienaise's was also convinced of its usefulness, but feared the dangers of sepsis, and advised postponing the operation till about three weeks after the healing of the injury.

The controversy continued, as the seventeenth century came to a close, and in 1699 Purman, who had been an army surgeon in the wars of Brandebourg, and had witnessed numerous cases of tendon suture, published statistics of twelve cases. He wrote "I suspect that one will be rather astonished by the precept that I give of suturing divided tendons and undoubtedly will say that this operation is very painful and difficult ...... But I affirm on my honour that in the numerous cases I have seen ...... a cure by suture has never failed; that union between the two ends has been as perfect as possible."

At the same time Wepper in his "Historia acutae aquaticae" related the results on experiments on the tendo achilles of dogs without really producing any new knowledge.

In the eighteenth century, strangely enough, instead of tendon suturing coming into general fashion, the literature of the period shows that surgical writers were less inclined to advise it, and for this reason one finds only occasional and scattered reports of cases of tendon suture in the surgical works of the epoch.

The eminent surgeon Garengeot, following on the example of the illustrious surgeon J.L. Petit still advocated tendon suture, but with an exaggerated and elaborate attention to care. He completely abandoned the use of forceps, and for fear of denuding the tendon, he included the skin in the suture.

In 1720, Chirac, who in general was against the use of sutures for obtaining healing by first intention, published his famous "Traite des Operations de Chirurgie" Vol II in Paris, in which he declared himself in favour of tendon suture.

In 1739, Samuel Sharp, published a "Treatise on Operative Surgery" in which he pronounced himself to be in favour of suturing divided tendons, although he retained a certain reserve in respect of incompletely severed tendons.

At about the same time Gooche in his "Cases and Remarks in Surgery" appears to have been still very undecided in his approach to cut tendons, but on the whole favoured suturing them.

Although these well accepted instances, in the literature of the period, were all more or less in favour of tendon suture, the profession as a whole, strange as it may seem today, still accepted the ancient ideas of the great sensitivity of tendons and quoted the maxim never to pass a needle through a tendon.

All these prejudices were destined to be overthrown eventually by Haller, the great physiologist of Berne, and Bornenave who in "Mercure de France" in 1757 demonstrated that the tendons were insensible and showed that the inflammatory complications following on tendon suture were due to outside causes.

The old ideas did not die easily however, although they were on the way out. Gaulthier in his "Elements de Chirurgie" continued the descriptions of the disasters and disturbances which might occur after division of a tendon and even discussed the circumstances under which amputation would be safer.

For a long time the treatment continued to be the application of bandages and dressings, which were designed and adapted to the injury. The technique of bandaging was greatly emphazised during this period. Jean Louis Petit publishing at the time a method of bandaging and the position for immobilising a ruptured tendo achilles. The positions of immobilisation of the limbs, in order to facilitate the approximation of the severed ends of the tendon, was also greatly studied.

Haller's and Bondenare's work was further prevented from becoming generally accepted by an important discussion at the Academy of Surgery in Paris at the time, aided by the writings of Louis and Pibrac, all of whom still laboured the dangers of sutures.

It was Marc Anthony Petit, one of the greatest surgeons of his epoch, who finally helped to swing the pendulum in favour of tendon suture, for after two brilliant successes which he published, many other surgeons decided to resort to Petit's practice.

The first patient he operated upon was a soldier with a cut tendon of the index finger - there is no record whether it was an extensor or a flexor tendon - but "after a few days he had a brilliant result!" The second patient was a certain Monsieur de Pisancon, who had a similar injury to his index finger of long standing. After some persuasion from the patient, Petit decided to operate. He writes "The back of the hand was split up and I searched for the two ends of the severed tendon. There was about two inches between them. They were bulbous at the ends. I trimmed them so as to get raw surfaces, then with a fine needle and silk thread, they were sutured. A perfect functional result was obtained on the twenty-fifth day."

In Milan in 1814 Monteggia in his "Instituzioni

Chirurgische" and in Paris in 1816 Dutertre in his "Traite de Medicine Opereatoire" both supported treatment by suture. Dutertre quoted a case which caused considerable tumult in the surgical world, and for years was quoted by surgical writers, in which he sutured muscles of the forearm, leaving a gap of almost an inch between the edges of the wound - yet obtaining a perfect functional result. It was not till 1858 that Sédillot at the French Academy of Science showed that this case was a muscular suture and therefore should not be considered as a tendon suture.

Syme, in England, performed a tendon suture on an old standing case, with success, which gave the needed impetus at the time to the method in England. From this time on the operation developed and came to be widely performed and generally accepted both in England and on the continent.

A CRITICAL EVALUATION OF THE RESULTS OF THE CONTEMPORARY METHODS OF TREATMENT OF SEVERED FLEXOR TENDONS WITHIN THE DIGITAL THECA.

To evaluate the results of any technique in surgery is always extremely difficult and therefore evaluations are at best probably always somewhat inaccurate. Bunnel (11), (17) has pointed out that one encounters too many variables, if one attempts the evaluation of the treatment of severed tendons, especially in the fingers, by statistics.

There are such great differences in the conditions of different hands. For example, the magnitude of the injury, the number of tendons severed, any associated nerve injuries, the state of nutrition of the hand, the amount of cicatrix, and the type of technique, used whether a free graft, a primary or delayed suture etc., Even apart from these measurable factors, the stamina of individuals to exercise post-operatively, and their will to exercise in spite of pain are of great importance.

In spite of the difficulties however, some attempt must be made to measure and report on results, for otherwise there is no method of presenting the success or otherwise of a technique, so that surgeons, not working in higly specialised clinics, can have some idea of their own chances of success in an individual case with a particular technique.

Unfortunately, even this kind of inference is not justified, for the personal experience, ability and skill of the surgeon are as important to the final success of the operation as any other factor. These factors are on the whole intangible however, and do not lend themselves to analysis by statistics.

The value of published series of cases therefore, from highly specialised centres, lies not so much in the successes but in the failures, for if in these specialised centres there are a significant number of patients whose final function is unsatisfactory, then even though there are many successes, the technique as far as the individual patient is concerned, is unsatisfactory. This may appear an unjust criticism, but it is probably near the truth. The majority of patients do not and cannot get highly specialised treatment, but the majority have the technique performed on them which is being practised by the experts of the day, supported by the statistics of their successes. In average hands the percentage of successes must be even lower however. Therefore to be really satisfactory, a technique must be able to produce good results, in nearly all patients, even in the hands of the non expert.

One further point is important in evaluating the results of a technique. In tendon repairs in the fingers, the patient's degree of normality, as far as he is concerned, is not necessarily in a direct ratio to the amount of movement he obtains. Thus when one is presented with the number of degrees of movement possible, or with the distance short of normal that the finger can flex, it is not necessarily any evaluation of the patient's ability to use his fingers and his hand.

In actual fact, few patients are genuinely satisfied, or even comfortable at their work and recreation, if even a single finger of their hand is limited to any degree in its movement. That they "adapt themselves", "get used to it", and "make do with it" for it is "a very good result considering" are all possibly true, but our attitude should be, that the finger is not fully repaired and the result is unsatisfactory, if after the injury, the patient's fingers and hand are not as good as they were before the injury!

If this method of assessment is applied, the percentage of successful cases by present methods is indeed small!

In evaluating the recovery after combined profundus and sublimus tendon injuries, the present fashions are either:-

(i) to record the degrees of movement present at the interphalangeal joints.

(ii) to measure the distance between the tip of the finger, and the distal palmar crease on full flexion, which in the normal finger is nil.

or (iii) to photograph the degree of flexion and extension of the finger.

If these figures and photographs are carefully examined and analysed, it may be seen that if there is no movement at either interphalangeal joint, the tip of the finger can still approach to within 2½ inches of the distal palmar crease by flexion of the metacarpo-phalangeal joints, whose movements depend upon the interossei muscles. Further, if as sometimes happens, after repairative surgery, the terminal and middle interphalangeal joints have a fixed flexion deformity of twenty to thirty degrees, this flexion deformity enables the tip of the finger to reach to within 2 inches of the distal palmar crease, by flexion of the metacarpo-phalangeal joints only, without any inter-phalangeal movement.

It will be seen therefore that in cases where the recorded distance from the tip of the finger to the distal palmar crease is given as 1½ inches, the actual degree of movement of the joints need be very little. Yet such results which form a large percentage of many series are often classified as "fair" or "satisfactory".

Photographic results can also be deceptive, if metacarpo-phalangeal flexion is not carefully excluded from the evaluation of the result. If this movement is excluded and the degree of fixed flexion deformity is discounted, then many an apparently good result has in fact markedly limited tendon glide, and the finger has in reality very poor function. (Fig. 11 and 12).

Finally if all these factors are genuinely assessed and finger movement is full or nearly full, the final value of the repair, still depends not upon the movement possible, but rather upon the patient's ability to use that movement. He must be able to use his fingers and hand. A hand which on exhibition can show a carefully taught full range of flexion and extension can yet be a useless tool to the patient for purposes of work and re-creation.

The comfort of the hand and the ability to use it are the only final and conclusive evaluations as far as the patient himself is concerned.

AN EVALUATION OF THE TECHNIQUE OF FREE TENDON GRAFTING.

Joseph H. Boyes (11), in presenting a series of 104 cases of severed flexor tendons in the digits for which free tendon grafts had been inserted, pointed out that the state of the finger, prior to the repair, influences the final result markedly.

He divides all fingers prior to surgery, into one of five groups for purposes of prognosis:

(i) Good - where there is minimal scarring and normal joints, capsules, ligaments and nerves.

(ii) Cicatrix - where there is scarring present on the finger from mid-line incisions, severe injuries etc.

(iii) Joint Damage - where passive movement is limited.

(iv) Nerve Damage - where there are associated major nerve injuries to the hand.

(v) Multiple Damage - where the tendons of more than one finger are damaged.

His assessment of movement in the series is by measuring the distance from the tip of the finger to the distal palmar crease, sometimes the distance being measured from the tip of the finger poised above the palm, and sometimes the distance being measured along the palm. The results for the 104 cases are as follows. The analysis below having been prepared and calculated from his total published results: (11)

DEGREE OF FLEXION POSSIBLE.

(from J.H. Boyes)

Full flexion	- 3 cases	- 14.3 %
Within ½ inch of the distal palmar crease	- 12 cases	
½ - 1 inch of the distal palmar crease	- 35 cases	- 50 %
1 - 1½ inches of the distal palmar crease	- 17 cases	
Beyond 1½ inches of the distal palmar crease	- 37 cases	- 35.7 %
Total	104 cases	

DEGREE OF EXTENSION POSSIBLE.

Full flexion	- 6 cases	(5.9 %)
Within 5° of full extension	- 71 cases	(68.2 %)
Within 5 - 30° of full extension	- 22 cases	(21.1 %)
Beyond 30° of full extension	- 5 cases	(4.8 %)
Total	104 cases	

It is not stated whether the cases with limitation of extension were also the cases with limitation of flexion. This, of course, is of great importance since if the cases with a significant fixed flexion deformity were part of the 14.3 % with almost full flexion, the apparently excellent measurement of flexion would be deceptive.

Even disregarding these factors, 35.7 % of all the cases were not able to flex nearer than to within 1½ inches of the distal palmar crease. The argument that these results are excellent for severed flexor tendons in the digital theca, does not detract from the fact that more than one patient in three, even after highly skilled and prolonged treatment was left with a functionally useless finger which furthermore was a handicap. If these are the results from a highly skilled and enthusiastic unit, how much worse must the results of the occasional surgeon be, unskilled and inexperienced as he is in this type of work, often without the facilities for prolonged physiotherapy.

Kyle and Eyrebrook (103) in reporting the results of 44 free tendon grafts for severed tendons in the digits, supply the following statistics. Their measurements again being based upon the distance between the tip of the finger and the distal palmar crease. The degrees of extension obtained are not published. The analysis below having been prepared and calculated from their total published results (103).

<u>EXTENT OF FLEXION POSSIBLE</u>.

(from Kyle & Eyrebrook)

Within ½ inch of the distal palmar crease	- 10 cases	(22.7 %)
Within 1¼ inches of the distal palmar crease	- 12 cases	(27.6 %)
Beyond 1¼ inches of the distal palmar crease	- 22 cases	(49.7 %)
<u>Total</u>	- 104 cases	

Thus, half the cases in this series, although expertly handled for a prolonged period by a highly specialised and experienced team, were left with a functionally useless finger and markedly limited movement.

It is noteworthy that Boyes' results agree fairly closely with those of Kyles' and Eyrebrook's and both are representative of the results which are being obtained today in big specialised units of these types.

In considering the results of tendon grafting for injuries to the thumb, Joseph H. Boyes (11) publishes the following results, for free tendon grafting of the flexor pollicis longus tendon in 23 cases.

More than 80 % of normal flexion	-	4 cases)	) - 53 % "satisfactory"
50 - 80 % of normal flexion	-	8 cases)	
Less than 50 % of normal flexion	-	11 cases	
Total	-	23 cases	

Boyes accepts movement of 50 % or more as satisfactory, but even if one does accept that this degree of flexion of the interphalangeal joint of the thumb is a satisfactory result (which is a doubtful assumption, since with 50 % limitation of movement the patient suffers some interference with function), the results of repair in the thumb reveal a significant percentage of cases, which suffer marked permanent disability.

AN EVALUATION OF THE TECHNIQUE OF PRIMARY AND DELAYED SUTURE.

Siler (148) publishes the results of 32 cases after profundus suture, performed for severed flexor tendons within the digital theca, the sublimus tendon being excised. The extent of extension possible is not published. Movement is measured by the percentage of normal movement possible at the combined interphalangeal joints. The following analysis has been prepared and calculated from his published results.

FINGER FLEXION POSSIBLE
(from Siler)

More than 80 %	-	3 cases	- 63 %
Between 50 - 80 %	-	17 cases	
Between 30 - 50 %	-	9 cases	- 37 %
Less than 30 %	-	3 cases	
Total	-	32 cases	

Siler accepts movement of up to 50 % as satisfactory. Even if this assessment was acceptable (and 50 % of movement is in our opinion a functionally useless finger, which hampers and limits the general use of the hand) the percentage of "satisfactory" cases is only 63 % leaving an unsatisfactory group of 37 % !

Of 9 severed flexor pollicis longus tendons Siler's results are as follows:-

<u>THUMB FLEXION POSSIBLE AFTER</u>

<u>SUTURE OF FLEXOR POLLICIS LONGUS</u>.

(from Siler)

More than 80 %	-	3 cases)	) - 88.8 % "satisfactory"
Between 50 - 80 %	-	5 cases)	
Between 30 - 50 %	-	1 case	
Less than 30 %	-	0 cases	
<u>Total</u>	-	9 cases	

Whilst of 24 tendons severed in the palm the results are:-

<u>DIGITAL FLEXION POSSIBLE AFTER</u>

<u>SUTURE OF THE PROFUNDUS TENDON IN THE PALM</u>.

(after Siler)

More than 80 %	-	9 cases)	) - 83 % "satisfactory"
Between 50 - 80 %	-	11 cases)	

Between 30 - 50 % - 1 case

Less than 30 % - 3 cases

<u>Total</u> - 24 cases

Bogdanov publishing the statistics for severed flexor tendons in the digits from 1936 - 1953 obtained in the Soviet Union with a technique of primary suture of the profundus tendon together with excision of the sublimus tendon, records 65 % satisfactory results with however no qualifications or attempts to record the degrees of movement obtained, or the conditions which he accepts as a "satisfactory" result.

Taking the results of all methods one find therefore, that a patient with both flexor tendons of the fingers severed within the digital theca, has about a 20 % chance of recovering almost full movement in his finger provided that the injury is a single one, with no complications and provided that he is treated by a highly specialised unit (68), (70), (71), (74), (78), (79). If he is treated by the average practioning surgeon, as the majority of patients probably are, his chances are appreciably lower. Furthermore to qualify for the 20 % chance of success he must be prepared to undergo treatment, and be under obserbation, for six to twelve months.

Of the remaining 80 %, a half will be left with a useless finger, which will handicap the movements of the remaining fingers, and will eventually require amputation.

It is little wonder therefore that the treatment of severed flexor tendons in the digital theca is today, more often than not, by an amputaion of the finger!

CHAPTER THREE

THE DEVELOPEMENT OF THE PLASTIC REPLACEMENT TECHNIQUE.

...oOo...

INTRODUCTION.

The investigation which lead to this thesis was begun with the object of developing a simple yet generally satisfactory method of treating severed flexor tendons within the digital theca. The technique should ideally be simple, require little skill, no experience and yet provide a result which is as near to normal as any patient can demand. Yet, in spite of this high standard it should not require a long period of physiotherapy and rehabilitation after the operation during which time the patient has to be off work.

A technique was sought which would be simple for the surgeon, and would give the patient a normal finger and hand enabling him to return within a short time to society and industry.

This appeared to be an almost unapproachable standard but I felt satisfied that anything short of this ideal, would always be unsatisfactory.

One further condition has since been added. The technique must provide a result which will last the lifetime of the patient , allowing him to perform hard active digital work.

All methods were at first performed experimentally in animals, and only those which appeared to be safe and satisfactory were eventually applied to clinical cases.

Rabbits were selected as the most convenient experimental animal and operations were in all cases performed under an anaesthesia of intraperitoneal "Nembutal", the veterinary solution of 1gr. per 1 cc. being used in all cases.

The dosage required was found to be on the average about 2 grains per five pounds body weight - this being sufficient to induce full surgical anaesthesia within about fifteen to twenty minutes and maintained for one-and-a-half to two hours. The anaesthetic death-rate by this method was one percent. It was, however, sometimes found necessary to continue artificial respiration for some time after the induction of anaesthesia, if breathing ceased whilst cardiac action remained normal. These cases nearly always subsequently regained spontaneous respirations without obvious after effects.

Frequently, the difference in the dosages of nembutal, for providing adequate surgical anaesthesia, on the one hand, and temporary cessation of respiration on the other, was found to be extremely small.

However, intra peritoneal nembutal, appears without doubt, to be the anaesthetic of choice in small animal surgery (144).

A large number of tendon operations were carried out on the rabbit. The technique was gradually developed and improved as errors became obvious and complications emerged. A full report of all the investigations and results is included, since certain of the facts elicited and certain of the methods tried, might be applied in other fields of surgery or modified with advantage, as well as serving the double purpose of showing the disadvantage and complications of many methods theoretically considered possible of application.

Each technique was investigated by a series of operations.

Each rabbit was designated by a number 1, 2, 3, 4 etc. and where both hind legs of the animal were operated upon the small letters "r" or "l" were added, to designate the side.

If the results of the experimental operations of a series appeared to justify it the method was applied to clinical cases. All the clinical cases with their detailed results are reported in Chapter V.

THE POLYTHENE PLATE TECHNIQUE.

The principle first investigated was an attempt to prevent adhesions from developing around the tendon by maintaining the full active and passive excursion of the tendon in an attempt to prevent the tendon from sticking down. This necessitated developing a method of suture which would be strong enough to take the full functional strain of the tendon from immediately after the suture, yet would avoid an increase in the reaction around the tendon which a thick or bulky suture was liable to do.

The technique of "polythene plate suturing" was thus developed, and although the method has since been discarded for the treatment of flexor tendon injuries in the fingers and hand, it is still, I believe, the method of choice for suturing tendons in all other areas in the body since it allows full active movements immediately. No immobilisation is required and function can immediately be undertaken thereby resulting in a much shorter period of rehabilitation and quicker return to work.

Polythene (otherwise known as polyethylene) is a polymerized ethylene and is a comparatively simple substance, since it consists of a long chain of carbon atoms, each attached to two hydrogen atoms (82), (83).

A long list of literature has gradually accumulated showing that polythene in the tissues of the body is completely inert and causes no reactions as long as it is pure and contains no contaminant (15), (16), (30), (31), (37), (38), (46), (64), (82), (83), (133), (144), (145), (165).

In theory it should be pure, as no plasticizer is needed to give it special physical characteristics. There is, however, a possibility when passing through machines which have previously been used for extruding cellophane sheets. This impure variety, made by casting from a solution onto rollers, contains a small amount (less than 1 per cent) of dicetyl phosphate, which gives to the polythene an irritating effect on the tissues.

The pure variety made by extracting the melted material, as a film, is completely inert (15).

Apparently thus, if one wants to be assured that the polythene used is completely inert, a sample produced by the heat extrusion process must be used. All British made polythene made by the Imperial Chemical Industries Limited, who are still the only producers of polythene in Britian today, is made by this process and is therefore inert. All polythene used in the cases in these investigations was supplied from Allen & Hanbury's Limited, and is consequently inert. It is produced in tubes of four sizes. Size 1, 2, 3, and 4 with bore .5 mm. and wall .5 mm. thick, bore 1 mm. and wall .5 mm. thick, bore 1.5 mm. and wall 1.0 mm. thick, and bore 2 mm. and wall 1 mm. thick, respectively.

TECHNIQUE FOR MAKING AND STERILISING THE POLYTHENE PLATE.

The polythene plate used in these experiments was made from the Size 4 tubing. (Fig. 13). One inch of tubing was split longitudinally throughout its length. The split tube was then opened out and tied to a flat wooden spatula so that it was firmly fixed on as a flat plate. It was then dipped into boiling water for about ten seconds and immediately afterwards was plunged into cold water for another ten seconds. The plate could now be removed from the spatula and remained an open plate with no tendency any longer to return to its tube-like shape.

The sterilisation of the plate was performed by keeping it immersed in a one per cent "Cetavlon" solution

Fig. 11: A photograph illustrating an apparently fair degree of flexion of the little finger. In actual fact nearly all flexion is at the metacarpo-phalangeal joint.

Fig. 12: The same case as in Fig. 9, with metacarpo-phalangeal movement excluded. The apparently fair movement is now seen to be markedly limited, in actual fact.

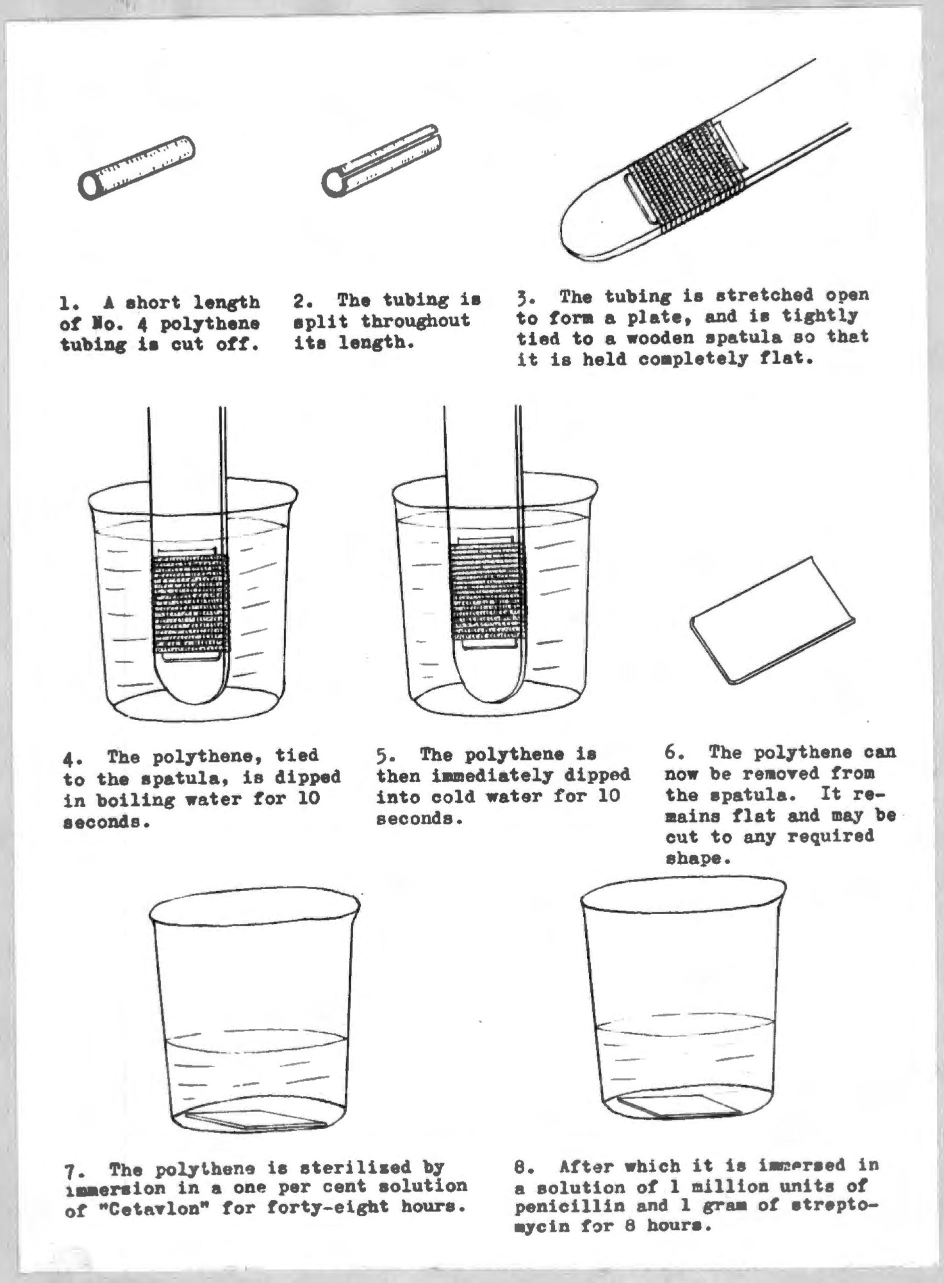


Fig. 13: Technique for making the "polythene plate", used in the "polythene plate" method of tendon suture.

for 48 hours, followed by immersion in a solution of 2 million units of penicillin and 1 gram of Streptomycin in 10 c.c. of water for 12 hours.

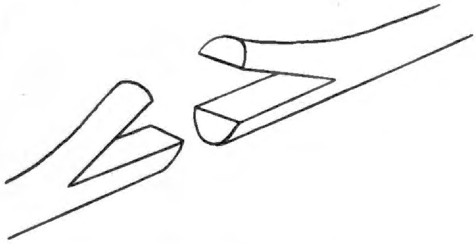
Boiling the polythene plate to sterilise it, is not possible once it has been moulded into plate form, since immersion in boiling water simply causes it to return to its original tubelike shape.

Autoclaving changes the composition of the polythene and tends to melt it.

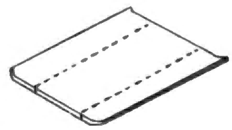
THE POLYTHENE PLATE TECHNIQUE OF TENDON SUTURE.

Each of the tendon ends to be sutured is split horizontally for a distance of about three quarters of an inch. (Fig. 14). The width of the polythene plate is then trimmed so that it is just less than the width of the tendon, polythene being easily cut with scissors.

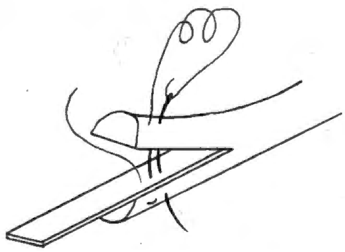
The polythene plate is inserted between the lips of the split tendon and 000 nylon (dermalon) sutures are passed back and forth through the tendon and the enclosed polythene plate. The polythene is easily pierced through



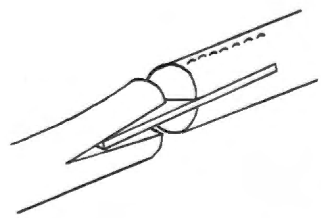
1. Both tendon ends are split horizontally down their centres for a short distance.



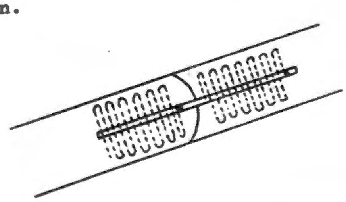
2. A polythene strip, slightly narrower than the diameter of the tendon, is cut from a polythene plate.



3. The polythene strip is inserted between the lips of one tendon end, and sutures are passed back and forth through the tendon and polythene plate. Suturing is commenced from within the tendon, so that the final knot is buried within the tendon.



4. The two tendon ends are next brought into close apposition by inserting the polythene plate between the lips of the opposite tendon end. This opposite end is then sutured in the same way.



5. The final junction is very firm and accurate, and the polythene strip is completely buried within the tendon.

Fig. 14: The polythene plate technique of tendon suture.

by the needle. If the stitching is commenced from the inner surface of one lip of the tendon and finished at the same spot, the knot when tied, can be left buried within the tendon.

The opposite end of the polythene plate is then inserted between the lips of the opposite tendon end, and is so positioned that the two tendon ends are in contact. Sutures are again passed back and forth through the tendon and the polythene plate, again in such a manner that the final knot lies within the tendon. In this manner the polythene plate is left completely buried within the tendon, with each tendon end sutured to it and not to each other. A very strong junction is thereby obtained, with no tendency to tear or rupture, since the sutures in passing through the polythene plate are prevented from cutting out.

Very little suture material is left outside the tendon and a very smooth accurate junction can be obtained even in very thin flat tendons, such as the extensor tendons of the finger.

This technique of suture was performed on the tendo achilles of rabbits, after they had been divided. The tendons were re-examined after one, three and five weeks. The tendon of one limb was examined macroscopically (Fig. 15) and microscopically, the tendon of the other limb was tested for its breaking strain.

Fig. 15: The tendo achilles of a rabbit sutured with a polythene plate one week previously. The darker dermalon stitches in the tendon can be seen.

From tables 1 and 2 it will thus be seen that the breaking strain of a normal tendo achilles was found to be 125 lbs., whilst the tendo achilles examined 1 week after

TABLE 1.

Rabbit	No. of days after op.	Macroscopic Appearance	Microscopic Appearance
A11	7	Haematoma around tendon ends but close apposition.	Early connective tissue proliferation.
$A_2 1$	21	Good union by tendon, but still some increased vascularity and adhesions along suture line and line of tendon split.	Tendon cell and collagen outgrowth with slight connective tissue proliferation still present.
$A_3 1$	35	Firm smooth union. Adhesions along suture line and line of split of tendon.	Union by tendon tissue, little disturbance of continuity. No marked foreign body reaction.

TABLE 2.

Rabbit	No. of days after op.	Microscopic Appearance	Breaking Strain
$A_1{}^r$	7	Close apposition of tendon ends but no true junction tissue.	100 lbs.
$A_2{}^r$	21	Good tendon tissue union but increased vascularity and swelling at suture line still present.	120 lbs.
$A_3{}^l$	35	Firm smooth union	130 lbs.
$A_4{}^l$	No op. performed	Normal T.A.	125 lbs.

having been sutured by the polythene plate technique revealed a breaking strain of 100 lbs. which although reduced, is little removed from normal. At the same time the tendon showed, as one would expect at this stage, no true tendon union either macroscopically or microscopically,

Three weeks after suture the breaking strain had increased to almost normal, whilst macroscopically and microscopically, except for slight increased vascularity and connective tissue proliferation and adhesions around the suture line and the line of split of each tendon end, the tendon was virtually back to normal.

After 5 weeks, apart from some persistant and apparently permanent peritendonous adhesions, the tendon was normal.

These results showed therefore that the method immediately gives to the tendon an almost normal strength and yet ensures good approximation of the ends with very little obvious foreign material externally.

The degree of adhesions were found however to be significantly increased, due to the extra adhesions along the lines of split of the two tendon ends. Where these occurred in areas of paratenon they were of little significance, but in areas where the tendon is surrounded by tendon sheath, they proved to be a significant factor in limiting the excursion of the tendon. The belief therefore that the adhesions would not form if the tendon could be kept moving, was found after experiment, to be probably without foundation.

Two clinical cases were repaired by the polythene plate technique and are reported here.

Case No. 1 - C.F. Non-European Female Aged 23 years.

The patient was operated upon six hours after having cut her right flexor pollicis longus tendon at the level of the proximal phalanx. Under general anaesthesia and sphygmomanometer tourniquet, the exposure was extended with a one inch mid-lateral incision along the lateral border of her thumb, from the level of her laceration. Both ends of the tendon were exposed and were sutured by the polythene plate technique. The skin was closed with interrupted 40 Dermalon sutures. Penicillin, 1 million units twice daily for 5 days, was commenced.

The stitches were removed on the tenth day, and the incisions were completely healed. The interphalangeal joint was then able to flex 60° and extension was full.

(Flexion of the equivalent joint of the opposite thumb was 90° when full).

Six weeks later flexion was reduced to 45°, but extension was still complete. The patient was satisfied, and said she was able to do her housework, cooking, washing etc.

She has not returned again to the out patient's clinic.

Case No. 2 - P.A. Non-European Male Aged 33 years.

The patient was operated on 10 hours after having been stabbed with a knife, two inches above the left wrist.

Under general anaesthesia and sphygmomanometer tourniquet, the tendons of the flexor digitorum sublimus and profundus to the little and ring fingers and the palmaris longus tendons, were found severed. The profundus and sublimus tendons were sutured by the polythene plate technique. The palmaris longus tendon was not sutured.

Three days later the patient had full movements of all the fingers and returned to work carrying and delivering parcels.

The stitches were removed on the tenth day and the laceration was well healed.

Three weeks later the patient returned complaining of a "drawing" sensation at the wrist on flexion of his fingers, and it was found that the skin scar had become attached to the tendons.

Under local anaesthetic the skin was dissected free, with a tenotomy knife, with immediate relief. The patient has since been seen periodically and is completely satisfied and is doing full work. He has full movements of all his fingers.

From the evidence therefore, it was felt that the presumption that adhesions could be avoided and excursion maintained as long as any limitation of movement was prevented, was basically incorrect. In both clinical cases adhesions had formed, and the good result which was obtained in each case was due to the fact that in the one the limitation of movement was not important, whilst in the second it could be corrected.

It was at this stage that a radically new approach was conceived and a completely new technique was investigated.

PLASTIC REPLACEMENT.

The idea was now developed not of attempting a repair of the severed tendons, but instead to functionally replace them by an artificial plastic "tendon", for since adhesions could not bind down this plastic tendon, it appeared reasonable to believe that no limitation of movement from this cause could occur.

Certain obvious questions and problems immediately presented themselves. To some of these the answers were obtained from the literature. For others animal and other experiments had to be designed and performed to provide the answers. The questions that required answering before a technique could be developed were:

Question 1. Although nylon appeared to be the obvious choice for the artificial plastic tendon, was there any plastic substance more suitable?

Question 2. Was nylon inert or would it cause immediate or delayed reactions either locally or generally?

Question 3. Could the fixation of the plastic at each end into the tendon be made strong enough and permanent enough to last the life time of the patient on hard active digital work, if necessary?

__Question 4__. Would the strength of the nylon be comparable to the strength of the normal flexor tendon units, and if so, would this strength be maintained for the life time of the patient on hard active digital work, if necessary?

__Question 5__. Was the nylon liable to stretch when tension was placed upon it, especially if it was warm and wet as occurred when it was buried within the tissues?

And later during the course of the developement of the technique, when it was decided to cover the nylon with polythene tubing, the following question arose.

__Question 6__. How permanent would the polythene tubing be inside the human tissues of the finger, where it would have to undergo bends of a right angle, or more, probably many thousands of times a day.

These questions were answered as follows:

__Question 1__. What plastic substance was the most suitable for use as an artificial tendon?

__Answer__: It became obvious after examining the literature that nylon was the obvious choice. Among the plastics nylon is reported as being relatively inert and is very strong and yet pliable and is obtainable in a form which is ideally suited for use as an artificial tendon. (3), (41), (47), (105), (123), (134). The only other plastic that appeared adaptable was polythene tubing. Polythene being far more inert than nylon but having a very low breaking strain. This latter fact decided against it.

Question 2. Was nylon inert or would it cause immediate or delayed reactions either locally or generally?

Answer: "Nylon" is a generic term applied to a large family of related chemical compounds, and not to a single pure product (41), and therefore to discuss "nylon" one should know the exact chemical compound one is dealing with. This is usually impossible however, since commercial secrets prevent the detailed composition of individual products from becoming general knowledge. In practice, however, clinical and experimental results from various workers, who probably obtained the nylon with which they experimented from different supply houses, agree so closely that one can conclude that the chemical differences in composition of the whole group are of more apparent than real importance in clinical practice.

Clinical trials of nylon have been reported by Stonham (153), Haxton (77) and Cumberland (41). On the whole all report good tolerance of the tissues to nylon without marked foreign body reaction around the nylon.

Cumberland (41) and Melick (123) in experimental and clinical reports on the use of buried nylon for hernial repair, showed that in all cases tissue reaction was minimal and wound healing satisfactory. Melick in order to test the reaction to nylon experimentally, imbedded sutures of nylon in the anterior abdominal wall of dogs for periods of from 2 to 103 days with virtually no observable reaction.

Cumberland repaired defects in the anterior abdominal wall of rabbits with buried nylon. Eight weeks later the wounds were re-opened, and sections showed absence of inflammatory or foreign body reaction. He then experimentally infected wounds in the anterior abdominal wall of rabbits, in which nylon had been buried. They all healed within fourteen days, without extrusion of the nylon and 9 months later sections taken from the area showed an almost complete absence of foreign body reaction.

Kuhns and Potter (101) imbedded small pieces of nylon into the rectus sheath of rats and also into the denuded under surface of patellae in rabbits. One month later the tissues around the foreign bodies were examined and sectioned. No irritation was seen around the nylon in either the rectus sheath of the rats or the knees of the rabbits. Later, they performed a series of arthroplasties on the knee joints of human patients, in which a nylon membrane was interposed between the femoral and tibial condyles. No reaction to the nylon was observed.

Evidence has also been produced to show that nylon is non-sensitizing. Jennes (84) in testing employees in a nylon plant, found no evidence of sensitisation to nylon in any of the subjects tested even after many years of contact, although some of the subjects chosen were known sufferers from allergy, whilst others had known contact eczemas of various aetiological origins.

<u>A Report on the experiments performed to confirm the inertness of Nylon</u>.

Animal experiments were however undertaken during this investigation, to confirm the inertness of nylon within animal tissue. Operating on rabbits, the flexor tendon of the toe was removed and replaced with a length of nylon which was looped at one end through a hole bored in the phalanx and sutured at the other end to the tendon near its origin from the muscle. (Figs. 16 and 17).

Fig. 16: Replacement of the flexor tendon of the toe, of a rabbit, by nylon. The nylon has been passed through a drill hole in the phalanx, on the left, then passed subcutaneously, and sutured to the tendon near the muscle, on the right.

Fig. 17: The same specimen as in Fig. 14, examined one month later. The nylon has been dissected out to show the lack of resulting fibrosis.

TABLE 3.

Rabbit.	No. of months after the op.	Macroscopic Appearance	Microscopic Appearance
B_2l	1	Normal	Minimal fibrous tissue.
B_1r	2	Slight fibrous tissue surrounding the termination of the nylon.	Slight but obvious fibrous tissue.
B_3r	3	Normal	Minimal fibrous tissue.
B_2r	5	Slight fibrous tissue surrounding the termination of the nylon.	Slight fibrous tissue.
B_1r	18	Normal	Minimal fibrous tissue.

These preparations were re-examined at intervals. (Table 3). In no case was any very marked degree of reaction to the implanted nylon noted apart from a mild increase in fibrous tissue in certain of the preparations. This mild degree of fibrous tissue, since it was slight, was not considered significant, although it appeared to demonstrate that the nylon was not completely inert within the body but did cause some foreign body reaction. Later, however, when the method was applied to clinical cases this small degree of foreign body reaction was found to be of significance, as will be described later. (Chapter V). Eventually it forced a modification of the method to be developed, which led to a further series of experiments which are described below.

Question 3. Could the fixation of the nylon into the tendon be made strong enough and permanent enough to last the life time of the patient on hard active digital work, if necessary?

Answer: In developing a satisfactory method of fixation of the nylon, a series of animal experiments were performed, and various methods were tried and discarded, before finally a simple yet strong and satisfactory method was evolved.

The series of experiments performed in attempting to evolve a method of fixation of the nylon were named Series D, E, F and G for record purposes.

SERIES D.

Undyed nylon with a breaking strain of 80 lbs. was used in this series. (Fig. 18). Prior to the operation, one end of the nylon was melted in an open flame and the small drop of melted nylon was compressed into the form of a small flat plate by pressing it against a cold metal surface as it set.

After sterilisation, by boiling, the nylon was passed through the one end of the tendon, the flat plate at the one end preventing it from sliding completely through. The length of nylon required was calculated and cut off, and this end was passed through the opposite tendon about a quarter of an inch from its end.

The nylon was then touched with an open flame or cautery which melted the end. It was then compressed against a cold flat metal object causing it to flatten, thus preventing the nylon from retracting back again through the tendon. If the melted drop of nylon was

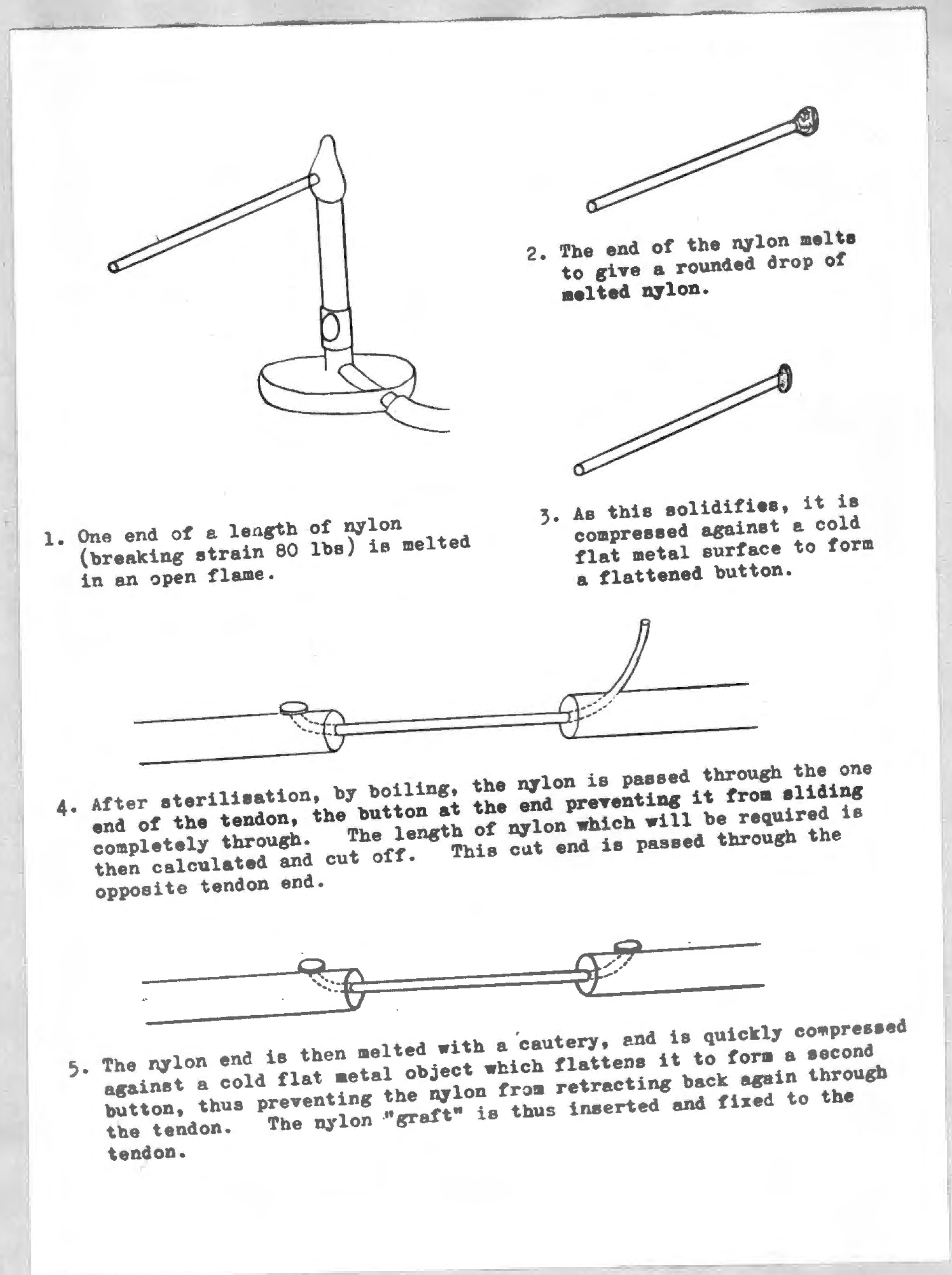


Fig. 18: The technique of Nylon fixation, used experimentally in rabbits, in Series D.

applied to the cold metal object at an angle, the final flattened end could be obtained at any angle desired. No stitching was used and the method appeared to provide a very simple and satisfactory method of fixation. The method was tried experimentally on the tendo achilles of rabbits. (Table 4).

TABLE 4.

Rabbit.	No. of weeks after operation.	Result.
D_1l	3	Nylon torn out at proximal end. Intact at distal end.
D_2r	5	Nylon fixation intact.
D_1r	7	Intact at proximal end. Nylon torn out at distal end.

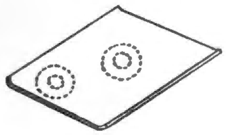
Three rabbits were operated upon and the tendo achilles of one leg of each was exposed. A section of tendon half an inch long was removed and a length of nylon was substitued and fixed by the above method.

The specimens were re-examined at the third, fifth and seventh weeks. In only the specimen examined at the fifth week had the fixation of both ends of the nylon been maintained. In the specimens examined at the third and seventh weeks the nylon at one or other end had torn out from the tendon.

It was thus apparent that this method of fixation of the nylon was inadequate.

SERIES E.

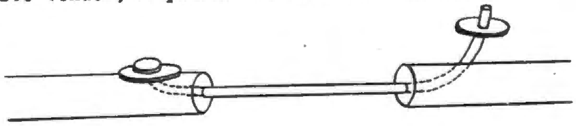
An improvement on the technique of fixation used in Series D was now tested. (Fig. 19). Two washers of polythene were cut from a polythene "plate" which had been made by the method described under polythene plate technique. The first polythene washer was slipped over the nylon up to the flattened button at the one end before it was passed through the tendon, the second washer being slipped over the nylon after it had been passed through the tendon but before the second end was flattened in a flame. The washers were an attempt to reduce the possibility of the rather small nylon buttons being pulling through the tendon. A series of rabbits were again operated upon to test this method. (Table 5).



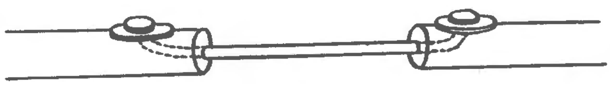
1. Two washers are cut from a polythene plate after it has been sterilised.

2. The two washers as they appear after they have been cut and trimmed with scissors.

3. The first polythene washer is slipped over the nylon, and slid as far as the flattened button at the end. The nylon is then passed through the one tendon end till the button and polythene washer lie flush with the tendon. The nylon is then passed through the opposite tendon, a quarter of an inch from its end.



4. The second washer is then slipped over the nylon.



5. After the length of the nylon has been accurately calculated, it is cut off and the end is flattened into a button with cautery. The nylon is thus prevented from retracting back through the tendon by the button and polythene washer.

Fig. 19: The technique of Nylon fixation used experimentally in rabbits in Series E.

Table 5.

Rabbit.	No. of weeks after operation.	Result.
E_1l	3	Good fixation. Nylon firmly incorporated in the tendon.
E_2r	5	Proximal end of nylon torn out.
E_2l	7	Good fixation. Nylon firmly incorporated in the tendon.
E_1r	9	Good fixation. Nylon firmly incorporated in the tendon.

Four rabbits were operated upon. Half inch segments of tendo achilles were removed and were substituted by nylon. The fixation of the nylon at each end was by the technique of Series D, but the polythene washers were added to prevent the ends of the nylon from slipping through.

The results in the four rabbits examined at the third, fifth, seventh and ninth weeks (Table 5) showed a much improved degree of fixation over the previous series. However, one of the four nylon lengths had pulled out from its proximal fixation and although the other three revealed firm and strong incorporation of the nylon within the tendon, the method was still unsafe and inadequate.

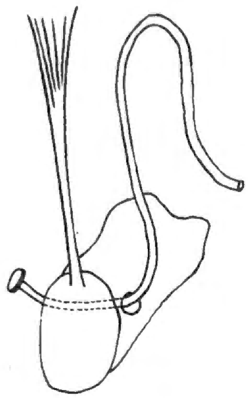
SERIES F.

The principle was now adopted of the fixation of the nylon through the distal bone. Rabbits were again operated upon.

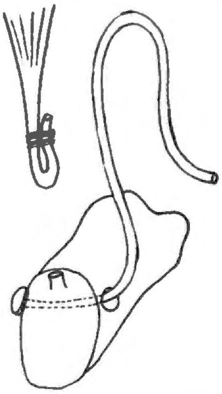
The tip of the one end of nylon, breaking strain 80 lbs., was again flattened in an open flame (Fig. 20), and after a tunnel had been bored transversely through the calcaneum, wide enough to allow a double thickness of this nylon to pass, the nylon was passed through the tunnel till its flattened end prevented it from being pulled through any further.

A half inch section of tendo achilles was then excised and the end of the proximal piece of tendon was firmly sown into a loop using 00 dermalon. The 80 lbs. nylon was passed through this loop and doubled back to once again pass through the transverse tunnel in the calcaneum but from the opposite direction. After the correct tension had been obtained, the end on the nylon was cut off almost flush with the bone, and was melted in a flame and flattened, thereby preventing it from slipping back through the calcaneum. The two flattened ends of the nylon thus lay on either side of the calcaneum.

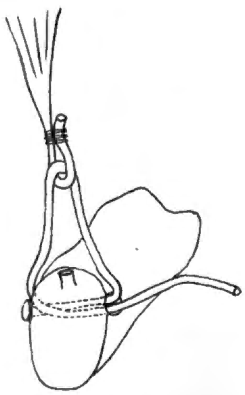
Four rabbits were operated upon and a half inch



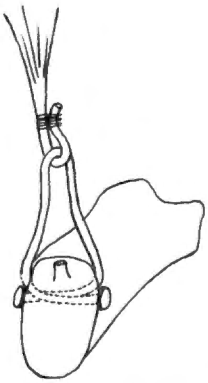
1. A length of the nylon (breaking strain 80 lbs) is passed through a borehole in the calcaneum after the one end has been melted and flattened to a button.



2. A half inch of the tendo achilles is excised and the proximal segment is sutured to form a loop.



3. The nylon is passed through this loop and is doubled back and passed through the calcaneum in the opposite direction.



4. After the correct tension is obtained, the nylon is cut off and the end is melted with a cautery and flattened to a button, thus preventing it from retracting back through the calcaneum. A length of the tendon is thus substituted by nylon.

Fig. 20: The technique of Nylon fixation, used experimentally in rabbits, in Series F.

of tendo achilles was replaced in this manner in each. The specimens were examined after the third, fifth, seventh and ninth weeks (Table 6).

TABLE 6.

Rabbit No.	No. of weeks after operation.	Result.
F_1l	3	Commencing erosion of the tendon loop.
F_2l	5	Marked erosion of the tendon loop.
F_2r	7	Complete rupture of the tendon loop.
F_1r	9	Complete rupture of the tendon loop.

In all specimens the fixation of the nylon through the bone was strong and intact and gave no evidence of loosening or reaction of the bone (Fig. 21). The nylon appeared to have been incorporated in the bone.

The tendon loop however, through which the nylon had been passed, had in each case eroded markedly. The specimens examined at the seventh and ninth weeks revealed a complete rupture of these loops, whilst the specimen examined at the fifth week showed marked erosion and evidence that rupture would soon have occured. (Fig. 22).

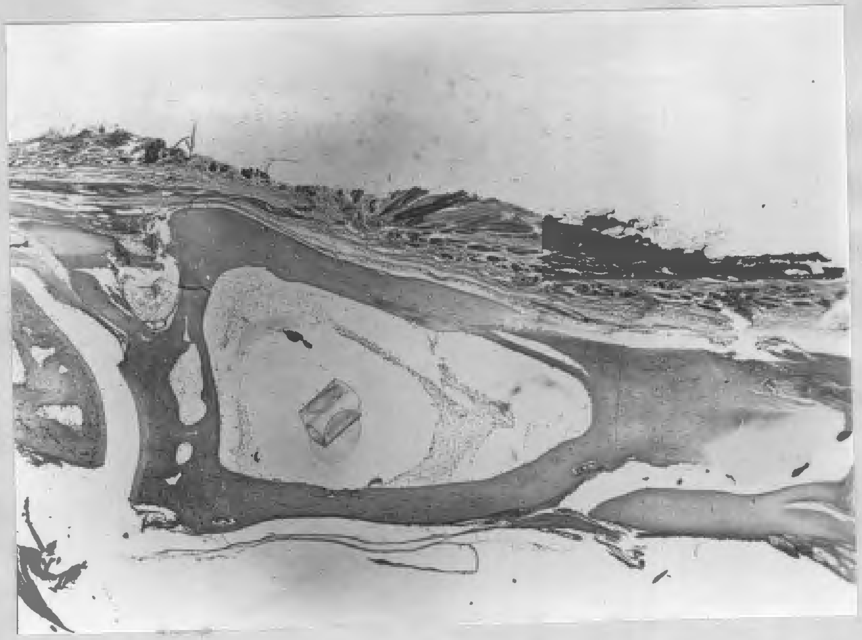


Fig. 21: Section through phalanx of the rabbit, showing borehole through which nylon passed. There is no erosion of the bone, or other alteration in its architectural or trabecular pattern.

Even in the specimen examined at the third week there was evidence of atrition and erosion of the tendon. In each case the sutures in the tendon had held firmly and the suture line was intact. The point of erosion and rupture had occurred in each case at the point where the nylon had pulled constantly on the tendon loop.

These experiments showed that the nylon fixation through the bone was satisfactory, stþong and permanent,

Fig. 22: Speciman from Series F. examined after 5 weeks. There is marked erosion of the tendon, and the nylon loop has almost eroded through. The nylon fixation to bone at the left end of the incision is very firm.

but that the constant pull of the nylon on one point of a tendon caused erosion and rupture. A better method of fixation of the nylon to the tendon was necessary, but the fixation through the bone was adequate.

SERIES G.

In this series the nylon fixation, to bone was developed and altered to a form which was eventually adapted to clinical cases.

The nylon was now commenced from the tendon and after passing to the bone and looping through a tunnel in the bone it was returned to the tendon.

The two nylon ends were sutured to the tendon by passing them back and forth up a length of about one inch of the tendon. The ends being them tied with a triple knot and cut off. In this manner the pull of the nylon was distributed over a long length of tendon, instead of being concentrated over a very short area. (Fig. 16 and 17).

This method of nylon fixation was performed in four rabbits, the nylon being passed through a tunnel in the distal phalanx and then woven into, and tied to, one of the flexor tendons. Nylon with a breaking strain of 37 lbs. was used.

In none of the four specimens examined, was there any evidence of loosening of the nylon either at the bone or tendon end. (Table 7).

At the bone end, there appeared to have been bone regeneration around the nylon so that the nylon was firmly incorporated in the bone. (Fig. 23 and 24).

At the tendon end there appeared to have been

Fig. 23: Illustrating the firm incorporation of the nylon in the terminal phalanx of the rabbit, nine weeks after its implantation.

Fig. 24: An X-ray photograph of the phalanx seen in Fig. 23. Note the absence of bone erosion or absorbtion.

marked tendon regeneration incorporating the nylon, so that the nylon could not be freed from out of the tendon except by sharp dissection. (Fig. 25).

Fig. 25: Complete incorporation of the nylon within the tendon as seen in the rabbit examined five weeks after implantation.

The breaking strains of the tendon-nylon-bone units were tested and compared with the breaking strain of a control. The point of rupture in each case was in the nylon in its loop through the bone. No weakness of the FIXATION of the nylon was revealed, clearly demonstrating that the fixation of the nylon was no longer the weakest link in the chain. This method of fixation was eventually adapted to clinical use.

Watson Jones (160) has shown that even a catgut suture tied tightly around a bone leads to gradual erosion of the bone and eventual fracture. Therefore the nylon in passing through the terminal phalanx, with periodic tensions placed on it through muscular contractions should, one might consider, eventually lead to the nylon cutting out.

This has not occurred, either experimentally or clinically however, possibly because the tension of the nylon on the phalanx is never sufficient nor prolonged enough to cause a pressure erosion. (Fig. 23 and 24). (Clinical results of this method are reported in Chapter V, together with an illustrated description of the clinical technique).

Certain further questions required elucidation in the developement of the technique.

<u>Question 4</u>. Is the strength of the nylon comparable to the strength of the normal flexor tendon units, and if so will this strength be maintained for the life time of the patient on hard active digital work, if necessary?

TABLE 7.

Rabbit No.	No. of weeks after operation.	Macroscopic Result.	Microscopic Result.	Breaking Strain
Control	-	-	-	110 lbs.
G_1r	3	Good fixation. No evidence of loosening.	Firm tendinous tissue surrounding proximal end of nylon. Firm bone regeneration with normal trabeculation around nylon in bone.	105 lbs.
G_1l	5	Good fixation. No evidence of loosening.	Ditto.	100 lbs.
G_2l	7	Ditto.	Ditto.	107 lbs.
G_2r	9	Ditto.	Ditto.	115 lbs.

Answer: Cronkite (40) in the course of a careful investigation into the tensile strength of human tendons showed that it is impossible to establish a normal tensile strength for tendons since this varies so enormously. In fact, he found surprisingly, that the cross-section of a tendon is not necessarily any criterion of its tensile strength. By investigating a large number of certain tendons however, he arrived at their average breaking strain. For the flexor digitorum sublimus and profundus tendons this was 220 pounds.

However, it is generally accepted, Mason (111), (112) and McMaster (121), (122), that normal tendons are seldom if ever, ruptured by either instrinsic or extrinsic force, they are either avulsed from the belly of the muscle or from the bone at its insertion, with or without an attached flake of bone. (12), (13), (56), (57), (80), (102), (130), (149). Since the tendon is therefore not the weakest link in the chain, it would appear more reasonable to test the breaking strain of the muscle, tendon and osseo-tendinous insertion as a unit, to find the breaking strain of the unit.

Fresh post-mortem specimens of the flexor digitorum profundus muscle, together with its tendon and the phalanx into which the tendon is inserted, were therefore tested for their breaking strain. In all cases the rupture occurred at the osseo-tendinous insertion into the phalanx with or without the avulsion of a flake of bone from the phalanx. The average breaking force was found to be 120 pounds.

The nylon to be used was then tested. The nylon used in this series was labelled by the manufacturer as having a 37 pound breaking strain. In actual fact when tested, the average breaking strain was 50 pounds.

Experimental specimens were then made from flexor digitorum profundus muscle-tendon-bone units by replacing a section of the flexor digitorum profundus tendon with a loop of nylon passed through a tunnel bored in the base of the terminal phalanx, and sutured proximally to the tendon, in exactly the manner described in the nylon bypass technique. The breaking strains of these units were then tested.

The rupture in each case occurred in the nylon in the area of its loop through the phalanx. The average breaking strain was found to be 115 pounds.

Thus in practice the unit, after nylon replacement of a segment of the tendon, appears experimentally, to be of virtually comparable strength to the normal muscle-tendon-bone unit.

(Clinically cases reported in Chapter V, show as powerful a finger clench and grip as is normally present, whilst patients frequently demonstrate their ability to perform single finger weight lifting as well as wielding hammars or using pliers and forceps).

Question 5. Is the nylon liable to stretch when tension is placed upon it, especially when it is warm and wet, as occurs when it is buried within the hand?

Answer: Nylon does not deteriorate significantly with age and is not affected by being buried in animal or human tissue, nor is its innate toughness and elasticity weakened by heating or repeated autoclaving (82), (83). It is capable of being stored in a wet condition for long periods without deterioration according to Stonham (153).

In personal experiments on rabbits in which the flexor tendons were replaced with nylon, no evidence of deterioration of the nylon, nor loss of tensile strength was observed even after being buried for a period of 8 months. (Fig. 24).

Clinically, in no case, has the accepted small degree of elasticity of the nylon caused any observable effects.

After these questions had been answered however, it became obvious in several clinical cases, that the foreign body reaction engendered by the nylon was being of greater clinical significance than had been anticipated.

Significant degrees of peri-articular fibrosis developed with resulting passive limitation of movement of the fingers. The degree of foreign body reaction of the nylon in the tissues was therefore reconsidered. As a result it was decided to attempt an insulation of the strong nylon with a tube of polythene which had a low breaking strain but which according to the literature was very inert, and its inertness had been supported by the results of the polythene plate method of suture. (15), (16), (30), (31), (37), (38), (46), (82), (83), (133), (144), (145), (165).

The following question arose however.

Question 6. How permanent would the polythene tube be inside the human tissues of the finger, where it would have to undergo bends of up to a right angle, possibly many thousands of times a day.

Answer: As there appeared no means of answering this problem without direct experimental investigation. A model of the phalanges and metacarpals was constructed (Fig. 26).

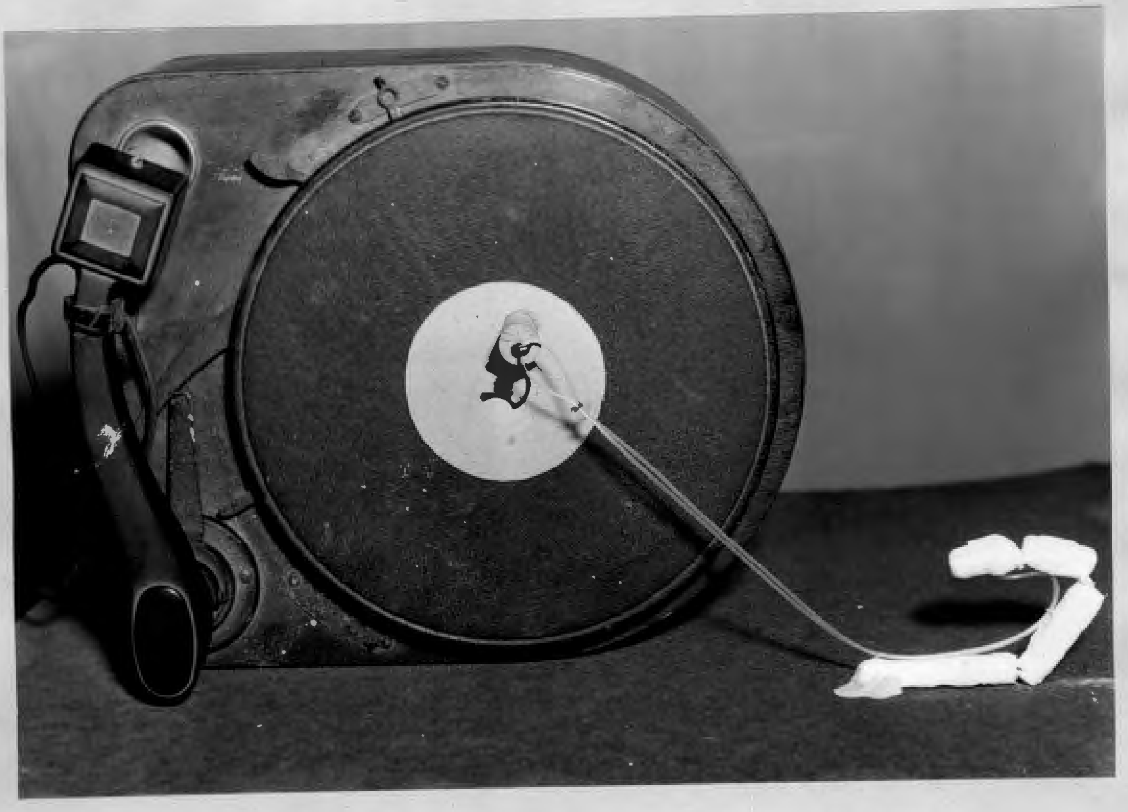


Fig. 26: Working model of the phalanges and metacarpals constructed with "tendons" of nylon and polythene. (The motive power, which provided 72 flexions per minute, is a radiogram turntable).

with a tendon system made of nylon covered in polythene tubing (Size 2). The plastic "tendon" was attached to an electric motor which revolved 72 times per minute with a diameter of 3.5 cms. Each revolution thus caused a "tendon" excursion of 3.5 cms. and created a close approximation to rapid flexion and extension of the phalanges of the model, thereby closely reproducing the bending strains which the polythene would be required to withstand.

This model was left to run continuously day and night for thirty-two days, during which time the nylon and polythene "tendon" system, had bent to a right angle at two sections of its length, more than three million, three hundred thousand times. The segment of nylon and polythene however, showed no evidence of wear and when tested for breaking strain showed no evidence of weakening over similar control lengbhs of plastic (Table 8).

TABLE 8.

Artificial "Nylon and Polythene Tendon"	Breaking Strain.
After 32 days bending.	115 lbs.
Control Segment 1	120 lbs.
Control Segment 2	110 lbs.
Control Segment 3	117 lbs.

It thus appeared reasonable to insulate the nylon with polythene tubing Size 2, which has an inner bore of 1 mm. and a wall .5 mm. thick.

Rabbits were again operated upon and a length of the flexor tendon to the toe was removed and nylon was passed through a bore hole in the distal phalanx and sutured to the tendon. The nylon being covered by tubes of polythene. (Fig. 27).

The specimens were then examined at intervals. (Table 9).

Macroscopically, the rabbit toes and legs revealed much freer movement and no evidence of fibrosis or limitation of joint movement. Microscopically there was no resulting fibrosis. (Fig. 27 a.).

The result of the insulation of the strong but mildly irritant nylon with the inert polythene, appeared to be very satisfactory and it was decided to adapt the method to clinical use. The results of the clinical cases using this techniqe are reported in Chapter V. The technique has proved to be highly satisfactory, and no further improvements or modifications have thus far proved necessary. It forms the bases of the present technique of "plastic replacement".

Fig. 27: Speciman showing replacement of the flexor tendon of the toe of a rabbit by nylon covered in polythene.

Fig. 27 a: Section of tendon (from speciman in Fig. 27), which was in close contqct with the nylon covered in polythene. Note the absence of fibrosis or other foreign body reaction.

TABLE 9.

Rabbit.	No. of weeks after operation.	Macroscopic Appearance.	Microscopic Appearance.
H_1r	3	Firm fixation at both ends. No evidence of fibrous tissue reaction.	No evidence of fibrous tissue or scar tissue around polythene.
H_2l	5	Ditto.	Ditto.
H_2r	7	Ditto.	Ditto.
H_1l	9	Ditto.	Ditto.

CHAPTER FOUR

AN ILLUSTRATED TECHNIQUE FOR THE PLASTIC REPLACEMENT OF SEVERED FLEXOR TENDONS IN THE DIGITS.

...oOo...

INTRODUCTION.

The key to succes in tendon repair in the fingers lies in the avoidance of all adhesions around the tendon.

On this rationale, the following technique was devised, whereby the cut flexor tendon is replaced by a length of nylon covered with polythene which functionally replaces the tendon between the distal phalanx and the wrist. Since adhesions cannot bind down this plastic "tendon", no limitation of movement from this cause can occur.

The technique therefore requires no emphasis on "atraumatic Surgery" and can successfully be performed without special skill or experience. Furthermore, since meticulousness in surgical technique is no longer the all important and overshadowing factor, the operation can be performed far more rapidly than free tendon grafting, with the result that, if necessary, the profundus tendons of all four fingers can be replaced by the plastic at a single operating session, frequently within the one and one half hour limits of a single tourniquet.

Furthermore, since the dangers and problems of adhesions loose their magnitude and importance, plastic replacement can in all cases, within the limits of the surgical principles of the primary suture of wounds, be performed as an emergency procedure at the time of the tendon's division, since minor degrees of infection, should they occur, do not lead to adhesions and tendon adherence, but can successfully be treated with full expectation of a functioning unit still emerging.

The problem of the divided profundus tendon in the presence of a funtioning sublimus unit can also be overcome by plastic replacement of the profundus tendon, without danger of disturbance of sublimus function. The plastic simply bypasses the sublimus tendon, without any interference with it, the nylon and polythene sliding between the elements of the split sublimus tendon, without any possibility of adherence developing between them.

Early results indicate that the period of rehabilitation is incomparably more rapid than with free tendon grafting, whilst an extremely important factor which has emerged is that organised physiotherapy, during rehabilitation, is not essential. Moreover, after plastic replacement, the strict surveillance and the usual continual encouragement to the patient to do his exercises, repeatedly and frequently, looses its importance. Thus the intelligent co-operation and willingness of the patient, is no longer as essential to a good result.

PRE-OPERATIVE MANAGEMENT.

The emergency treatment of a hand injury is as for all wounds of violence (4), (7), (9), (44), (69), (72), (76), (81). The use of a tourniquet for the control of haemorrhage should be strictly baned, whilst the haphhazard clamping and ligating of blood vessels is a harmful and dangerous practice. (1), (14), (55).

Haemorrhage is best controlled by means of a well applied pressure bandage, and whilst shock is not usually a marked feature, it may occur with extensive injuries, necessitating a blood transfusion.

Further contamination of the wound, should be avoided by covering it with a sterile towel, as soon as possible after the injury, whilst everyone in immediate contact with the open would should have their nose and mouth covered with a face mask. The surgeon, before beginning his examination prior to surgery, should meticulously scrub his hands.

Anti-tetanus serum and routine chemotherapy should be given as soon as possible after the injury.

A careful local physical examination is one of the most important phases of pre-operative treatment. A systematic examination of all the movements of the fingers, thumb and hand must be made before the presence or absence of tendon injury can be determined. A careful neurological examination of the area must also be performed to determine any associated nerve injuries. In nearly all cases, the surgeon should be able to arm himself prior to the operation, with an accurate assessment of the vital structures damaged (106), (108), (142), (164), and thus with a planned program for their repair (73). Care, kindness and experience are often necessary in differentiating lack of movement due to pain from absence of movement due to tendon injury, whilst interference with sensation may be as difficult to assess in the presence of pain and the general anxiety of the patient.

GENERAL FEATURES OF THE OPERATION.

Hand repair, requires conditions suitable for major surgery. Small instruments to do delicate surgery and the willingness and patience to deal with the small delicate tissues and structures involved, are essential. (91), (92), (93), (94), (95), (96), (97), (118), (151).

On the whole, general anaesthesia is always preferable, not the least reason being the length of time which operations of tendon repair frequently take, making it unpleasant and uncomfortable for the patient to lie quietly in a fixed position, if only a nerve block is used.

A bloodless field, to ensure complete visability is essential (154), and is best provided by a bloodpressure cuff, applied on the arm as a tourniquet at a pressure of 260 mms. of mercury, after expression of all venous blood with an Esmarch's bandage.

The surgeon then after carefully and fully scrubbing his hands and applying sterile gloves, performs a thorough skin and wound cleansing. For skin preparation "Cetavlon" in a one per cent solution is very satisfactory, the hand and forearm being shaved as well if necessary. Antiseptics are not applied.

All instruments, towels, swabs, etc. used during this wound cleansing should be regarded as contaminated and discarded, whilst the surgeon, after having performed this preparation, should rescrub completely, and then regown and reglove. The Theatre Sister plays no part in this wound preparation and should remain clean to towel the hand, whilst the surgeon rescrubs for the reconstructive phase of the operation.

A formal wound excision cannot be practised in the hand for as Mason (113), (115) points out, there is no skin to spare. Only devitalised tags of skin and tags of subcutaneous tissue are removed, together with any deep dirt and foreign material.

Severed branches of the main median and ulnar nerves are best sutured at the primary operation. When the laceration is thus debrided and the tendon has been dealt with, as described below, the edges of the skin are completely and meticulously closed. No drainage is required. (135), (136), (155), (157), (158).

A mild pressure dressing is applied to the hand and forearm with the digits separated from each other, and bandaged individually.

POST OPERATIVE TREATMENT.

Very little care is needed in the period immediately following the operation. The forearm and hand should be kept elevated, and since the patient is usually up and walking the day after the operation, the arm should be held elevated in a sling.

Antibiotics are used routinely, one million units of penicillin being administered twice daily for five days after the operation. Anti gas-gangrene serum is not given routinely.

The patient may be allowed to return home a day or two after the operation, after which he is followed in the Out Patient's clinics.

The first change of dressing is on the tenth day, at which time the sutures are removed, and active movements are encouraged.

THE "PLASTIC REPLACEMENT" TECHNIQUE.

The operation varies slightly, when performed as an emergency at the time the tendon is divided, or if performed in an old case after skin healing has occurred.

The technique for each of these cases will therefore be described separately.

In practice it has been found easier, if the operation is performed as an emergency procedure at the time of the injury, the usual contraindications to anything more extensive than emergency surgery at the initial operation holding good however, but no hard and fast rules or time limits can be laid down. The appearance of the wound, the type of injury, its cleanliness or contamination, all must be taken into account, but in our experience wounds which were clean and appeared uninfected were considered as such, in some cases even when they were as much as thirty six hours old. In all cases full antibiotic cover was given.

THE EMERGENCY CASE, AT THE TIME OF INJURY.

After general anaesthesia has been induced, a pneumatic tourniquet is applied, since a bloodless field is essential for the operation. Thorough and meticulous cleansing of the wound, the hand and the arm is then performed with a 1% "Cetavlon" solution.

Incision:- A ½ inch incision is made in the mid-lateral line, opposite the distal interphalangeal joint, and a second incision to joint the first at a right angle, is made in the flexor crease of the distal inter-phalangeal joint (Fig. 28). The right angled flaps so formed are

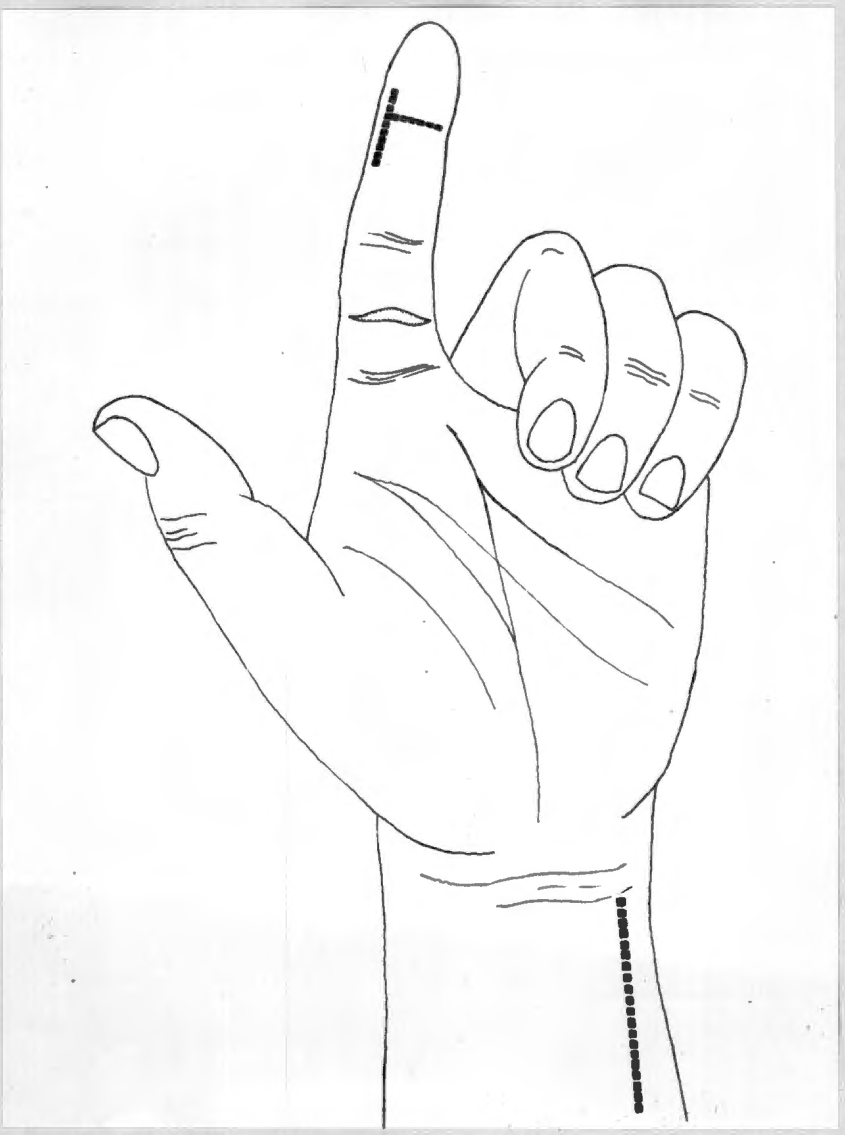


Fig. 28: The skin incisions in the plastic replacement operation.

raised, carefully avoiding any damage to the digital nerves, and the termination of the flexor digitorum profundus tendon as it passes to its insertion into the base of the distal phalanx is identified.

At the level of the insertion of the profundus tendon, a fine awl is carefully worked transversely through the base of the distal phalanx, a very short mid-lateral incision being made on the opposite side of the finger for the point of the awl to emerge (Fig. 29). The awl is withdrawn, and through the track bored by it, a Size 18 Luer-Lock needle is passed, (or any hypodermic needle through the bore of which the nylon to be used can just comfortably be passed).

A 24 inch length of undyed fishing nylon (Breaking strain 37 pounds) is then threaded through the bore of the needle (Fig. 30) after which the needle is withdrawn over the nylon leaving the nylon threaded through the finger. Both ends of the nylon are then doubled back on themselves and passed through the skin incision on each side, so that they are brought out through the transverse incision in the distal flexor crease. The nylon now, instead of passing through the full thickness of the finger, only passes through the terminal phalanx, the ends of the nylon protruding through the transverse

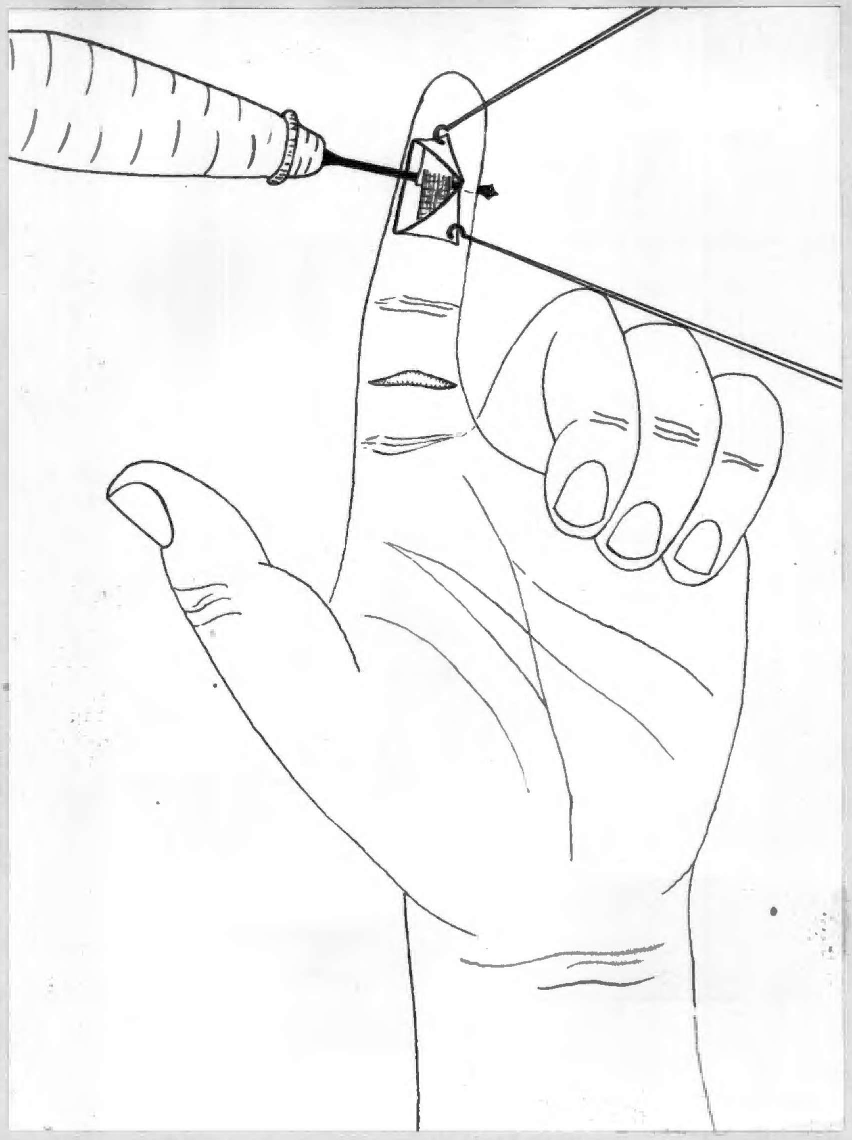


Fig. 29: A fine awl is worked transversely through the base of the distal phalanx, and a very short midlateral incision is made on the opposite side of the finger for the awl to emerge.

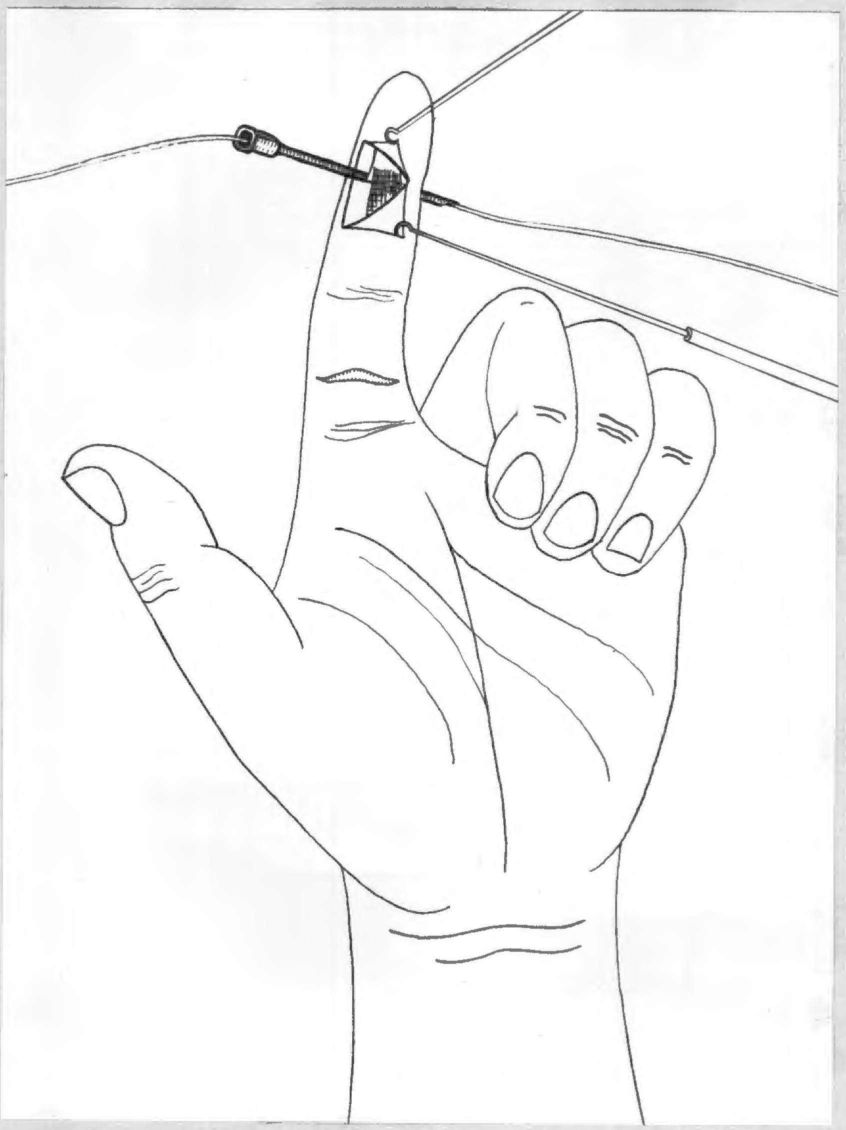


Fig. 30: A needle is passed through the borehole in the base of the terminal phalanx and the nylon is passed through the bore of the needle. The needle is then withdrawn over the nylon, leaving it threaded through the phalanx.

incision in the flexor crease. Care must be taken at this stage that the nylon passes cleanly forward on either side of the distal phalanx and that no soft tissue is caught up and strangulated in the loop of the nylon, as resulting fibrosis tends later to cause limitation of full extension of the terminal inter-phalangeal joint.

The flexor tunnel, at the level of the insertion of the profundus tendon is now incised and the distal segments of the cut profundus and sublimus tendons are pulled out of the sheath and excised. A malleoble silver probe is passed into and down the sheath, as far as the level of the division of the tendon and tendon sheath, where the progress of the probe is often arrested.

Small retractors are now inserted into the laceration, where the tendon is divided, and the edges of the laceration are retracted. The tip of the probe, can then usually be seen peeping out through the cut end of the tendon sheath. Usually, without much difficulty, the opposite cut end of the sheath is identified and the probe is guided into it, after which the probe can usually be easily slid, alongside the tendons, down the length of the sheath, completely through the hand and into the wrist, where the tip of the probe can once again be seen and felt as it presents almost under the skin. (Fig. 31).

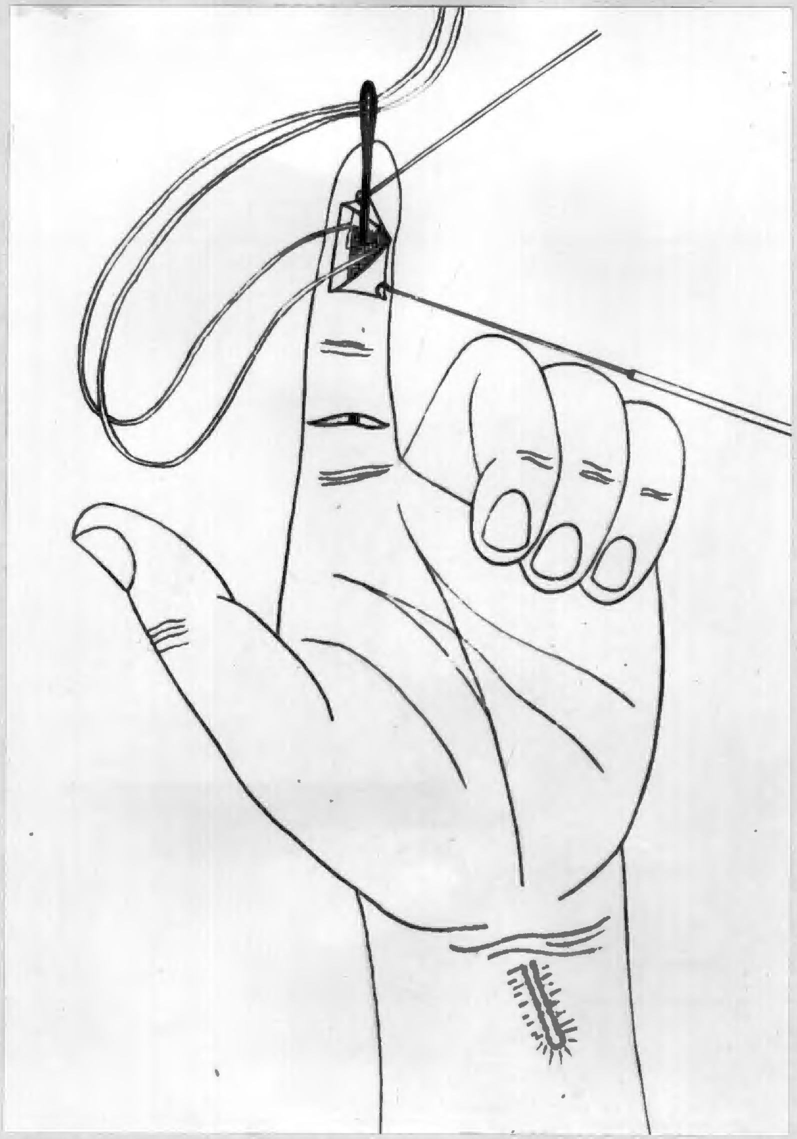


Fig. 31: A sliver probe is slid down the sheath to the wrist, and the nylon is threaded through its eye.

A further two inch incision is now made longitudinally, at the wrist, passing proximally from the transverse carpal crease in the line of the ulnar nerve, the incision being purposely placed more medial than usual so that the possibility of adhesions between the flexor tendons and an overlying incision are avoided. (Fig. 28).

After incising the deep fascia, the median nerve and the flexor digitorum sublimus muscle with its tendons are identified and retracted laterally and the ulnar nerve is retracted medially, exposing the flexor digitorum profundus tendons, amongst which the probe will be lying if it has been passed accurately through the tendon sheath.

The ends of the length of nylon, which was looped through the distal phalanx, are now threaded through the eye of the probe, and the probe is drawn through into the wrist, thereby drawing the nylon through the tendon sheath of the finger and hand right through into the wrist. (Fig. 32).

(Occasionally instead of passing the probe the full distance from the tip of the finger to the wrist in one stage, it is easier to pass it in two stages. As a first stage the probe and the nylon are passed from

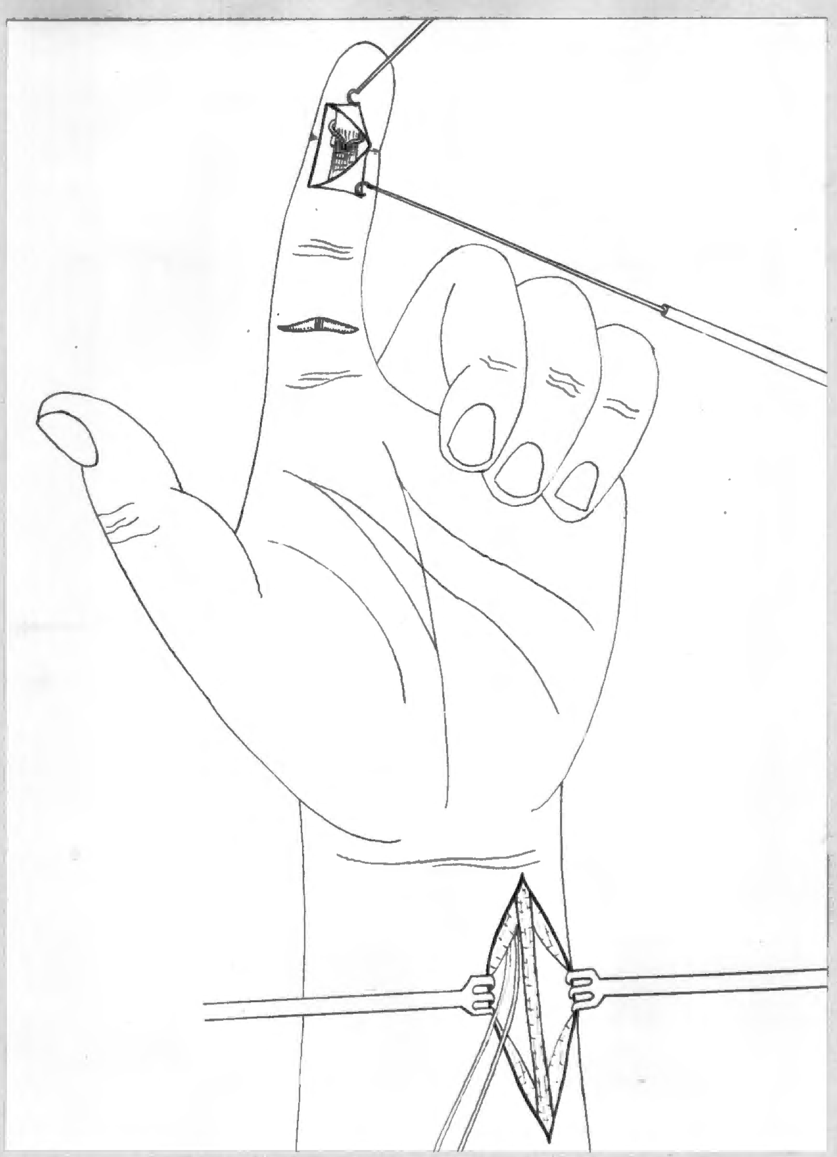


Fig. 32: The nylon is threaded through the tendon sheath, through the hand, to the wrist.

the distal end of the sheath out through the laceration, and as a second stage the probe is re-inserted through the laceration into the opposite end of the cut tendon sheath and only then slid completely through to the wrist).

The tendons of the flexor digitorum profundus muscle are next examined. The profundus tendon to the finger being operated on, or the tendon to the finger alongside the one being operated upon is carefully identified and isolated. The nylon may be sutured to either one of these tendons.

Two
Tow polythene tubes (Size 2) are next slid completely over the nylon strands so that they are covered right up to the phalanx (Fig. 33). Traction is now applied to the nylon, so that the finger is flexed to its normal degree of flexion in relation to the other fingers.

With the finger held at this degree of flexion, the point at which the nylon strands meet and will eventually enter and join the profundus tendon is noted. The polythene tubing is divided at this point and the excess is removed. In this way the nylon strands are covered and insulated over their whole length, from the phalanx to their junction into the tendon with polythene tubing.

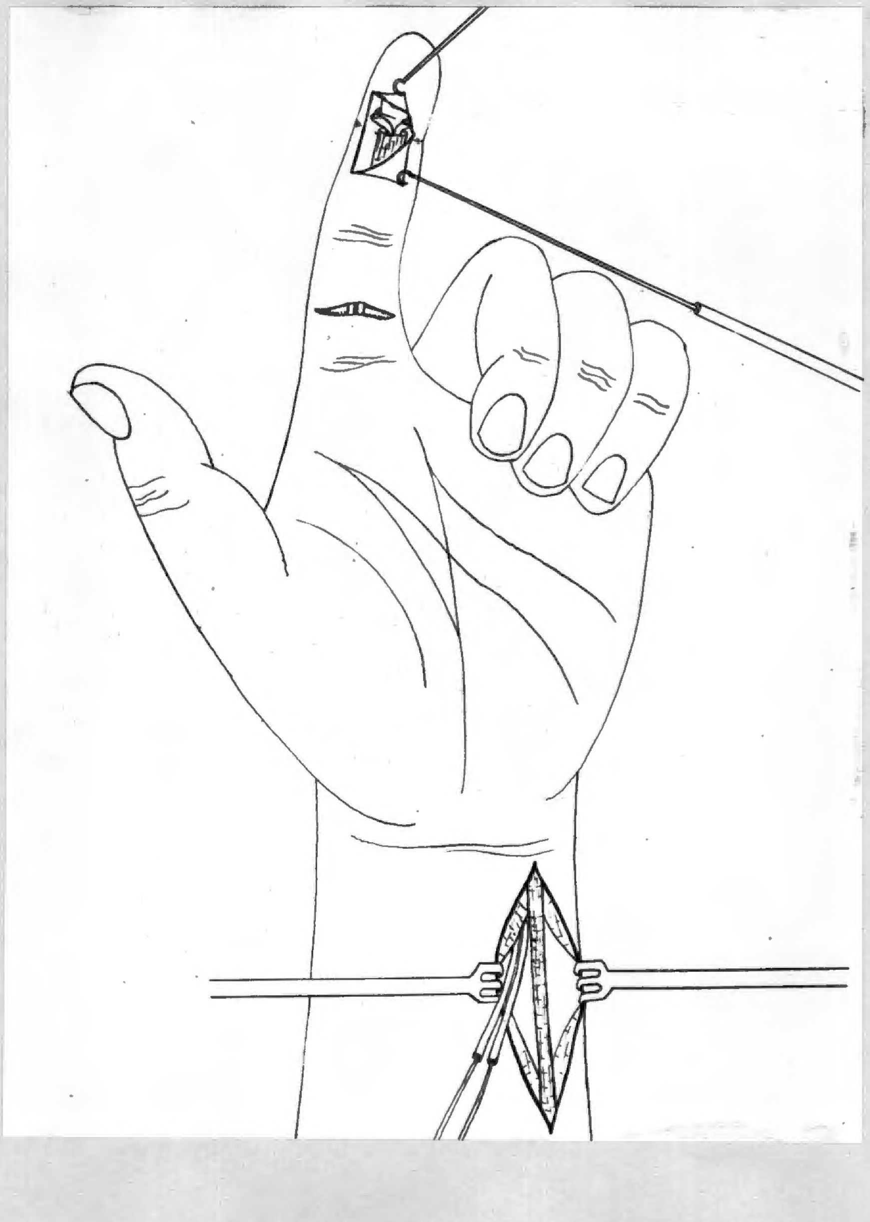


Fig. 33: Polythene tubes are slipped up over the nylon, so that the latter are covered completely to the terminal phalanx.

The size 18 Luer-Lok needle (which was previously used for threading the nylon through the distal phalanx) is now passed obliquely through the profundus tendon selected, and one of the free ends of the nylon is passed through the bore of the needle, from the direction of its point (Fig. 34). Once the nylon is through the needle, the needle is withdrawn, leaving the nylon threaded through the tip of the tendon. A similar procedure is performed to thread the opposite end of the nylon through the tendon, and this procedure is then continued so that the two nylon ends are passed back and forth through the tendon, gradually working proximally till a distance 1½ to 2 inches of the tendon has been interlaced by the nylon. The needle being used to thread the nylon back and forth through the tendon much in the manner of an atraumatic suture, thereby avoiding tearing the tendon.

Finally, the length of the nylon and its covering of polythene between the finger and the tendon is checked, so that the nylon is pulled just sufficiently through the tendon to hold the finger in its normal degree of flexion, it being extremely important that this is checked at this stage before the nylon is tied and cut short. In the normal hand, under anaesthesia, the fingers lie in a characteristic attitude, with the little finger most flexed,

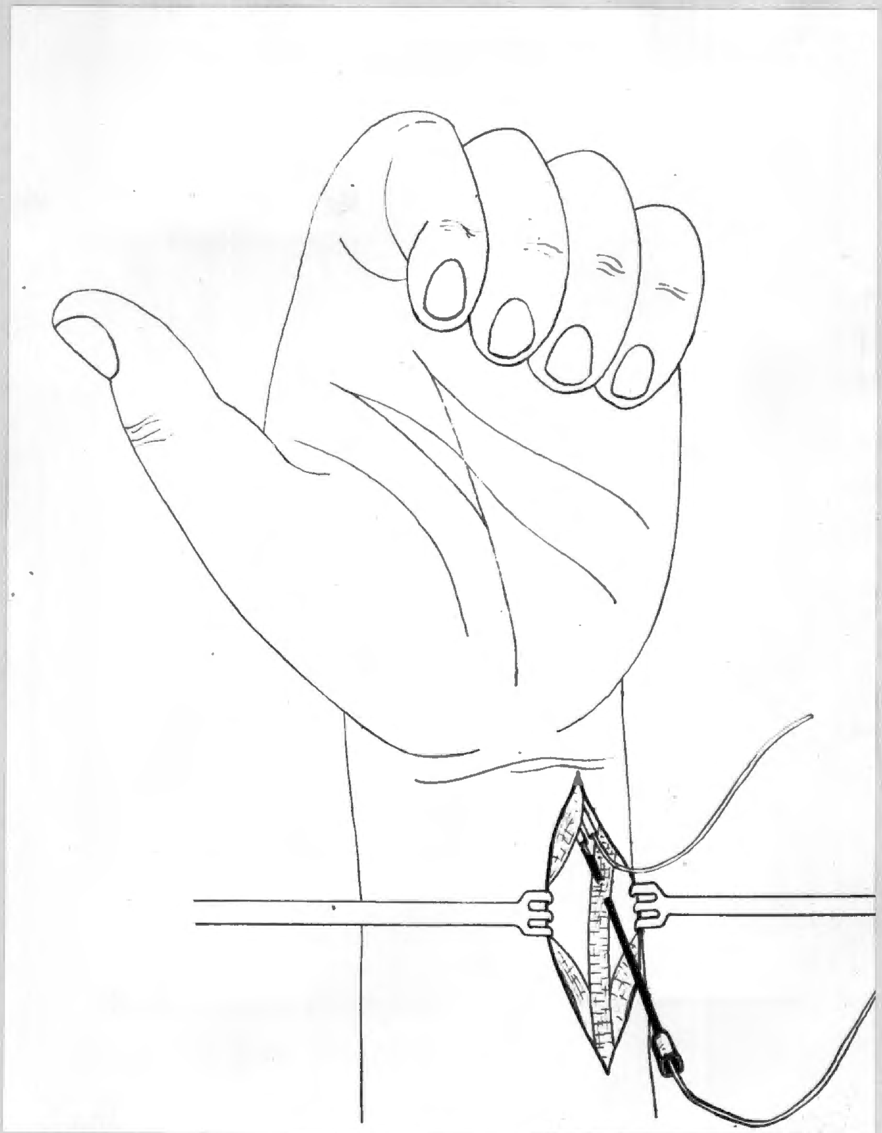


Fig. 34: The nylon is laced back and forth through one to two inches of the tendon, using a hypodermic needle.

and the succeeding fingers in lessening degrees of flexion. The length of nylon with its covering of polythene should be so adjusted that the finger lies in its normal degree of flexion in relation to the other fingers, and although this can be adjusted after the nylon has been interlaced through the tendon, it should preferably be judged prior to this, as it is far easier to alter at this earlier stage.

Once the nylon has been laced through the tendon and the length checked and found correct, it is tied with a triple knot, The ends of the knot are then laced once again through the tendon prior to being cut off, so that they are completely buried within the tendon (Fig. 35).

The incision in the wrist, those in the finger and the original laceration are all closed with interrupted Dermalon sutures without drainage.

Pressure dressings are applied to the wrist, the palm of the hand and the affected finger. The tourniquet is then released.

After-Care:- Full antibiotic cover is routinely maintained for seven days. The dressings are untouched for ten days during which period movements are not prohibited.

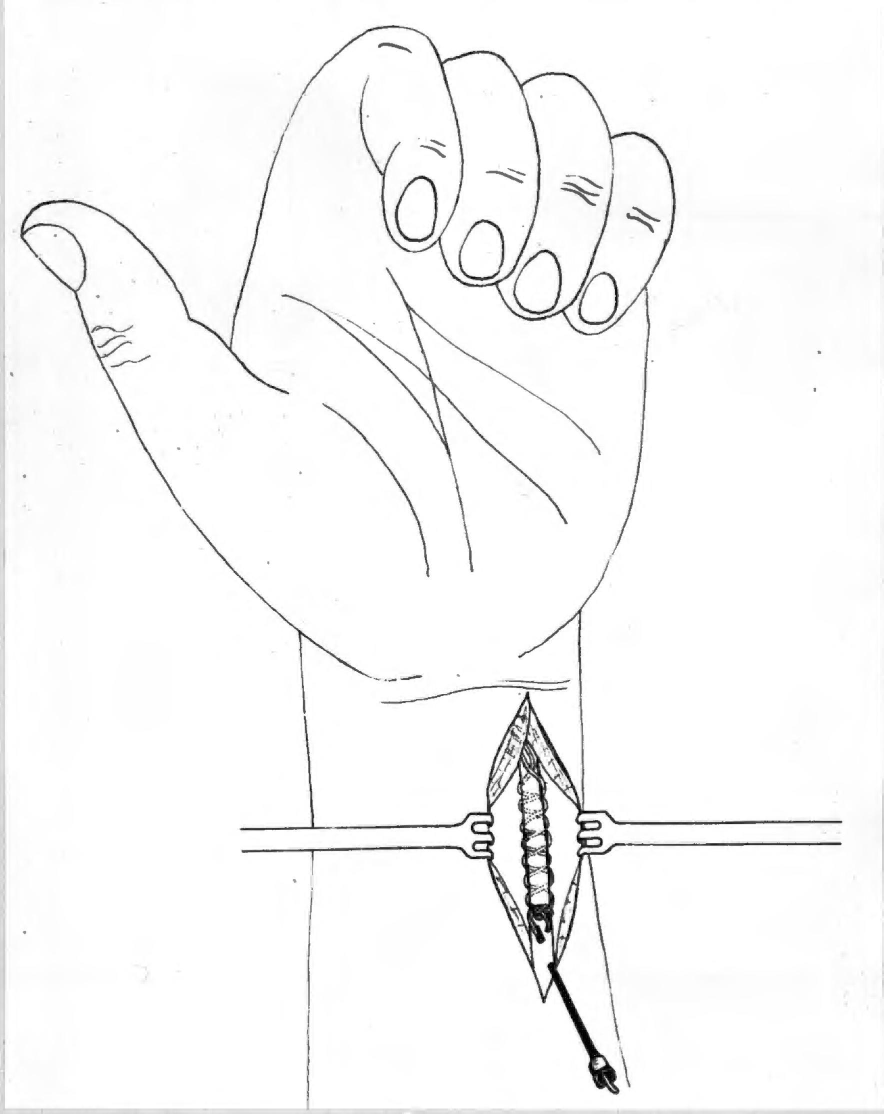


Fig. 35: Once the nylon has been laced through the tendon, it is tied with a triple knot, and the ends are buried within the tendon and cut short.

On the tenth day the stitches are removed, no dressing, beyond painting the finger with tinct. benz. co. usually being necessary.

Active movements are then commenced and encouraged.

THE LATE CASE.

In dealing with the late case i.e. any time after skin healing of the laceration has occurred, it is important that a full range of passive movements of the finger be present before the operation is undertaken, since although some improvement in joint stiffness can be obtained after the operation, it tends to limit the progress and fullness of recovery.

Incision:- A true midlateral incision is made along the affected finger from the distal interphalangeal joint to the proximal digital crease. A cross incision is made in the flexion crease of the distal interphalangeal joint and the flap thus formed is carefully raised, avoiding damage to the digital nerves. The tendon sheath throughout the length of the finger is thereby revealed.

A fine awl is bored through the base of the distal phalanx and the nylon is threaded through the phalanx in exactly the same manner as described in the emergency case.

A short incision is then made, into the distal end of the tendon sheath and a malleoble silver probe is passed into and down the sheath as far as the level of the original division of the tendon, at which level the progress of the probe is usually arrested by adhesions. It is usually then necessary to incise and open the collapsed and adherent sheath and free the adherent tendon ends, care being taken to preserve any necessary pulley in this area. The distal segment of the profundus and sublimus tendons lying in the finger can now be pulled out, leaving the sheath in the finger empty. If the original division into the tendon sheath was in the hand, it may be necessary to make an incision, in the distal palmar crease, to approach this area of adherent sheath, in which case the incision on the finger need be no more extensive than in the emergency case.

Once the area of adhesions is passed, the probe can usually be slid down the sheath, through the hand, and on into the wrist, where the tip of the probe can be seen and felt as it presents under the skin.

The remainder of the operation is performed in exactly the same manner as described for the emergency case. The nylon is drawn through the finger and hand into the wrist, and after being covered with the polythene tubing, is sutured to a profundus tendon exactly as in the emergency case. The tension is judged as before so that all the fingers lie flexed in their characteristic attitude of relaxation.

The skin is sutured with interrupted dermalon sutures and pressure dressings are applied. The tourniquet is then released.

After-Care:- Prophylactic Antibiotic cover is maintained for a few days.

The post operative treatment is exactly the same as for the emergency case.

CHAPTER FIVE

A REPORT ON THE RESULTS
OF THE
"PLASTIC REPLACEMENT" TECHNIQUE
IN
20 CLINICAL CASES.

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The cases reported in this series were all operated upon by the author personally and subsequently followed up personally by him. Seventeen of these cases were performed in the Orthopaedic Department of the Groote Schuur Hospital, and 3 in other hospitals.

The operations were performed over the space of 13 months and comprised all the patients with cut flexor tendons of the fingers arriving at the Groote Schuur Hospital during that period. Eight cases were operated upon as an emergency procedure, having been seen at the time of the initial laceration, the remaining twelve cases being operated upon from between 5 weeks and 3 years after the original injury.

The techniques varied as lessons were learned and the method was developed (See Chapter IV). Only the final 5 cases have been performed with the technique of the "nylon and polythene plastic replacement".

The details of each case are presented individually and the series is discussed and analysed as a whole and individually.

CASE NO. 1.

W.M. NATIVE MALE AGED 29 YEARS.

Eight months prior to admission the patient had been assaulted and stabbed with a knife which had cut across the bases of the little and ring fingers cutting both the sublimus and profundus tendons. (Fig. 36).

Fig. 36: Case No. 1. W.M. Prior to operative repair.

On examination the lacerations were well healed, and he had full passive movements. There were no associated nerve injuries.

Under general anaesthesia and sphygmomanometer tourniquet the following repair was carried out.

A midlateral incision was made along the medial side of the ring finger, exposing the tendon sheath. A 24 inch length of nylon with a breaking strain of 37 lbs., was passed through (Fig. 38), and then back again (Fig. 39), the base of the distal phalanx, through a borehole made with an awl. (Fig. 37).

The ends of the nylon were then passed through the loop formed by the nylon to form a running knot which was pulled tightly to encompass the base of the phalanx. (Fig. 40 and 41).

A probe was then passed through the tendon sheath, which had been destroyed in part, by previous infection. Sufficient sheath still survived however, to form adequate pulleys (Fig. 42). The nylon was now threaded through the eye of the probe, after which the probe was passed in stages through the sheath, drawing the nylon through with it until it was finally slid through the hand into the wrist where the tip of the probe could be seen and

Fig. 37: An awl was passed transversely through the base of the terminal phalanx.

Fig. 38: The nylon is passed through the bore of a needle which is inserted through the borehole in the phalanx. The needle is then withdrawn over the nylon.

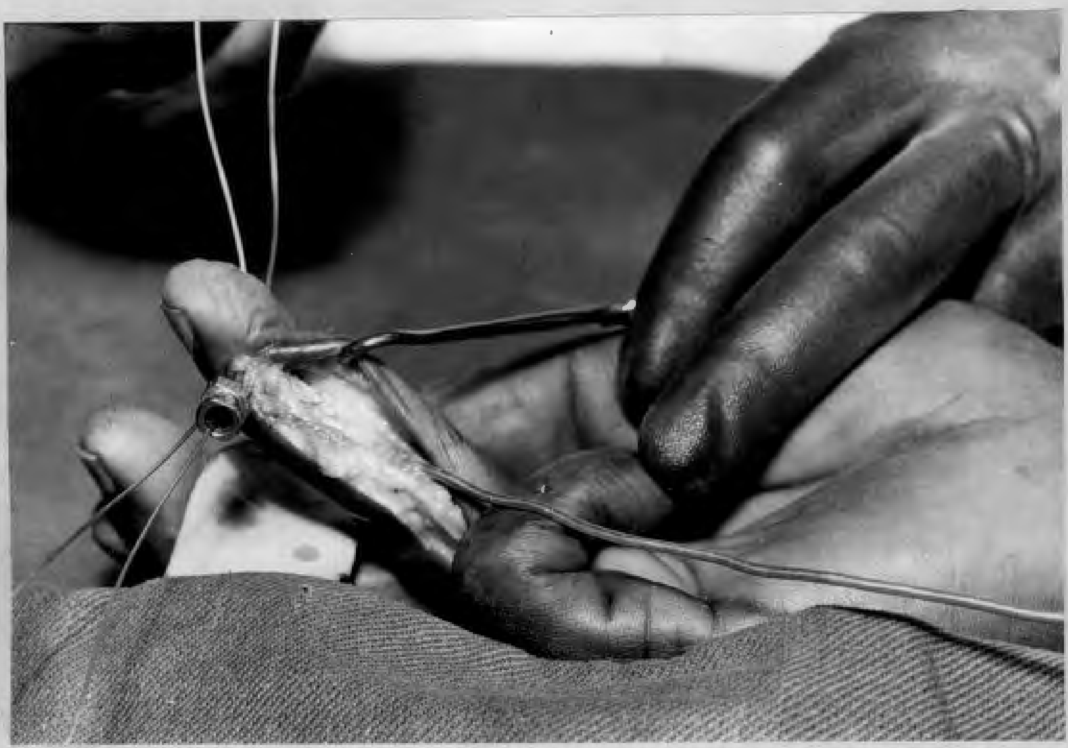

Fig. 39: The needle was re-inserted through the borehole in the phalanx alongside the nylon. The nylon was then looped back through the phalanx.

Fig. 40: Illustrating the method by which the nylon loop was pulled through anterior to the phalanx.

Fig. 41: The ends of the nylon were passed through the loop to form a running knot which was pulled tightly to encompass the base of the phalanx.

Fig. 42: The nylon was threaded down the inside of the tendon sheath, part of which had been destroyed by previous infection. Adequate pulleys remained however.

felt presenting. (Fig. 43).

A second, two inch longitudinal incision was made at the wrist, in the line of the ulnar nerve, and the profundus tendon to the little and ring finger was isolated. This tendon was then split to give two elements, one acting on the ring finger, the other on the little finger.

The tendon to the ring finger was cut at the level of the wrist and the nylon ends were sutured to it by weaving them back and forth through the tendon by means of a Size 18 Luer-Lok needle. (Fig. 44).

The tension of the nylon was then adjusted, so that the little finger lay in its position of relaxation in relation to the other fingers.

The nylon was then tied with a triple knot and the ends were buried within the tendon and cut short. (Fig. 45).

The same procedure was performed on the little finger the nylon being sutured to the segment of the profundus tendon acting on it.

The skin was closed with interrupted 40 Dermalon sutures (Fig. 46) and after pressure dressings had been applied which held the finger in flexion, the tourniquet was released.

Fig. 43: The probe was slid down the sheath through the hand into the wrist, where the tip of the probe could be seen presenting. A longitudinal incision was made at the wrist.

Fig. 44: The profundus to the ring finger was cut and the nylon was sutured back and forth through it.

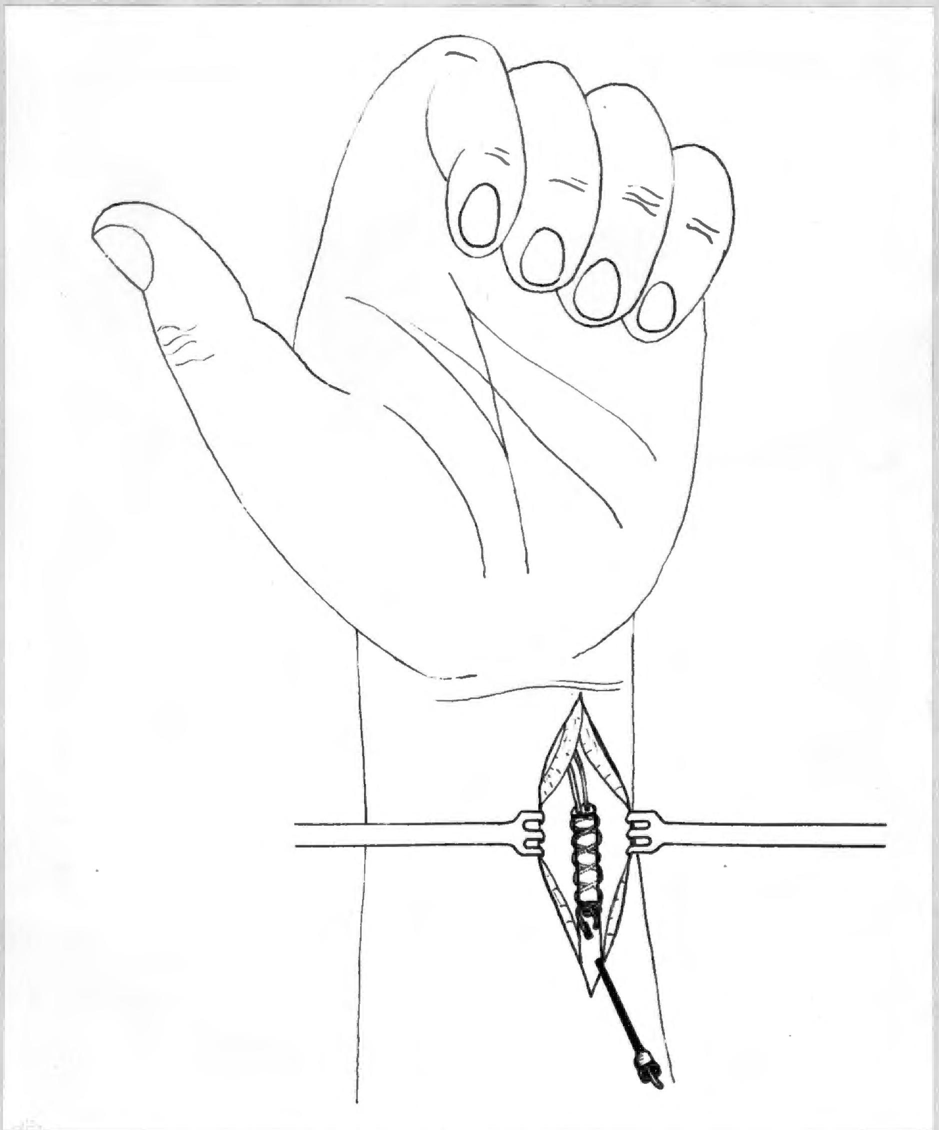

Fig. 45: After the nylon has been passed back and forth through the tendon, it is tied with a triple knot and the ends are buried within the tendon and cut short.

Fig. 46: The skin was closed with interrupted 0000 Dermalon sutures.

Post-Operatively.

1st Post operative day: The fingers were kept elevated. Able to flex the fingers within the bandages.

3rd Post operative day: Patient discharged from hospital after heavy pressure dressings had been removed and active exercises encouraged.

10th Post operative day: Stitches removed. Incisions well healed. Active exercises encouraged. Extension still markedly limited.

Fig. 47: Case No. 1. W.M. Degree of flexioh possible 14 days after the operation. The incisions still have dressings on.

Fig. 48: Case No. 1. W.M. Degree of extension present 14 days after the operation.

Fig. 49 : Case No. 1. W.M. Degree of flexion present 8 weeks after the operation.

Fig. 50: Case No. 1. W.M. Degree of extension present 8 weeks after the operation.

CASE NO. 1. W.M. MOVEMENTS OF LITTLE & RING FINGERS.

Post Operative Date	Finger	Joint	Extension	Flexion	Distance to Distal Palmar Crease	Remarks
14th day	Ring	Distal I.P.	45° short of full	50°	1 inch	Incisions well healed. Slight swelling. Patient exercising well.
		Prox. I.P.	70° short of full	80°		
		M.P.	45° short of full	50°		
	Little	Distal I.P.	55° short of full	60°	1 inch	
		Prox. I.P.	90° short of full	90°		
		M.P.	45° short of full	70°		
28th day	Ring	Distal I.P.	30° short of full	50°	¾ inch	No swelling. Extension improving. Dryness of fingers. No pain or discomfort.
		Prox. I.P.	60° short of full	25°		
		M.P.	45° short of full	55°		
	Little	Distal I.P.	50° short of full	60°	¾ inch	
		Prox. I.P.	50° short of full	90°		
		M.P.	40° short of full	70°		
6 weeks	Ring	Distal I.P.	20° short of full	60°	½ inch	Patient satisfied. No pain. No swelling. Says he is already using his hand for everyday use. He is a delivery boy and can lift parcels and use his hand for riding his bicycle etc.
		Prox. I.P.	40° short of full	85°		
		M.P.	30° short of full	70°		
	Little	Distal I.P.	50° short of full	60°	½ inch	
		Prox. I.P.	40° short of full	90°		
		M.P.	30° short of full	70°		

2./.......

CASE NO. 1. W.M. MOVEMENTS OF LITTLE & RING FINGERS(CONTINUED).

Post Operative Date	Finger	Joint	Extension	Flexion	Distance to Distal Palmar Crease	Remarks
8 weeks	Ring	Distal I.P.	15^{o} short of full	60^{o}	nil	Marked induration around interphalangeal joints. Limitation of extension Patient satisfied. Physiotherapy commenced.
		Prox. I.P.	10^{o} short of full	85^{o}		
		M.P.	30^{o} short of full	90^{o}		
	Little	Distal I.P.	45^{o} short of full	60^{o}	nil	
		Prox. I.P.	30^{o} short of full	90^{o}		
		M.P.	20^{o} short of full	90^{o}		
10 weeks	Ring	Distal I.P.	15^{o} short of full	60^{o}	nil	Patient asked whether he can stop Physiotherapy and practice at home. Has not returned to clinics.
		Prox. I.P.	10^{o} short of full	85^{o}		
		M.P.	30^{o} short of full	90^{o}		
	Little	Distal I.P.	40^{o} short of full	60^{o}	nil	
		Prox. I.P.	30^{o} short of full	90^{o}		
		M.P.	20^{o} short of full	90^{o}		

CASE NO. 2.

C.R. EUROPEAN MALE. AGED 19 YEARS.

Five weeks before coming to hospital, the patient had cut the palmar surface of his right little finger, just distal to the metacarpo-phalangeal crease, on a knife whilst fishing. The laceration had healed spontaneously without medical attention and without the intervention of any complications. He is an apprentice turner and fitter and finds it difficult to work since his little finger "gets in the way by sticking out".

On examination both profundus and sublimus tendons are cut, but passive movement is full and there is no nerve injury, or excessive cicatrix.

Under general anaesthesia and sphygmomanometer tourniquet the following repair was performed.

A mid-lateral incision was made along the medial surface of the right little finger, commencing a quarter of an inch distal to the distal interphalangeal crease and ending at the metacarpo-phalangeal crease. A palmar flap was elevated to disclose the tendon sheath. A fine awl was passed through the base of the distal phalanx, a short incision being made at the opposite side for the awl to emerge through, and a size 18 Luer-Lok needle was passed through the bore hole thus formed.

A twenty-four inch length of nylon (breaking strain 37 lbs.) was threaded through the bore of the needle and the needle was withdrawn. The needle was then reinserted through the same drill hole alongside the nylon and the end of the nylon was again passed through the needle, but in the opposite direction. The needle was then again withdrawn, leaving both ends of the nylon passing through the phalanx and looped on the one side.

The loop of nylon was then doubled back on itself through the small skin incision through which it passed and the nylon ends were then passed through the loop to form a running noose which was pulled tight to fit against the base of the terminal phalanx.

A silver probe was next inserted into the distal end of the tendon sheath and slid down the inside of the sheath as far as the original laceration which had severed the tendons. At his point the progress of the probe was halted and the sheath had to be opened and excised over a length of about a quarter of an inch where it had become sealed off. Once passed this area, the probe slid on through the sheath through the hand and into the wrist where the tip could be seen and felt presenting.

A two inch longitudinal incision was now made at the wrist in the line of the ulnar nerve and the probe was found amongst the profundus tendons. The nylon was threaded through the eye of the probe, which was then withdrawn into the wrist, drawing the nylon after it.

The profundus tendon, to the little and ring fingers, was then identified and the nylon was sutured to this tendon by weaving it back and forth through two inches of the tendon using the Luer-Lok needle to thread the nylon through the tendon.

The tension of the nylon was then adjusted to flex the little finger to its resting degree of flexion, after which the nylon was tied with a triple knot, the ends of which were buried within the tendon and cut short.

The incisions were closed with interrupted 4 0 Dermalon sutures and the tourniquet was released after a pressure dressing had been applied holding the little finger in the flexed position.

Operating time was one hour.

Post-operatively:-

1st post-operative day: Slight pain in the hand relieved by two tablets of Aspirin gr. 3

phenacetic gr. 2 and codein gr. $\frac{1}{4}$, repeated four hourly. Hand kept elevated. Some flexion of the little finger within the bandages present.

3rd post-operative day: Patient discharged from hospital, with arm elevated in a sling. Advised to do gentle exercises within the limits of the bandages.

Fig. 51 : Case No. 2. C.R. Degree of flexion present 21 days after the operation.

Fig. 52 : Case No. 2. C.R. Degree of extension present 21 days after the operation.

Fig. 53: Case No. 2. C.R. Degree of flexion present 7 weeks after the operation.

Fig. 54: Case No. 2. C.R. Degree of Extension present 7 weeks after the operation.

CASE NO. 2. C.R. PROGRESS OF MOVEMENTS OF LITTLE FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance from Distal Palmar Crease.	Remarks.
10th day.	Distal I.P. Prox. I.P. M.P.	45° short of full 45° short of full 45° short of full	60° 80° 60°	1 inch.	Stitches removed. Incisions well healed. Complains of tightness at wrist on attempting extension.
21st day.	Distal I.P. Prox. I.P. M.P.	45° short of full 30° short of full 10° short of full	80° 80° 75°	$\frac{1}{2}$ inch.	Slight dryness of skin. Slight pain at wrist at limits of flexion and extension. Is able to pick up a glass and shake hand. Little finger is weak.
5 weeks.	Distal I.P. Prox. I.P. M.P.	45° short of full 25° short of full 10° short of full	85° 80° 80°	$\frac{1}{2}$ inch.	Slight"drawing" feeling at wrist and in hand at limits of flexion and extension. Finger is much stronger and he is able to do his usual work with his hand, although limitation of extension troubles him.
7 weeks.	Distal I.P. Prox. I.P. M.P.	30° short of full 20° short of full Full.	95° 80° 95°	Full.	Slight tightness at wrists on forcing extension. At full work, but limitation of extension still troubles him.

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CASE NO. 2. C.R. PROGRESS OF MOVEMENTS OF LITTLE FINGER(CONTINUED).

Post Operative Date	Joint.	Extension.	Flexion.	Distance from Distal Palmar Crease.	Remarks.
10 weeks.	Distal I.P. Prox. I.P. M.P.	30^{o} short of full. 20^{o} short of full. Full.	95^{o} 80^{o} 95^{o}	Full.	No discomfort. Doing full work but is not completely satisfied due to slight fixed flexion deformity. Good power in the finger.
18 months.	Distal I.P. Prox. I.P. M.P.	30^{o} short of full. 20^{o} short of full. Full.	95^{o} 80^{o} 95^{o}	Full.	Patient says he manages reasonably, but lack of extension sometimes troubles him(Does not want an amputation).Good power in finger. No pain.

CASE NO. 3.

H.A. NON EUROPEAN MALE, AGED 44 YEARS.

Patient was admitted six hours after having cut his little finger on a pocket knife.

He had a $\frac{1}{2}$ inch laceration in the metacarpo-phalangeal crease, which had divided both profundus and sublimus tendons. There were no associated nerve injuries.

The following repair was carried out under general anaesthesia with a Sphygmomanometer tourniquet.

A $\frac{1}{2}$ inch incision was made in the midlateral line on the medial side of the little finger opposite the distal interphalangeal crease, and a cross incision, in the crease, was made to join this incision.

A 24 inch length of undyed nylon (breaking strain 37 lbs.) was passed through and back again through the base of the distal phalanx, through a bore hole made by an awl.

The nylon ends were then passed through the loop of the nylon to form a running knot which was tied around the base of the phalanx.

A sliver probe was then inserted into the tendon sheath and slid down the finger, passed the laceration and into the wrist, where the tip of the probe could be seen and felt.

A 2 inch longitudinal incision was made at the wrist, in the line of the ulnar nerve and the profundus tendon to the little and ring finger was identified, and whilst on tension, it was divided at the wrist. The nylon ends were then woven into the proximal inch of this tendon.

After the tension of the nylon was adjusted to keep the little finger in full flexion, the nylon was tied and the ends were buried in the tendon.

The incisions were closed with interrupted 40 Dermalon sutures and the tourniquet was released, after a pressure bandage had been applied.

Post-operatively:-

1st Post-operative day: Penicillin one million units and Streptomycin 1 Gram twice daily commenced. Arm in a sling.

3rd Post-operative day: Patient discharged home with arm in a sling. Little finger flexing within the limits of the bandages.

10th Post-operative day: Stitches removed in out-patient's clinic. Incisions well healed. Movements actively commenced and encouraged.

<u>CASE NO. 3.</u>

<u>H.A. NON EUROPEAN MALE, AGED 44 YEARS.</u>

Patient was admitted six hours after having cut his little finger on a pocket knife.

He had a ½ inch laceration in the metacarpo-phalangeal crease, which had divided both profundus and sublimus tendons. There were no associated nerve injuries.

The following repair was carried out under general anaesthesia with a Sphygmomanometer tourniquet.

A ½ inch incision was made in the midlateral line on the medial side of the little finger opposite the distal interphalangeal crease, and a cross incision, in the crease, was made to join this incision.

A 24 inch length of undyed nylon (breaking strain 37 lbs.) was passed through and back again through the base of the distal phalanx, through a bore hole made by an awl.

The nylon ends were then passed through the loop of the nylon to form a running knot which was tied around the base of the phalanx.

A sliver probe was then inserted into the tendon sheath and slid down the finger, passed the laceration and into the wrist, where the tip of the probe could be seen and felt.

A 2 inch longitudinal incision was made at the wrist, in the line of the ulnar nerve and the profundus tendon to the little and ring fingers was identified, and whilst on tension, it was divided at the wrist. The nylon ends were then woven into the proximal inch of this tendon.

After the tension of the nylon was adjusted to keep the little finger in full flexion, the nylon was tied and the ends were buried in the tendon.

The incisions were closed with interrupted 40 Dermalon sutures and the tourniquet was released, after a pressure bandage had been applied.

Post-operatively:-

1st Post-operative day:	Penicillin one million units and Streptomycin 1 Gram twice daily commenced. Arm in a sling.
3rd Post-operative day:	Patient discharged home with arm in a sling. Little finger flexing within the limits of the bandages.
10th Post-operative day:	Stitches removed in out-patient's clinic. Incisions well healed. Movements actively commenced and encouraged.

CASE NO. 3. H.A. MOVEMENTS OF LITTLE FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
14th day.	Distal I.P. Prox. I.P. M.P.	45° short of full. 30° short of full. 10° short of full.	45° 50° 30°	2 inches.	Hyperkeratosis and dryness of finger. Slight pain at wrist on full extension.
28th day.	Distal I.P. Prox. I.P. M.P.	30° short of full. 20° short of full. 10° short of full.	45° 50° 60°	$1\frac{1}{2}$ inches.	Organised Physiotherapy commenced for 1 hour, three times weekly.
6 weeks.	Distal I.P. Prox. I.P. M.P.	10° short of full. 5° short of full. Full.	45° 60° 70°	$\frac{3}{4}$ of an inch.	Markedly improved. Hyperkeratosis and induration much reduced.
8 weeks.	Distal I.P. Prox. I.P. M.P.	10° short of full. 5° short of full. Full.	45° 60° 70°	$\frac{3}{4}$ of an inch.	Patient back at work as a lorry driver. Says he is able to do his work and is fully satisfied. Has not returned to follow-up clinic again.

DISCUSSION ON CASES 1, 2 AND 3.

Although the results in these cases did not approach the ideal standard which was desired, they were, on the whole, encouraging. Movements were fair, flexion to at least within three quarters of an inch of the distal palmar crease being obtained within 8 weeks. There was, however, limitation of extension and obvious induration and stiffness around the joints in each case. Movements had been commenced and encouraged from the first post-operative day and it appeared possible that too early movements, together with insufficient elevation of the hand, might have been contributory to the limitation of function, which on the whole, appeared to be extra tendinous.

It was therefore decided that future cases would be completely immobilised for 10 days before movements were commenced, and that elevation of the hand, to reduce oedoema, would be continued for these first 10 days.

CASE NO. 4.

D.B. NON EUROPEAN MALE. AGED 28 YEARS.

Six hours prior to admission the patient was stabbed with a carving knife over the proximal phalanx of his right little finger cutting both profundus and sublimis tendons, without associated nerve involvement.

Under general anaesthesia and sphygmomanometer tourniquet, a double nylon (breaking strain 37 lbs) was inserted through a bore hole in the base of the distal phalanx and after being passed through the tendon sheath was sutured to the profundus tendon of the little finger at the wrist. The tension of the nylon being so adjusted, that the finger lay in its normal position of relaxation, under anaesthesia, in relation to the other fingers. The cut tendons were not removed.

After suturing the skin with interrupted 40 Dermalon sutures, the tourniquet was removed and the finger was immobilised by pressure dressings in full flexion.

Post-operatively:-

1st post-operative day: Penicillin 1 million units twice daily for 5 days commenced. Arm elevated in sling.

10th post-operative day: Stitches removed. Incision well healed. Movements commenced. Patient discharged home.

CASE NO.4. D.B. MOVEMENTS OF LITTLE FINGER.

Post Operative Date	Joint	Extension	Flexion	Distance to Distal Palmar Crease.	Remarks.
14th day.	Distal I.P. Prox. I.P. M.P.	45° short of full 60° short of full 30° short of full	60° 60° 60°	$\frac{3}{4}$ of an inch	Hyperkeratosis, induration and swelling of finger.
28th day.	Distal I.P. Prox. I.P. M.P.	40° short of full 50° short of full 25° short of full	60° 60° 70°	$\frac{1}{2}$ an inch	Extension very limited. No pain.
6 weeks.	Distal I.P. Prox. I.P. M.P.	30° short of full 45° short of full 25° short of full	60° 60° 70°	$\frac{1}{2}$ an inch	Marked induration and stiffness. Able to use hand but little finger interferes with function.
10 weeks.	Distal I.P. Prox. I.P. M.P.	30° short of full 35° short of full 25° short of full	60° 60° 70°	$\frac{1}{2}$ an inch	Patient back at work as a labourer, says he is able to do his work, which is digging, but is unable to perform finer movements. Has not come to clinic since this time.

CASE NO. 5.

S.D. NON EUROPEAN MALE, AGED 33 YEARS.

Five months prior to admission the patient, whilst in a fight, felt a tearing sensation at the distal interphalangeal joint of the ring finger of his right hand. Since then he had been unable to flex that joint but had developed a painful nodule in the plam of his hand.

On examination he was unable to flex the terminal interphalangeal joint of the ring finger of his right hand. In addition a tender lump was present, a half an inch proximal to the metacarpo-phalangeal joint. The sublimis tendon was functioning satisfactorily. A diagnosis of a ruptured profundus tendon at its insertion was made, with the tendon curled up in the palm of the hand.

The following repair was performed under general anaesthesia with a sphygmomanometer tourniquet.

A mid-lateral incision was made along the medial border of the right ring finger and the tendon sheath was exposed.

A second incision was made in the distal palmar crease opposite the ring finger, and the proximal end of the curled up profundus tendon was exposed. It was found to be impossible to resuture the tendon to the terminal phalanx.

A borehole was made with an awl in the base of the distal phalanx through which a twenty-four inch length of nylon (breaking strain 37 lbs.) was passed.

A probe was inserted into the distal end of the tendon sheath and slid down the sheath till the tip emerged through the incision in the palm of the hand. The nylon was then threaded through the eye of the probe, and the probe was withdrawn through the incision in the palm of the hand, drawing the nylon with it through the sheath and out through the hand.

The nylon was then sutured to the profundus tendon in the palm by being passed back and forth throughout about an inch of the proximal part of the profundus tendon. After the tension of the nylon had been adjusted so that the ring finger was in full flexion, the nylon was tied with a triple knot, the ends were buried within the nylon, and were cut short. The incisions were closed with interrupted 40 Dermalon sutures and pressure dressings were applied holding the finger in full flexion.

Post-operatively:-

1st Post-operative day: Slight movement of finger possible within the limits of the bandage. Arm kept in sling. Not encouraged to move finger.

5th Post-operative day: Patient discharged home with his arm elevated in a sling.

10th Post-operative day: Stitches removed. Slight gaping of the wound in the region of the proximal inter-phalangeal joint. Dry dressing applied.

CASE NO. 5. S.D. MOVEMENTS OF RING FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance from Distal Palmar Crease.	Remarks.
14th day.	Distal I.P. Prox. I.P. M.P.	45° short of full 45° short of full 45° short of full	50° 70° 70°	$\frac{3}{4}$ of an inch.	Incision healed. Active movements encouraged.
28th day.	Distal I.P. Prox. I.P. M.P.	30° short of full 30° short of full 40° short of full	55° 75° 75°	$\frac{1}{2}$ an inch.	Induration and fibrosis at flexion creases. Physiotherapy commenced.
6 weeks.	Distal I.P. Prox. I.P. M.P.	30° short of full 30° short of full 40° short of full	55° 75° 80°	$\frac{1}{2}$ an inch.	No swelling of finger, but marked induration.Patient is unable to use his hand as the finger gets in the way.
10 weeks.	-	-	-	-	For past 2 days has had swelling,redness and pain over anterior aspect of metacarpo-phalangeal joint. Abscess incised under general anaesthetic, and nylon removed.
12 weeks.	-	-	-	-	Incision healing satisfactorily.
14 weeks.	Distal I.P. Prox. I.P. M.P.	10° short of full. 10° short of full. 15° short of full.	Nil 20° 80°	2 inches.	He says he is able to do his work as a fisherman. Has not returned to clinic.

DISCUSSION ON CASE NO. 5 S.D.

From this case, it was felt that certain valuable lessons had been learned. The suture of the nylon into the tendon in the palm of the hand was unsatisfactory. It was technically difficult to perform at this level and smooth glide of the tendon did not ensue. It was decided that in all future cases, the nylon would be continued through to the wrist where its suture could be more easily performed.

The late infection in this case was important and disappointing, but the rapidity and ease with which the infection cleared was an encouraging feature.

The removal of the nylon revealed many interesting features. It was found impossible to pull the nylon free from the tendon in the palm. An incision in the distal palmar crease being necessary to dissect the nylon free.

It was also found impossible to pull the nylon free from its fixation to the phalanx. Once the nylon was freed from the tendon however, it was possible to slide it completely through the phalanx and out.

The nylon showed no evidence of erosion or any other deterioration from its period of burial, or the associated infection.

CASE NO. 6.

D.E. NON EUROPEAN MALE AGED. 23 YEARS.

The patient was admitted to hospital three hours after having been involved in a fight during which his hand was slashed with a knife.

He had lacerations on all four fingers.

The little finger was lacerated in the proximal interphalangeal flexion crease.

The ring finger was lacerated just proximal to the proximal interphalangeal flexion crease.

The middle finger was lacerated just proximal to the proximal interphalangeal flexion crease.

The index finger was lacerated just distal to the proximal interphalangeal flexion crease.

The sublimis and profundus tendons of the little, ring and middle fingers were severed, and in the index finger the profundus tendon only.

Under general anaesthesia and sphygmomanometer tourniquet the following repair was carried out.

An incision was made in the distal palmar crease, exposing the tendon sheaths, which were incised. A half inch midlateral incision was then made on the lateral border of the index finger opposite the distal interphalangeal joint. Through this incision an awl was passed through the base of the distal phalanx, and through the tunnel so formed a 24 inch length of nylon (breaking strain 37 lbs) was passed. A probe was next inserted into the tendon sheath and slid through the index finger to pass out through the incision in the distal palmar crease.

The nylon ends were threaded through the eye of the probe, and it was withdrawn through the finger and out through the palm pulling the nylon with it.

The probe was then reinserted through the palmar incision and slid proximally through the sheath to the wrist, where the tip could be seen and felt presenting.

A longitudinal incision, two inches long, in the line of the ulnar nerve, was next made at the wrist, through which the profundus tendons were exposed, with the probe lying amongst them. The nylon ends were again threaded through the eye of the probe and it was withdrawn into the wrist, drawing the nylon with it completely through to the wrist.

The profundus tendon to the index fingers was next divided at the level of the wrist, and the nylon ends were passed back and forth weaving it through the tendon for one and a half inches.

The tension of the nylon was finally adjusted so that the index finger lay in its normal relaxed position, under anaesthesia, in relation to the other fingers. The nylon was then tied with a triple knot and after the ends had been buried within the tendon, they were cut off.

The three other fingers were repaired in precisely the same manner.

Finally the skin incisions and lacerations were closed with 40 Dermalon, and pressure dressings were applied, holding the fingers in flexion.

The operative time was 2 hours, the tourniquet being released for 10 minutes at the end of 1½ hours.

<u>Post-operatively</u>:-

1st post-operative day:	Hand kept elevated. Penicillin 1 million units twice daily for 5 days commenced.
5th post-operative day:	Patient discharged from hospital with hand elevated.
10th post-operative day:	Stitches removed. All incisioms and lacerations well healed except for laceration on little finger which is gaping slightly with a slight discharge of serum. Dressing applied.
12th post-operative day:	New dressing applied to little finger. Laceration healing well and much drier.

CASE NO. 6. D.E. MOVEMENTS OF LITTLE, RING, MIDDLE AND INDEX FINGERS.

Post Operative Date	Finger.	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
21st day.	Little	Distal IP.	45^{o} short of full	40^{o}	$1\frac{1}{4}$ inches.	Marked hyperkeratosis and dryness of the fingers. Induration of the peri-articular tissues. Exercises encouraged.
		Prox. IP.	45^{o} short of full	45^{o}		
		M.P.	Full	90^{o}		
	Ring	Distal IP.	40^{o} short of full	50^{o}	2 inches.	
		Prox. IP.	40^{o} short of full	40^{o}		
		M.P.	10^{o} short of full	60^{o}		
	Middle	Distal IP.	45^{o} short of full	45^{o}	2 inches.	
		Prox. IP.	40^{o} short of full	40^{o}		
		M.P.	10^{o} short of full	60^{o}		
	Index	Distal IP.	40^{o} short of full	40^{o}	2 inches.	
		Prox. IP.	40^{o} short of full	40^{o}		
		M.P.	10^{o} short of full	40		
6 weeks.	Little	Distal IP.	40^{o} short of full	40^{o}	$1\frac{1}{4}$ inches.	No pain. Hyperkeratosis less. Fingers still very dry. Is beginning to use his hand for general daily uses. Able to hold glass, hammer, and larger parcels. Hand not very strong.
		Prox. IP.	40^{o} short of full	50^{o}		
		M.P.	Full	90^{o}		
	Ring	Distal IP.	40^{o} short of full	50^{o}	$1\frac{1}{2}$ inches.	
		Prox. IP.	35^{o} short of full	45^{o}		
		M.P.	Full	70^{o}		
	Middle	Distal IP.	30^{o} short of full	45^{o}	$1\frac{1}{2}$ inches.	
		Prox. IP.	30^{o} short of full	45^{o}		
		M.P.	5^{o} short of full	65^{o}		
	Index	Distal IP.	20^{o} short of full	45^{o}	$1\frac{1}{2}$ inches	
		Prox. IP.	20^{o} short of full	45^{o}		
		M.P.	5^{o} short of full	60^{o}		

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CASE NO. 6. D.E. MOVEMENTS OF LITTLE, RING, MIDDLE AND INDEX FINGERS(CONTINUED).

Post Operative Date	Finger	Joint	Extension	Flexion	Distance to Distal Palmar Crease.	Remarks.
9 weeks.	Little	Distal IP.	40^o short of full	40^o	1 inch	Hyperkeratosis much diminished. Still some periarticular fibrosis around distal interphalangeal joints especially. Back at work as a painter. Says he is able to do most of his work, but not using his hand normally.
		Prox. IP.	30^o short of full	60^o		
		M.P.	Full	80^o		
	Ring	Distal IP.	40^o short of full	50^o	1 inch	
		Prox. IP.	30^o short of full	45^o		
		M.P.	Full	70^o		
	Middle	Distal IP.	20^o short of full	45^o	1 inch	
		Prox. IP.	20^o short of full	45^o		
		M.P.	Full	70^o		
	Index	Distal IP.	10^o short of full	45^o	1 inch	
		Prox. IP.	Full	45^o		
		M.P.	Full	70^o		
12 weeks.	Little	Distal IP.	Full	50^o	½ inch.	At 9 weeks the patient was given a general anaesthetic and the interphalangeal joints were manipulated into full extension which in each case occured with a sharp snap. The manipulation was followed by active exercises and organised physiotherapy. Hand has now almost full movement but not full power or fine co-ordinated independant movement. Patient able to do his work however and says he is satisfied.
		Prox. IP.	10^o short of full	70^o		
		M.P.	Full	80^o		
	Ring	Distal IP.	30^o short of full	50^o	½ inch.	
		Prox. IP.	Full	80^o		
		M.P.	Full	80^o		
	Middle	Distal IP.	10^o short of full	45^o	½ inch.	
		Prox. IP.	Full	90^o		
		M.P.	Full	90^o		
	Index	Distal IP.	5^o short of full	45^o	¼ inch	
		Prox. IP.	Full	90^o		
		M.P.	Full	90^o		

Fig. 57: Case No. 6 D.E. The appearance of the hand 3 weeks after the operation.

Fig. 58: Case No. 6 D.E. Degree of flexion present 3 weeks after the operation.

Fig. 59: Case No. 6 D.E. Degree of extension present 3 weeks after the operation.

Fig. 60: Case No. 6 D.E. Degree of flexion present 9 weeks after the operation.

Fig. 61: Case No. 6 D.E. Degree of extension present 9 weeks after the operation.

Fig. 62: Case No. 6 D.E. Degree of flexion present 12 weeks after the operation.

Fig. 63: Case No. 6 D.E. Degree of extension present 12 weeks after the operation.

DISCUSSION ON CASE NO. 6 D.E.

This case, more than any of the previous 5 patients, showed great difficulty and delay in regaining extension. A possible explanation considered at this stage, was that the fingers were being allowed to remain flexed after the operation, during the period when reactionary swelling occurred, and that the joints were becoming stiff and fixed in this position. This complication had been present in all the previous cases to a varying degree.

It was decided that the future cases would be immobilised post-operatively in full extension, although the tension of the nylon at its insertion, would still be judged so as to hold the fingers, under anaesthesia, in their accepted positions of relaxation in relationship to each other. The following 7 cases were therefore all immobilised for 10 days post-operatively in full extension.

CASE NO. 7.

C.P. NON EUROPEAN MALE. AGED 25 YEARS.

Some months prior to admission the patient had cut his right little finger just proximal to the middle interphalangeal crease, on a broken milk bottle.

On examination he had full sublimis action but was uhable to flex the distal interphalangeal joint. Passive movements were full and there was no nerve involvement.

Under general anaesthesia and tourniquet, the following repair was performed:-

An incision was made in the distal palmar crease at the base of the little finger and the tendon sheath to the little finger was exposed. The proximal end of the profundus tendon was curled up at this level. A probe was passed distally along the tendon sheath, but was held up at the site of the old laceration.

A second mid-lateral incision was therefore made down the medial side of the little finger and the tendon sheath was exposed.

An awl was passed transversely through the base of the distal phalanx and through the hole so formed, a 24 inch length of nylon (breaking strain 37 lbs.) was passed with the aid of a size 18 Luer-Lok needle. The nylon being passed through the bore of the needle, after which the needle was withdrawn.

A probe was then inserted into the tendon sheath and slid as far as the original laceration. The tendon sheath in this area was collapsed and adherent, and was excised, care being taken not to damage the pulley in the area.

After this the probe slid easily down the finger, through the hand and into the wrist where the tip of the probe could be seen and felt.

A longitudinal incision, two inches long was now made at the wrist, in the line of the ulnar nerve, and the profundus tendons were exposed. The tip of the probe was found lying amongst them.

The nylon ends were threaded through the eye of the probe, and it was then withdrawn into the wrist, drawing the nylon through the finger and hand to the wrist.

The common profundus tendon to the little and ring fingers was split longitudinally, to give separate slips and the slip to the little finger was divided at the level of the wrist joint.

With the aid of the size 18 Luer-Lok needle, the nylon was sutured to the tendon, weaving it back and forth through the tendon for one and a half inches.

The tension of the nylon was then adjusted so as to hold the little finger in its correct position of flexion in relationship to the other fingers, and after tying the nylon with a triple knot, the ends were buried within the tendon and cut off.

The skin incisions were closed with interrupted sutures of 40 Dermalon and after a pressure dressing had been applied with a large pad of cotton wool holding the finger in full extension, the tourniquet was removed.

Post-operatively:-

1st Post-operative day: Hand kept elevated. Finger able to move within the limits of the cotton wool splint.

5th Post-operative day: Patient discharged home, with hand in a sling and finger still splinted in full extension.

10th Post-operative day: Stitches removed. Incision well healed. Exercises commenced. Complaining of some pain at terminal phalanx on commencing active flexion.

CASE NO. 7. C.P. MOVEMENTS OF LITTLE FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
14th day.	Distal I.P.	Full.	20°	2 inches.	No pain or discomfort. Active movements encouraged.
	Prox. I.P.	Full.	20°		
	M.P.	Full.	45°		
21st day.	Distal I.P.	Full.	30°	$1\frac{3}{4}$ inches.	Marked hyperkeratosis and dryness of finger and induration.
	Prox. I.P.	Full.	30°		
	M.P.	Full.	50°		
6 weeks.	Distal I.P.	Full.	45°	$1\frac{1}{4}$ inches.	Marked stiffening of the joints. Limitation of flexion is articular and not tendinous.
	Prox. I.P.	Full.	45°		
	M.P.	Full.	90°		
9 weeks.	Distal I.P.	Full.	45°	1 inch.	Patient able to lift and use a hammer and spanner and do his work as a greengrocer.
	Prox. I.P.	Full.	50°		
	M.P.	Full.	90°		
12 weeks.	Distal I.P.	Full.	45°	1 inch.	Patient says he is satisfied although the little finger does get in the way at times. Has not returned to clinics or answered written questionaire.
	Prox. I.P.	Full.	50°		
	M.P.	Full.	90°		

CASE NO. 8.

E.P. COLOURED FEMALE. AGED 21 YEARS.

The patient was admitted to the hospital 14 hours after having accidentally cut her hand on a knife whilst under the influence of alcohol.

She had a laceration extending across the palm of her left hand, a quarter of an inch distal to the distal palmar crease severing the profundus and sublimus tendons to the index, middle and ring fingers, and a laceration in the metacarpo-phalangeal flexion crease of the little finger dividing both flexor tendons. There were also lacerations midway between the middle and distal inter-phalangeal creases of the index and middle fingers and at the distal creases of the ring and little fingers.

There was no nerve involvement.

She had no other injuries, and her general condition was excellent. Although the lacerations were 14 hours old they looked clean and uninfected and it was decided to carry out a primary repair.

After general anaesthesia had been induced, a sphygmomanometer tourniquet was applied, the blood having been expressed from the arm and hand with an Esmarch's bandage. After the lacerations had been meticulously washed with a one percent "Cetavlon" solution, the following operation was carried out.

<u>Index Finger:</u> A ½ inch incision was made in the midlateral line, commencing a ¼ of an inch proximal to the distal interphalangeal joint. A cross incision in the crease was made. The flaps so formed were raised. At the level of the insertion of the profundus tendon, an awl was worked transversely through the base of the distal phalanx, a quarter of an inch midlateral incision being made on the opposite side of the finger for the point of the awl to emerge. The awl was withdrawn and replaced by a size 18 Luer-Lok needle, through which a 24 inch length of nylon (breaking strain 37 lbs.) was passed. After the needle had been withdrawn the ends of the nylon were doubled back on themselves and passed through the skin incisions on both sides, so that they were brought out through the transverse incision in the distal flexor crease.

The tendon sheath at the level of the insertion of the profundus tendon was next incised, and a malleoble silver probe was passed into and down the sheath, alongside the tendon, and slid proximally till it emerged through the laceration in the palm.

The ends of the nylon were next threaded through the eye of the probe, and the probe was withdrawn through the laceration in the palm drawing the nylon after it.

Small retractors were now inserted into the laceration, and the opposite cut end of the sheath was identified. The silver probe was inserted into this open end and slid through the sheath, alongside the tendons till the tip of the probe could be seen and felt presenting under the skin at the wrist.

A two inch incision was next made longitudinally at the wrist, passing proximally from the transverse carpal crease in the line of the ulnar nerve. The probe was identified lying amongst the profundus tendons and after the nylon ends had again been threaded through its eye, it was withdrawn into the wrist drawing the nylon after it, and the nylon was held and clipped in an artery forceps, till the other fingers had been dealt with.

Middle and Ring Fingers: The same incisions and procedures were performed on these fingers and the nylon ends were also clipped once they had been withdrawn into the wrist.

Little Finger: A similar procedure was performed in this finger, but difficulty was met in attempting to guide the probe into the proximal end of the severed sheath at the metacarpo-phalangeal crease where it was divided, and a mid-lateral incision along the full length of the little finger was necessary in order to display the sheath completely.

Once the probe had entered the proximal sheath it was easily slid through to the wrist drawing the nylon threads, through to the wrist behind it.

<u>The Wrist</u>: The nylon from all four fingers now presented at the wrist. The tendons of the profundus muscle were identified and the individual tendons to each finger were identified as far as it was possible. Each finger was then dealt with in turn.

The tendon was placed on tension, by pulling it a short distance out of the hand, and whilst this tension was maintained, the tendon was divided at about the level of the transverse carpal crease, the distal end of the tendon being allowed to disappear back into the hand.

With the aid of the Size 18 Luer-Lok needle, the nylon was then passed obliquely through the cut end of the tendon, the nylon being slid through the bore of the needle. The nylon ends were passed back and forth through the tendon for 1½ - 2 inches, and after the tensions of the nylon had been so adjusted that the fingers lay in their accepted positions of rest, the nylon was tied with a triple knot, the ends of which were buried in the tendon and cut off.

This manoevre was performed for all four fingers.

The skin was then closed with interrupted 40 Dermalon sutures and once a pressure bandage had been applied, the tourniquet was removed.

The total operating time was one and one half hours. The fingers were immobilised in the fully extended position with the wrist in slight dorsiflexion.

Post-operatively:-

1st post-operative day:	Patient complained of some pain in the hand, relieved by 100 mgm Pethidine given hypodermically. Hand kept elevated. Penicillin 1 mill. units twice daily and Streptomycin 1 gram twice daily commenced for 5 days.
4th post-operative day:	Patient discharged home.
10th post-operative day:	Seen in Out Patient clinic. Stitches removed. Incisions and lacerations well healed. Active movements commenced and encouraged.

CASE NO. 8. E.P. PROGRESS OF MOVEMENTS.

Post Operative Date	Finger.	Joint.	Extension.	Flexion.	Distance from Distal Palmar Crease.	Remarks.
13th day.	Index.	Distal IP.	Full.	20°	2 inches.	No pain on active movements. Pain in joints on forced passive movement. No pain at wrist. General stiffness of joints. Hyperkeratosis and dryness of all four fingers and palm.
		Prox. IP.	10° short of full.	80°		
		M.P.	Full.	20°		
	Middle.	Distal IP.	Full.	10°	2 inches.	
		Prox. IP.	10° short of full.	45°		
		M.P.	Full.	45°		
	Ring.	Distal IP.	Full.	10°	2 inches.	
		Prox. IP.	5° short of full.	45°		
		M.P.	Full.	45°		
	Little.	Distal IP.	Full.	10°	2 inches.	
		Prox. IP.	Full.	20°		
		M.P.	Full.	20°		
21st day.	Index.	Distal IP.	Full.	45°	$1\frac{3}{4}$ inches.	Examination much as at 13th day. Hyperkeratosis and dryness of fingers and palm still marked. Advised to ex--ercise more, actively and passively.
		Prox. IP.	5° short of full.	80°		
		M.P.	Full.	35°		
	Middle.	Distal IP.	Full.	15°	$1\frac{1}{2}$ inches.	
		Prox. IP.	Full.	45°		
		M.P.	Full.	50°		
	Ring.	Distal IP.	Full.	15°	$1\frac{1}{2}$ inches.	
		Prox. IP.	Full.	45°		
		M.P.	Full.	50°		
	Little.	Distal IP.	Full.	15°	$1\frac{1}{2}$ inches.	
		Prox. IP.	Full.	45°		
		M.P.	Full.	45°		

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CASE NO. 8. E.P. PROGRESS OF MOVEMENTS(CONTINUED.)

Post Operative Date	Finger.	Joint.	Extension.	Flexion.	Distance from Distal Palmar Crease.	Remarks.
6 weeks.	Index.	Distal IP.	Full	45°	$1\frac{3}{4}$ inches.	Patient did not come to outpatient clinic for 3 weeks. Fingers still very stiff and dry. Hyperkeratosis less marked. Physiotherapy three times weekly commenced in physiotherapy dept. Able to lift a glass and carry it but hand very weak.
		Prox. IP.	5° short of full	80°		
		M.P.	Full	80°		
	Middle.	Distal IP.	Full	20°	$1\frac{3}{4}$ inches.	
		Prox. IP.	Full	45°		
		M.P.	Full	80°		
	Ring.	Distal IP.	Full	20°	$1\frac{1}{4}$ inches.	
		Prox. IP.	Full	45°		
		M.P.	Full	80°		
	Little.	Distal IP.	Full	20°	$1\frac{1}{4}$ inches.	
		Prox. IP.	Full	45°		
		M.P.	Full	80°		
8 weeks.	Index.	Distal IP.	Full	45°	$1\frac{1}{2}$ inches.	Patient refuses to come for physiotherapy any more. Hyperkeratosis less marked. Patient able to shake hands, lift a cup and use and work with the hand. Power much increased.
		Prox. IP.	Full	80°		
		M.P.	Full	90°		
	Middle.	Distal IP.	Full	25°	$1\frac{3}{4}$ inches.	
		Prox. IP.	Full	45°		
		M.P.	Full	80°		
	Ring.	Distal IP.	Full	25°	$1\frac{1}{4}$ inches.	
		Prox. IP.	Full	45°		
		M.P.	Full	80°		
	Little.	Distal IP.	Full	25°	$1\frac{1}{4}$ inches.	
		Prox. IP.	Full	45°		
		M.P.	Full	80°		
3 months.	Index.	Distal IP.	Full.	45°	$1\frac{1}{2}$ inches.	Has not attended clinic for past 4 weeks. Examination is much as at 8th
		Prox. IP.	Full.	80°		
		M.P.	Full.	90°		

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CASE NO.8. E.P. PROGRESS OF MOVEMENTS(CONTINUED).

Post Operative Date	Finger	Joint	Extension	Flexion	Distance from Distal Palmar Crease	Remarks.
	Middle	Distal IP.	Full	25^{o}	$1\frac{3}{4}$ inches.	week but she says she is able to use the hand for what she requires, but would like it to "work better" if possible.
		Prox. IP.	Full	45^{o}		
		M.P.	Full	80^{o}		
	Ring	Distal IP.	Full	25^{o}	$1\frac{1}{4}$ inches.	
		Prox. IP.	Full	45^{o}		
		M.P.	Full	80^{o}		
	Little	Distal IP.	Full	25^{o}	$1\frac{1}{4}$ inches.	
		Prox. IP.	Full	45^{o}		
		M.P.	Full	80^{o}		
	Index	Distal IP.	Full	45^{o}	$1\frac{1}{2}$ inches.	
		Prox. IP.	Full	80^{o}		
		M.P.	Full	90^{o}		
						Has not re-attended Clinic, and has not answered written requests to do so, or questionaire sent to her.

Fig. 64: Case No. 8 E.P. Degree of flexion present 13 days after the operation.

Fig. 65: Case No. 8 E.P. Degree of extension present 13 days after the operation.

Fig. 66: Case No. 8 E.P. Degree of flexion present 21 days after the operation.

Fig. 67: Case No. 8 E.P. Degree of extension present 21 days after the operation.

Fig. 68: Case No. 8 E.P. Degree of flexion present 6 weeks after the operation.

Fig. 69: Case No. 8 E.P. Degree of extension present 6 weeks after the operation.

CASE NO. 9.

G.J. NON EUROPEAN MALE. AGED 9 YEARS.

One year prior to admission the patient had fallen on a piece of glass, which had lacerated the base of his left index finger. When seen he had a well healed scar in the metacarpo-phalangeal flexion crease of his left index finger with severence of both the profundus and sublimis tendons. There was no nerve involvement and passive movements were full.

Under general anaesthesia and sphygmomanometer tourniquet the following repair was carried out.

A ½ inch midlateral incision was made on the medial side of the distal flexion crease of the left index finger. A hole was bored through the base of the distal phalanx and a length of nylon (breaking strain 37 lbs.) was threaded through the phalanx by means of a size 18 Luer-Lok needle. A silver probe was then slid down the inside of the tendon sheath through the finger and into the wrist. A second incision was made at the wrist, 2 inches long in the line of the ulnar nerve and the tip of the probe was found amongst the profundus tendons.

The nylon ends were threaded onto the eye of the probe, which was then withdrawn into the wrist drawing the nylon through the tendon sheath and hand into the wrist. The nylon was then interlaced back and forth through the tendon and after the tension of the nylon had been so adjusted that the finger was held in its normal position of rest under anaesthesia, the nylon was tied with a triple knot and the ends were buried in the nylon and cut short.

The incisions were closed with interrupted dermalon sutures and after pressure dressings had been applied, the tourniquet was released. The finger was splinted in the position of full extension, with the wrist slightly dorsiflexed.

Post-operatively:

1st post-operative day: Hand kept elevated. Patient comfortable.

3rd post-operative day: Patient discharged home with his arm in a sling.

10th post-operative day: Stitches removed. Movements commenced and encouraged.

CASE NO. 9. G.J. MOVEMENTS OF INDEX FINGER.

Post Operative Date.	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease from tip of finger.	Remarks.
14th day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	10° 30° 45°	2 inches.	Marked swelling of finger. Child not moving finger well. Incisions well-healed.
21st day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	20° 40° 50°	$1\frac{1}{2}$ inches.	Finger still swollen. Physiotherapy commenced.
5 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	25° 45° 60°	$1\frac{1}{4}$ inches.	Finger still markedly swollen. Marked stiffness of joints. No pain.
8 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	25° 45° 65°	$1\frac{1}{4}$ inches.	Swelling less but still present.
12 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	30° 45° 70°	1 inch.	Finger still swollen, indurated and stiff. Able to use finger for lifting large objects.
16 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full	30° 45° 70°	1 inch.	Finger still swollen and indurated. Patient has gone to live up country.

CASE NO. 10.

F.J. NON EUROPEAN MALE. AGED 41 YEARS.

Three months prior to admission, the patient had cut the palm of his hand a quarter of an inch proximal to the metacarpo-phalangeal flexor crease.

On examination he had a healed scar in the site of the original laceration and was unable to actively flex the distal or middle inter-phalangeal creases. There was no evidence of cicatrix but there was passive limitation of flexion of the indes finger. Physiotherapy was commenced and continued for 3 weeks prior to the operation. Passive movement did not improve much however, and just prior to operation the passive movements were as follows:

MOVEMENT OF INDEX FINGER PRIOR TO OPERATION.

Joint.	Passive Extension.	Passive Flexion.
Distal I.P.	Full	50°
Prox. I.P.	Full	50°
M.P.	Full	90°

Under general anaesthesia and sphygmomanometer tourniquet the following repair was performed.

An incision was made in the midlateral line on the lateral side of the index finger, and an awl was passed through the base of the distal phalanx. A 24 inch length of nylon (37 lbs. breaking strain) was passed through this bore hole with the aid of a Size 18 Luer-Lok needle.

The tendon sheath was incised and a silver probe was then slid proximally down the sheath only to be arrested at the site of the original laceration in the palm.

An incision was therefore made in the palmar crease parallel to the thenar eminence and the tendon sheath to the index finger was identified and incised and the probe was guided through the area of adhesions ad slid on so that the tip of the probe could be seen and felt at the wrist. (Fig. 70).

A 2 inch longitudinal incision was now made at the wrist, in the line of the ulnar nerve and the profundus tendons and probe were exposed. The nylon ends were now threaded through the eye of the probe, and the probe and nylon were withdrawn into the wrist (Fig. 71).

Traction was then applied to the profundus tendon of the index finger and it was divided at the level of the wrist joint.

Fig. 70: The probe is guided from the finger, through the hand and into the wrist, where the tip can be seen presenting.

Fig. 71: The nylon ends are drawn through the tendon sheath and into the wrist.

The nylon ends were then inter woven into the tendon for $1\frac{1}{2}$ - 2 inches (Fig. 72), and after the tendon had been so adjusted that the index finger lay in its correct position of rest in relation to the other fingers, the nylon was tied with a triple knot, (Fig. 73) and the ends were buried within the tendon and cut short.

The skin was closed with interrupted 40 Dermalon sutures and the tourniquet was removed after a pressure dressing had been applied. The finger being splinted in the position of full extension.

Post-operatively:-

1st post-operative day: Patient comfortable. Hand kept elevated.

3rd post-operative day: Discharged home.

10th post-operative day: Stitches removed. Incisions well healed.

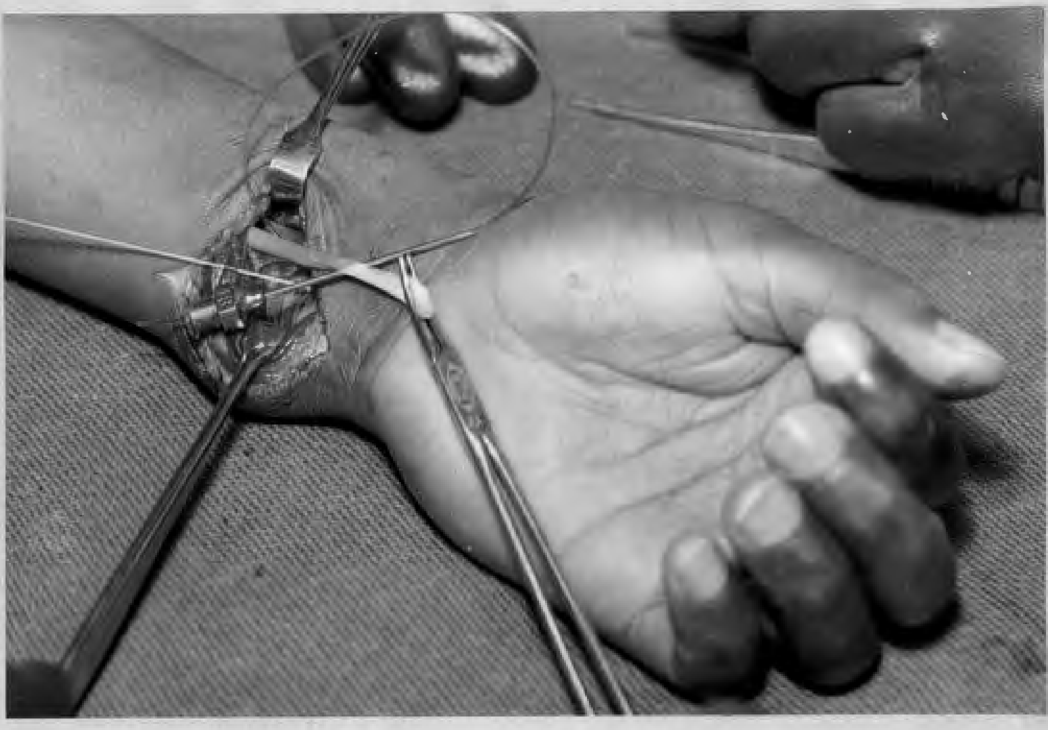

Fig. 72: The nylon is passed back and forth up 1½ - 2 inches of the tendon, with the aid of a hypodermic needle.

Fig. 73: Once the tension of the nylon has been correctly adjusted, it is tied with a triple knot.

CASE NO. 10. F.J. MOVEMENTS OF INDEX FINGER.

Post Operative Date	Joint	Extension	Flexion	Distance to Distal Palmar Crease.	Remarks.
14th day.	Distal I.P.	45° short of full	50°	2 inches	Incisions well healed. No swelling or induration.
	Prox. I.P.	35° short of full	50°		
	M.P.	Full	35°		
28th day.	Distal I.P.	40° short of full	50°	$1\frac{3}{4}$ inches	No swelling or pain.
	Prox. I.P.	40° short of full	50°		
	M.P.	Full	45°		
6 weeks.	Distal I.P.	30° short of full	50°	$1\frac{1}{2}$ inches	Patient satisfied. Says he is able to do his farm work.
	Prox. I.P.	40° short of full	50°		
	M.P.	Full	60°		
8 weeks.	Distal I.P.	30° short of full	50°	$1\frac{1}{2}$ inches	Patient returning up country.
	Prox. I.P.	30° short of full	50°		
	M.P.	Full	60°		

Fig. 74: Case No. 10 F.J. Degree of flexion present 14 days after the operation.

Fig. 75: Case No. 10 F.J. Degree of extension present 14 days after the operation.

Fig. 76: Case No. 10 F.J. Degree of flexion present 6 weeks after operation.

Fig. 77: Case No. 10 F.J. Degree of extension present 6 weeks after operation.

CASE NO. 11.

W.G. EUROPEAN MALE. AGED 20 YEARS.

Six months prior to admission patient had cut his little and ring fingers on a knife whilst on a fishing trip.

On examination there were healed scars over the flexor surfaces of the little and ring fingers between the metacarpo-phalangeal creases and the proximal interphalangeal creases, and both fingers lacked sublimis and profundus action. There were no associated nerve injuries and passive movements were full.

Under general anaesthesia and a sphygmomanometer tourniquet, the following repair was carried out.

A midlateral incision was made along the medial side of the little finger exposing the tendon sheath.

A 24 inch length of nylon (breaking strain 37 lbs.) was passed transversely through the base of the distal phalanx after a hole had been bored in it with an awl.

The distal end of the tendon sheath was incised and a probe was inserted into the sheath and slid down the finger, through the hand and into the wrist, where the tip of the probe could be seen and felt presenting.

A two inch longitudinal incision was made at the wrist in the line of the ulnar nerve and the profundus tendon to the little and ring fingers was exposed.

After the nylon had been guided through to the wrist with the probe, the nylon ends were passed back and forth through the common tendon to the little and ring finger for a distance of one and a half inches, the tension of the nylon being so adjusted that the little finger lay in its normal degree of flexion, in relationship to the other fingers, under anaesthesia.

The nylon was then tied with a triple knot and after the ends had been buried within the tendon, they were cut short.

The same procedure was performed on the ring finger, the nylon ends being sutured to the same profundus tendon.

After the skin had been sutured with interrupted 40 Dermalon sutures, a pressure dressing was applied, with a large pad of cotton wool holding the finger in full extension. The tourniquet was then removed.

Post-operatively:-

1st post-operative day: Hand kept elevated.

5th post-operative day: Patient discharged from hospital with arm elevated in a sling.

10th Post-operative day: Stitches removed. Incision well healed. Light bandages applied and active exercises commenced and encouraged.

CASE NO. 11. W.G. MOVEMENTS OF LITTLE AND RING FINGERS.

Post Operative Date	Finger	Joint	Extension	Flexion	Distance to Distal Palmar Crease.	Remarks.
14th day.	Little.	Distal IP.	30° short of full	45°	$1\frac{3}{4}$ inches.	Some evidence of bow-stringing of nylon of little finger ? cause.
		Prox. IP.	Full.	45°		
		M.P.	Full.	45°		
	Ring.	Distal IP.	Full.	20°	$1\frac{3}{4}$ inches.	
		Prox. IP.	10° short of full	45°		
		M.P.	Full	50°		
21st day.	Little.	Distal IP.	20° short of full	45°	$1\frac{1}{4}$ inches.	Slight swelling of fingers. No pain or discomfort. Encouraged to do both active and passive exercises.
		Prox. IP.	Full	50°		
		M.P.	Full	60°		
	Ring.	Distal IP.	Full	30°	$1\frac{1}{4}$ inches.	
		Prox. IP.	Full	45°		
		M.P.	Full	60°		
6 weeks.	Little.	Distal IP.	10° short of full	45°	1 inch.	There is some tendency to bowstring in both fingers. On pressing on flexor surface of the fingers much improved movements are possible.
		Prox. IP.	Full.	50°		
		M.P.	Full.	80°		
	Ring.	Distal IP.	Full.	40°	1 inch.	
		Prox. IP.	Full.	45°		
		M.P.	Full.	80°		
9 weeks.	Little.	Distal IP.	Full.	45°	1 inch.	Patient able to work with pliers and carry out his work as an electrician. He requires full flexion to
		Prox. IP.	Full	55°		
		M.P.	Full	80°		

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CASE NO.11. W.G.MOVEMENTS OF LITTLE AND RING FINGERS (CONTINUED).

Post Operative Date	Finger.	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
	Ring.	Distal IP. Prox. IP. M.P.	Full. Full. Full.	45° 45° 90°	¾ inch.	do his work fully, but he manages, he says.
12 weeks.	Little.	Distal IP. Prox. IP. M.P.	Full. Full. Full.	45° 55° 90°	¾ inch.	Limitation of full flexion is partly bow-stringing of tendon but mainly peri-articular fibrosis. Patient back at full work. In answer to a letter at 6 months post-operatively, he says his fingers have the same movement, full power and he is at full work. He is "fairly satisfied".
	Ring.	Distal IP. Prox. IP. M.P.	Full. Full. Full.	45° 45° 90°	¾ inch.	

Fig. 78: Case No. 11 W.G. Degree of flexion present 14 days after operation.

Fig. 79: Case No. 11 W.G. Degree of extension present 14 days after operation.

CASE NO. 12.

R.R. EUROPEAN MALE AGED 44 YEARS.

Patient cut the base of his right middle finger four months prior to admission, on a broken bottle whilst at a party. He says he was taken to a hospital and the finger was operated on the same night and sown up.

On examination there was a healed scar just distal to the metacarpo-phalangeal joint of the middle finger of the right hand. There was no sublimis or profundus action in the finger, but passive movements were full. There were no associated nerve injuries.

Under general anaesthesia and sphygmomanometer tourniquet a mid-lateral incision was made along the lateral border of the middle finger exposing the tendon sheath.

A 24 inch length of nylon (breaking strain 37 lbs.) was passed transversely through the base of the distal phalanx, through a bore hole made with an awl.

After the distal end of the tendon sheath had been incised, a probe was passed proximally down the sheath but was arrested in the region of the original laceration.

The tendon sheath was incised in this area and it was found that a primary suture of the profundus tendon had been attempted with linen thread. The tendon was tightly adherent to the sheath, by a large amount of fibrous tissue. The tendon sheath in the area was excised, care being taken to preserve a sufficient pulley.

The probe now slid easily through the tendon sheath and hand into the wrist where the tip could be seen and felt presenting.

A two inch longitudinal incision was made at the wrist in the line of the ulnar nerve and the profundus tendon to the middle finger was isolated. The tip of the probe was found to be lying amongst the profundus tendons.

The nylon ends were threaded through the eye of the probe, which was then withdrawn into the wrist drawing the nylon through the hand and into the wrist.

The nylon was then passed back and forth through the profundus tendon to the middle finger for a distance of about two inches.

After the tension of the nylon had been so adjusted that the middle finger lay in its normal position of flexion in relationship to the other fingers, under anaesthesia, the nylon was tied with a triple knot and the ends were buried within the tendon and cut short.

The skin was closed with interrupted 40 Dermalon sutures and a pressure dressing was applied with a large pad of cotton wool acting as a splint, to hold the middle finger in full extension. The tourniquet was then removed.

Post-operatively:-

1st Post-operative day: Hand kept elevated.

5th Post-operative day: Patient discharged from hospital with hand kept elevated in a sling.

10th Post-operative day: Stitches removed. Incisions well healed. Tinct. Benz. Co. dressing applied, and active exercises commenced and encouraged.

CASE NO. 12. R.R. MOVEMENT OF MIDDLE FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
14th day.	Distal I.P.	10° short of full.	20°	$2\frac{1}{2}$ inches.	Slight swelling but no discomfort.
	Prox. I.P.	Full.	20°		
	M.P.	Full.	40°		
21st day.	Distal I.P.	5° short of full.	30°	2 inches.	Physiotherapy commenced with active and passive movements.
	Prox. I.P.	Full.	30°		
	M.P.	Full.	60°		
6 weeks.	Distal I.P.	Full.	30°	$1\frac{1}{2}$ inches.	Patient using his hand. Says middle finger still gets in the way.
	Prox. I.P.	Full.	40°		
	M.P.	Full.	70°		
9 weeks.	Distal IP.	Full.	35°	$1\frac{1}{4}$ inches.	Power in finger increasing. Finger still a handicap.
	Prox. I.P.	Full.	45°		
	M.P.	Full.	80°		
4 months.	Distal I.P.	Full.	35°	1 inch.	Power of flexion good. Patient back at work as a lorry driver. Says he is able to work satisfactorily. Limitation of full flexion a handicap.
	Prox. I.P.	Full.	50°		
	M.P.	Full.	80°		

DISCUSSION ON CASE NO. 12.

The important feature of this case and cases numbers 8 - 11 were that they all regained full extension but failed to regáin full flexion.

The cause of this failure was still obscure. It was manifestly not due to tendon adherence, but rather to limitation of joint movement.

The earlier animal experiments were re-examined, and the clinical cases were reconsidered. There was however, no evidence of reaction to the nylon or of peri-articular fibrosis due to any other obvious cause.

The possibility suggested itself that the tension under which the nylon was being placed might be in error, and that our ideas of tendon tension in general might be falacious.

It was therefore decided that the next case would have the nylon implanted under much less tension, and if this was successful and the slack was taken up by the muscle, a later case would be attempted in which the nylon was inserted with complete lack of tension, so that the finger was held, under anaesthesia, in full extension.

CASE NO. 13.

J.S. NON EUROPEAN MALE. AGED 52 YEARS.

The patient was admitted to the Hospital three hours after having cut the palm of his right hand on a broken window pane. On examination there was a two inch laceration across the palm of his right hand, a quarter of an inch proximal to the metacarpo-phalangeal joints. Both profundus and sublimis tendons to the index finger were cut. The tendons of the other fingers were undamaged and there was no nerve involvement.

Under general anaesthesia and sphygmomanometer tourniquet, a 24 inch of nylon (breaking strain 37 lbs.) was inserted from the base of the distal phalanx, through which the nylon was passed, and the relevant profundus tendon at the wrist.

The identical technique to the preceeding cases being used.

The tension of the nylon was altered however. Instead of being inserted at such a tension as to hold the finger in its normal degree of flexion in relationship to the other fingers, whilst under anaesthesia, it was inserted with slightly less tension so that the finger eventually lay in greater extension than the other fingers.

The skin was closed as usual with 0000 Dermalon and pressure dressings were applied without splintage. The tourniquet was then removed.

<u>Post-operatively</u>:-

1st Post-operative day:	Patient comfortable. Able to extend finger easily. Some flexion possible within the limits of the bandage.
5th Post-operative day:	Patient discharged home with his arm elevated in a sling.
10th Post-operative day:	Stitches removed. Incision well healed. Active movements commenced and encouraged.

CASE NO. 13. J.S. MOVEMENTS OF INDEX FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
14th day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	10° 20° 40°	$2\frac{1}{2}$ inches.	Slight swelling and hyperkeratosis.
21st day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	10° 25° 60°	$2\frac{1}{2}$ inches.	Some swelling still present. Limitation of full joint movements.
6 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	15° 30° 90°	2 inches.	Hyperkeratosis and d ryness of the finger fairly marked. Patient says the finger interferes with his work as a bricklayer.
12 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	15° 30° 90°	2 inches.	Patient is dis-satisfied. Wants finger off. Says he will decided after a further trial with it. Has not returned to Clinic.

DISCUSSION OF CASE NO. 13 J.S.

The marked inability to regain flexion of the finger, was the outstanding feature of this case.

The degree of joint stiffness and swelling was in no way less than the previous cases.

It was therefore decided that inserting the nylon under lessened tension had no influence upon the degree of joint stiffness that was occurring, whilst in addition the muscle was evidently unable to overcome the "Slack" of the tendon (within the time of the follow up of this case which was three months).

It was therefore decided that future cases would again have the nylon inserted under normal tension.

CASE NO. 14.

M.H. NON EUROPEAN FEMALE. AGED 35 YEARS.

Three hours prior to admission, whilst working in the kitchen, the patient cut her right thumb on a bread knife. On examination, she had a laceration in the interphalangeal crease of her right thumb, severing the flexor pollicis longus tendon. There were no associated nerve injuries. (Fig. 80).

Fig. 80: Case No. 14. M.H. On admission she had a laceration in the interphalangeal crease of her thumb severing the flexor pollicis longus tendon.

Under general anaesthesia and sphygmomanometer tourniquet, the following repair was performed.

The exposure was increased by making a half inch incision along the mid-lateral line on the lateral side of the thumb distally from the laceration. A triangular flap was thus raised exposing the base of the distal phalanx and the insertion of the flexor pollicis longus tendon.

The distal end of the tendon was extracted from its sheath and excised.

Through the base of the distal phalanx, a 24 inch length of nylon (breaking strain 37 lbs.) was passed with the aid of a size 18 Luer-Lok needle, through a borehole in the phalanx made with an awl.

A probe was then slid proximally down the tendon sheath, passed the laceration and on into the wrist where the tip of the probe could be seen and felt presenting.

A second two inch longitudinal incision was made at the wrist just medial to the plamaris longus tendon and the flexor pollicis longus tendon was exposed.

The nylon ends were threaded through the eye of the probe, which was withdrawn into the wrist, drawing the nylon through after it.

The nylon ends were sutured to the tendon of the flexor pollicis longus by passing them back and forth through the tendon for a distance of about two inches. The tension of the nylon finally being adjusted so that the terminal phalanx of the thumb was held in slight flexion.

The nylon ends were then tied with a triple knot and after the ends had been buried within the tendon, they were cut short.

Dressings were applied and the tourniquet was released.

<u>Post-operatively</u>:-

1st Post-operative day:	Patient able to flex terminal phalanx slightly within the limits of the bandages. Hand kept elevated.
5th Post-operative day:	Patient discharged home.
10th Post-operative day:	Stitches removed. Incisions well healed.

CASE NO.14. M.H. MOVEMENTS OF INTER-PHALANGEAL JOINT OF THUMB.

Post Operative Date.	Extension.	Flexion.	Remarks.
14th day.	30° short of full.	45°	Slight swelling of thumb. Slight pain on full active flexion over base of terminal phalanx.
21st day.	20° short of full.	45°	Swelling less. Still some pain and tenderness at base of terminal phalanx.
6 weeks.	15° short of full.	45°	Swelling subsiding. Patient has almost a full range of flexion as compared with the opposite thumb. She is very satisfied.
12 weeks.	15° short of full.	45°	Patient says she does all her work easily. She has not even noticed the limitation of extension! Has not returned to clinics.

DISCUSSION ON CASE NO. 14.

This case was the only one in the total series in which the flexor pollicis longus tendon was severed.

The result on the whole was satisfactory, and the patient was able to return to full normal housework within three weeks of the operation, although neither full flexion nor full extension were regained.

The patient was completely satisfied however, and stated that she was neither socially nor economically limited in any way by her thumb.

CASE NO. 15.

N.R. EUROPEAN MALE. AGED 45 YEARS.

Patient was a signalman on the Railway.

Six months prior to admission to hospital, he had caught the middle finger of his right hand on a signal lever clutch which had severely lacerated the flexor surface of the finger just proximal to the proximal interphalangeal flexion crease.

On examination he had a healed scar at the site of the old laceration and no sublimis or profundus action in the middle finger. There was some limitation of extension of the proximal interphalangeal joint.

The passive movements of the finger on admission being as follows:-

Joint.	Passive Extension.	Passive Flexion.
Distal I.P.	Full.	80°
Prox. I.P.	30° short of full.	90°
M.P.	Full.	90°

The digital nerve on the lateral side of the middle finger had evidently also been damaged since he had a small area of anaesthesia along the lateral border of the middle and terminal phalanges.

The patient requested that the finger be amputated as it handicapped him. He was prevailed upon to undergo a reparative operation however.

Under general anaesthesia and sphygmomanometer tourniquet, the following repair was performed.

A mid lateral incision was made along the lateral border of right ring finger exposing the tendon sheath. The lateral digital nerve was also exposed and was found to have been completely divided at the level of the proximal interphalangeal joint.

Three fine sutures of 5-0 "Deknatal", were inserted through the perineurium of the nerve holding the ends in accurate apposition after the small neuromata at either end of the nerve had been excised and normal axons revealed. The nerve ends could be easily approximated without tension.

The tendon sheath in the area of the old laceration was then opened, and the distal cut end of the profundus tendon was freed. The distal end of the tendon sheath was incised and the distal part of the profundus tendon was extracted from the sheath and excised.

A 24 inch length of nylon (breaking strain 37 lbs.) was passed through the base of the terminal phalanx, with the aid of a size 18 Luer-Lok needle passed through a borehole made with an awl.

A probe was then slid down the tendon sheath, and after the adhesions in the sheath, at the level of the old laceration, had been freed sufficiently, it was slid onwards through the hand and into the wrist where the tip of the probe could be seen and felt presenting.

A two inch longitudinal incision was made at the wrist, in the line of the ulnar nerve, and the profundus tendon to the middle finger was identified.

The nylon ends were then threaded through the eye of the probe and the probe was withdrawn into the wrist drawing the nylon through the hand after it.

The profundus tendon to the middle finger was next divided at the level of the wrist joint and the nylon was sutured to the tendon by lacing it back and forth through the tendon for a distance of one and one half inches.

The tension of the nylon was then adjusted so that the finger lay in its correct degree of flexion in relationship with the other fingers under anaesthesia.

The nylon was finally tied with a triple knot and after the ends had been buried within the tendon they were cut short.

The incisions were closed with interrupted sutures of 4-0 Dermalon, and after dressings had been applied, with a large pad of cotton wool holding the finger in partial extension the tourniquet was released.

<u>Post-operatively</u>:-

1st post-operative day:	Hand kept elevated. Patient able to move terminal interphalangeal joint within the limits of the bandages.
5th post-operative day:	Doctor in charge of the patient (the case being treated in a private hospital) removed the splintage in order "to let the patient move his finger fully". The finger is thus now flexed and no longer splinted in extension.
10th post-operative day:	Stitches removed. Tint. Benz. Co. dressing applied. Active exercises commenced.

CASE NO. 15. N.R. MOVEMENTS OF MIDDLE FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
14th day.	Distal I.P. Prox. I.P. M.P.	30° short of full. 60° short of full. 30° short of full.	90° 70° 60°	$1\frac{1}{2}$ inches.	Incision well healed. No swelling. Some induration Active movements encouraged.
21st day.	Distal I.P. Prox. I.P. M.P.	30° short of full. 60° short of full. 20° short of full.	90° 90° 90°	Nil.	Extension is more limited. Patient advised to do active and passive extension exercises. Says he is unable to work.
6 weeks.	Distal I.P. Prox. I.P. M.P.	50° short of full. 60° short of full. Full.	90° 90° 90°	Nil.	Patient requests amputation of his finger. Says he will get compensation anyway, and will be able to go back to work.
12 weeks.	Distal I.P. Prox. I.P. M.P.	50° short of full. 60° short of full. Full.	90° 90° 90°	Nil.	Marked stiffness of joints Patient demands amputation. AMPUTATION PERFORMED. (See photographs of specimen).

DISCUSSION ON CASE NO. 15. N.R.

It was realised at this stage that the nylon replacement was not fulfilling the original hopes that had been placed in the possibilities of the method. The end results were on the whole unsatisfactory, although movements were being recovered in all cases, and limitation of movements were not due to tendon adherence but rather to joint stiffness.

It was apparant that a far greater degree of reaction to the nylon, was occurring within the finger in clinical cases than had been anticipated. The post-operative position of fixation of the finger and the tension of the nylon did not appear to be important factors, as these had been varied, without significant influence upon the final outcome of result.

The animal results and reactions were therefore re-examined and reconsidered.

The small amount of peritendinous fibrosis around the nylon was again considered. Previously it had been accepted as of an insignificant degree, but was this so? Possibly, in the human clinical case, with the greater range of finger movement, there was even more reaction. Perhaps the limitation of movement that was occurring was directly due to foreign body reaction to the buried nylon.

The amputation specimen from N.R. Case No. 15 on the whole did not appear to support this hypothesis. (Fig. 81, 82, 83).

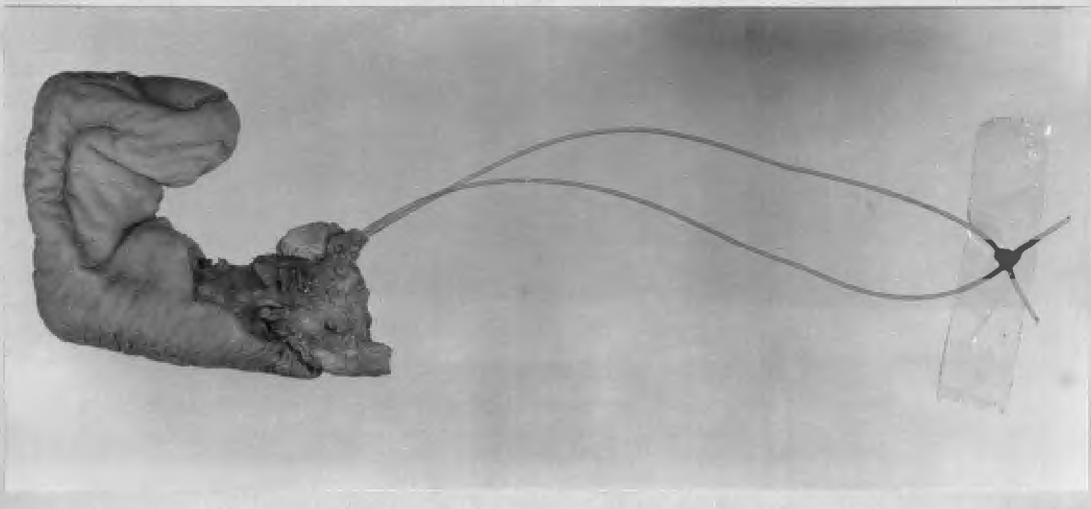


Fig. 81: Amputated middle finger from N.R. Case No. 15. The nylon ends can be seen protruding from the tendon sheath. Note the flexion deformity and the midlateral scar.

Fig. 82: The specimen has been dissected to show the tendon sheath. Minimal fibrous tissue reaction was found.

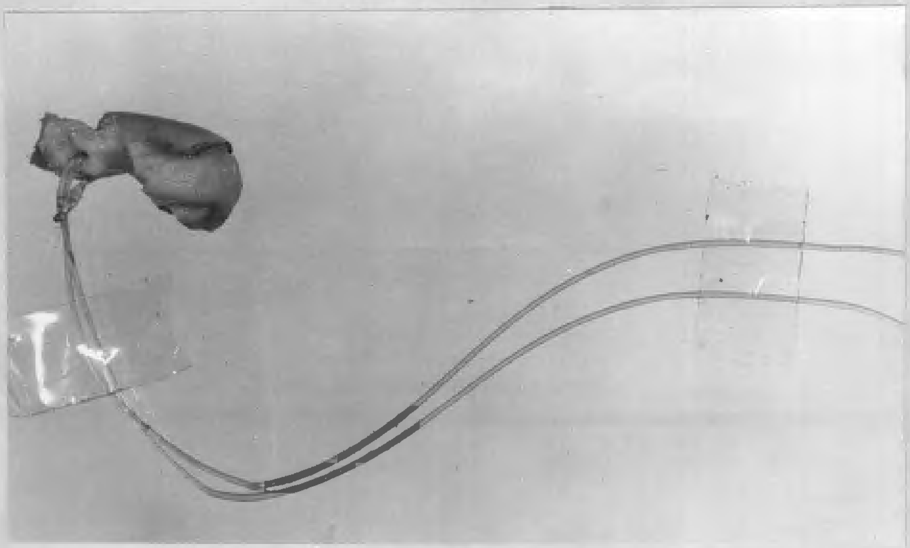


Fig. 83: Dissection of the terminal phalanx. Note the firm fixation of the nylon to the phalanx, with no tendency to bone erosion.

The histology of the finger showing: A minimal amount of inflammatory exudate and fibrous tissue in the sheath and tendon. The histology of the underlying bone was normal. (Fig. 84 & 85).

Where the suture had passed through the phalanx, there was a small cavity in the bone lined by fibrous tissue, but no evidence of bone destruction, absorption or alteration in architectural or trabecular pattern. (Fig. 86 & 87). X-rays of the phalanx also revealed no evidence of bone destruction or erosion (Fig. 88 & 89). Although this histology did not indicate gross foreign body reaction, it

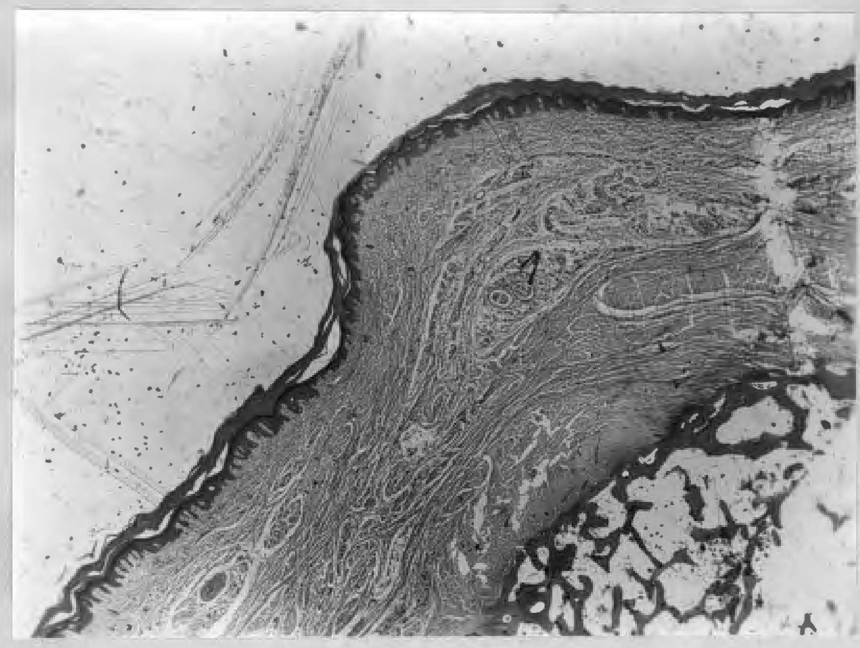


Fig. 84: Section through middle phalanx of amputated middle finger of N.R. Note the almost complete absence of fibrous tissue or foreign body reaction.

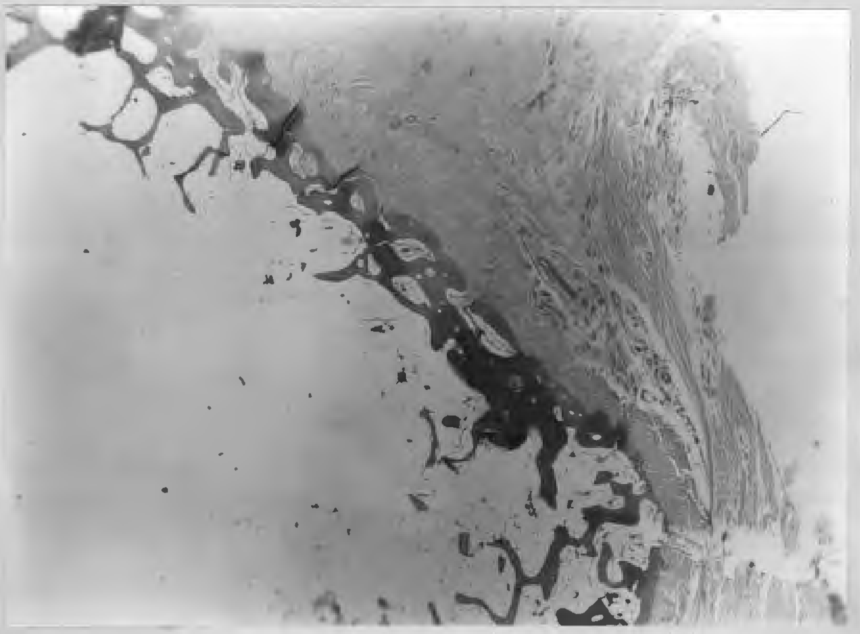


Fig. 85: Section through middle phalanx. Note the normal architecture of the bone and tendon sheath.

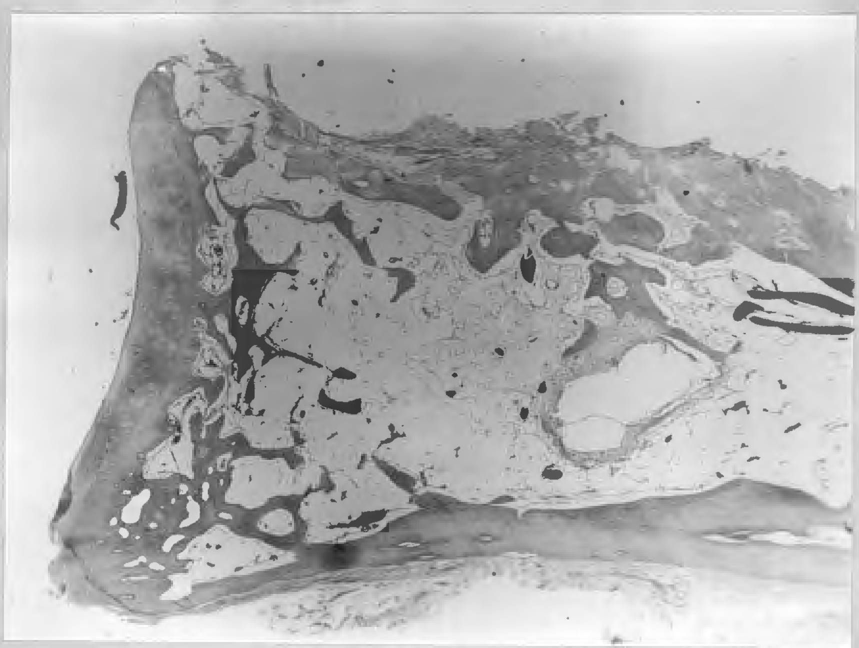
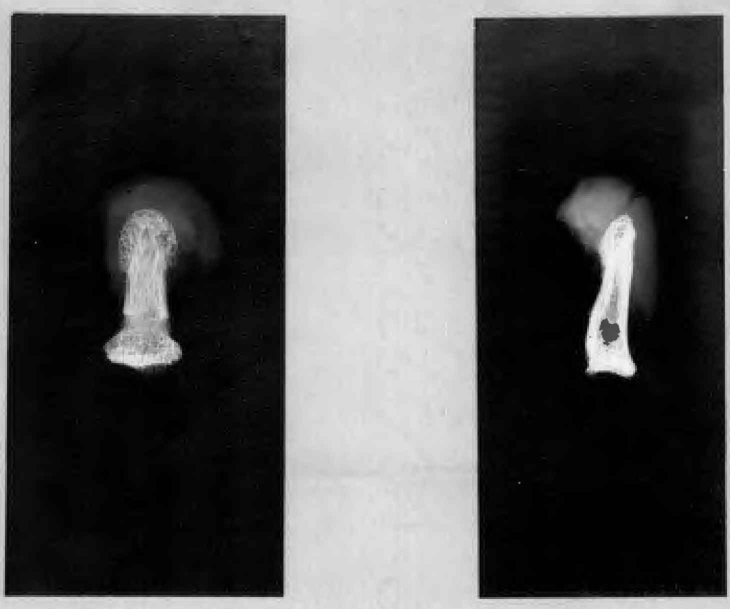


Fig. 86: Section through terminal phalanx. Where the nylon has passed through the phalanx a small tunnel can be seen lined by fibrous tissue. Note the absence of bone absorbtion or destruction. The trabecular bone pattern is normal.

Fig. 87: A section of Fig. 86 seen under greater magnification. The normal bone trabeculae are clearly shown.



Figs. 88 and 89: X-ray photographs showing antero-posterior and lateral views of the terminal phalanx of the amputated middle finger of N.R. Note the absence of any tendency to bone erosion or absorbtion around the tunnel through which the nylon passed.

was decided to act on the premise that such reaction did occur. It was therefore decided to "insulate" the nylon from the tissues with polythene which had the reputation of being completely inert within the human body.

Further animal and other experiments (as related in Chapter III) were therefore performed.

As a result of these, the method of "the plastic replacement technique" was developed. The next five cases were all performed using this technique. The surgical exposure and details of performance of each of these cases was by the technique described and illustrated in Chapter IV.

CASE NO. 16.

I.F. NON EUROPEAN MALE. AGED 21 YEARS.

Five months prior to admission to hospital, the patient had cut the palm of his right hand on a chisel, whilst doing carpentry. Since then, he had been unable to bend his little finger and had a sensation of pins and needles along the lateral side of his little finger when he touched it.

On examination, he had the healed scar of a laceration on the palm of his right hand, a quarter of an inch proximal to the metacarpo-phalangeal crease of the little finger. There was absent sublimis and profundus action in the little finger and there was hyperaesthesia and analgesia along the lateral border of the whole of the little finger. Passive flexion and extension was full.

Under general anaesthesia and sphygmomanometer tourniquet, the "plastic replacement" operation was performed on the little finger. The digital nerve was dissected and exposed and found to be intact but incorporated and compressed by fibrous tissue and fibrous strands. A complete neurolysis in this area was performed.

Post-Operatively:-

1st post-operative day: The hand was kept elevated. Movement of all joints within the limits of the bandage were possible.

3rd post-operative day: Good movements within the limits of the bandages already present. Heavy bandages and dressings removed and active exercises encouraged. Patient discharged from hospital.

10th post-operative day: Stitches removed. Incisions well healed. Tinct. Benz. Co. dressings applied. Active movements encouraged.

CASE NO. 16. I.F. MOVEMENTS OF LITTLE FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
10th day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	30° 45° 60°	1 inch.	No swelling or induration. No periarticular fibrosis or thickening. No discomfort.
14th day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	50° 110° 90°	¼ inch.	Full active and passive movement. Skin loose. No evidence of reaction. Patient satisfied. Still slight hypoalgesia but hyperaesthesia and pins and needles gone. Wants to go back to his work as a carpenter. Able to hold all tools and do all work. Power slightly less than normal.
6 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	80° 110° 90°	Nil.	Patient completely satisfied. Full power. Able to do all his work. Normal sensation now present.

Fig. 90: Case No. 16 I.F. Degree of flexion present 10 days after the operation.

Fig. 91: Case No. 16 I.F. Degree of extension present 10 days after the operation.

Fig. 92: Case No. 16. I.F. Degree of flexion present 14 days after the operation.

Fig. 93: Case No. 16 I.F. Degree of extension present 14 days after the operation.

Fig. 94: Case No. 16 I.F. X-ray photograph of lateral view of little finger, 6 weeks after the operation. Note the absence of bone erosion in the terminal phalanx, and the shadow of the plastic down the length of the finger.

Fig. 95: Case No. 16 I.F. X-ray photograph of antero-posterior view of the little finger.

DISCUSSION ON I.F. CASE NO. 16.

The results with this case were dramatic, and approached the ideal conditions which had been laid down at the beginning of the investigation.

The technique was simple and yet within two weeks the patient had full movements, no discomfort and was fit to return to work, without any specialised post-operative treatment having been given him.

The polythene appeared to have fulfilled its work, and was "insulating" the strong yet irritant nylon from the tissues.

CASE NO. 17.

W.H. NATIVE MALE. AGED 33 YEARS.

Twenty-four hours prior to admission, the patient had suffered a laceration of the palmar surface of his right little finger which had severed both profundus and sublimis tendons. There was no associated nerve injury.

Although the wound was already 24 hours old, it looked clean and uninfected and it was decided to repair the finger as a primary procedure.

Anti-Tetanus Serum 1500 international units and penicillin 1 million units was immediately given.

Under general anaesthesia and sphygmomanometer tourniquet, the classical plastic replacement repair was performed. (Figs. 96 - 101).

Operating time one hour.

Post-Operatively:-

1st post-operative day: Patient comfortable and able to move his finger within the limits of the bandage. Penicillin 1 million units twice daily commenced, for 5 days. Hand kept elevated.

2nd post-operative day: Patient discharged home with his hand in a sling.

10th Post-operative day: Stitches removed. Tinct. Benz. Co. dressing applied. Active movements encouraged.

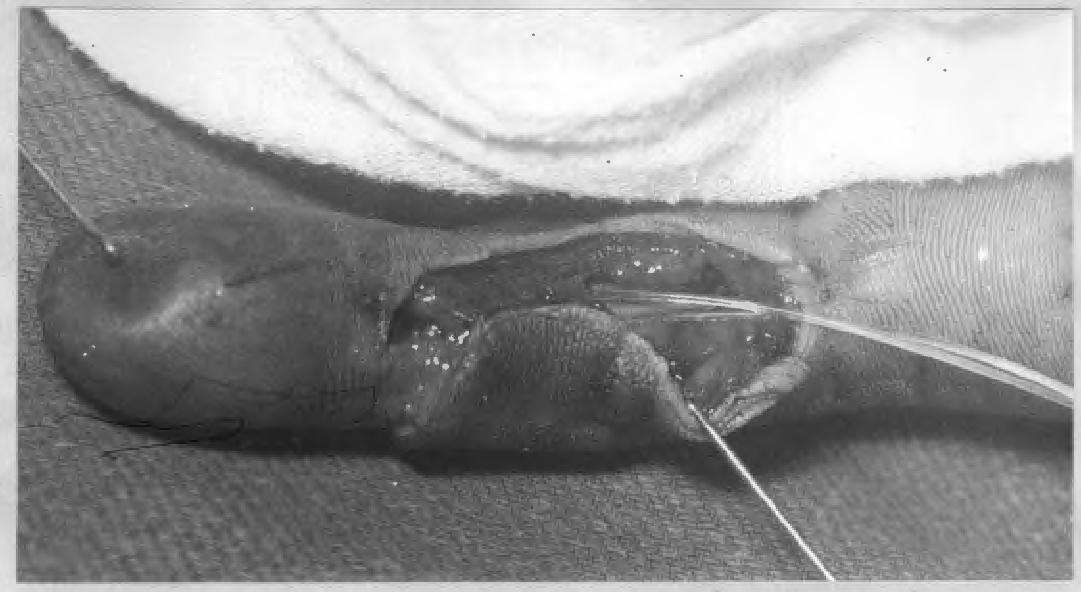


Fig. 96: The nylon has been threaded through the terminal phalanx and the distal tendon sheath, and can be seen presenting through the laceration in the finger.

Fig. 97: The nylon is being threaded through the tendon sheath.

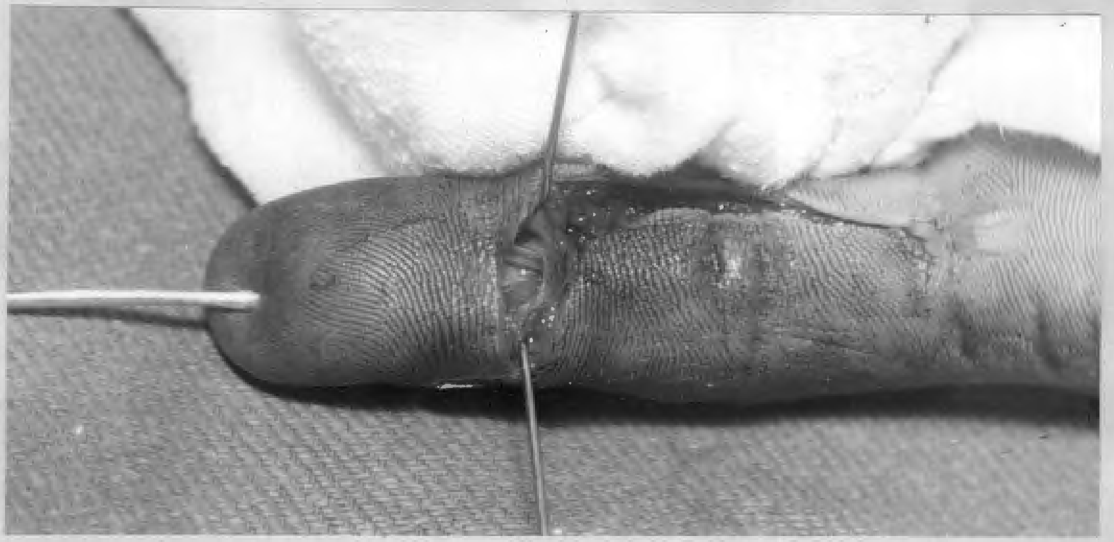


Fig. 100: The nylon, covered in polythene tubing, can be seen within the tendon sheath, at the base of the laceration in the finger.

Fig. 101: The nylon is fixed to the tendon by passing it back and forth through the tendon for 1 - 2 inches.

CASE NO. 17. W.H. MOVEMENTS OF LITTLE FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
10th day.	Distal I.P. Prox. I.P. M.P.	10° short of full. Full. Full.	45° 90° 90°	$\frac{1}{2}$ inch.	Slight dryness and swelling of finger present. No discomfort. Wants to go back to work as a labourer in a factory.
14th day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	50° 90° 90°	$\frac{1}{4}$ inch.	Permission given for patient to return to work. Power not yet as strong as opposite little finger.
6 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	50° 90° 90°	$\frac{1}{4}$ inch.	At full hard work. Says he can do everything he wants to. Able to lift five pound weight with little finger. No discomfort.

Fig. 102: Case No. 17 W.H. Degree of flexion present 10 days after the operation.

Fig. 103: Case No. 17 W.H. Degree of extension present 10 days after the operation.

CASE NO. 18.

P.B. EUROPEAN MALE. AGED 28 YEARS.

Four months prior to admission, the patient had cut the palmar surface of his left ring finger just distal to the proximal interphalangeal joint. He complained that the terminal joint of the finger would not flex and interfered with the other fingers. He was an electrician.

On examination, he had a healed scar at the site of the laceration. The finger had normal active flexion at the proximal interphalangeal crease but lacked profundus action. Passive movements were full. There was no associated nerve injury.

Under general anaesthesia and sphygmomanometer tourniquet, a "plastic replacement" repair was performed. The sublimis tendon was not interfered with, but was simply bypassed by the plastic.

Operating time was three quarters of an hour.

Post-Operatively:-

1st post-operative day: Patient comfortable. Able to move the tip of his finger within the limits of the bandages. Says the finger feels stronger.

3rd post-operative day:	Heavy dressings removed. Active exercises encouraged.
5th post-operative day:	Patient discharged from hospital with hand in a sling.
10th post-operative day:	Stitches removed. Incisions well healed. Tinct. Benz. Co. dressing applied. Active exercises encouraged.

CASE NO. 18. P.B. MOVEMENTS OF RING FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
10th day.	Distal I.P. Prox. I.P. M.P.	10° short of full. Full. Full.	45° 90° 90°	½ inch.	Patient well satisfied. Says finger feels stronger and no longer interferes with other fingers. No swelling or induration. No discomfort. Flexion of terminal interphalangeal joint weaker than normal.
14th day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	50° 100° 90°	Nil.	Patient well satisfied. Power increasing. Wants to return to work.
4 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	50° 100° 90°	Nil.	Patient at full work as an electrician, says he can do all work with the hand. Able to lift five pound weight hung from terminal phalanx.

CASE NO. 19.

B.W. NON EUROPEAN FEMALE. AGED 28 YEARS.

Patient says that three years prior to admission, she developed a severe acute inflammation of the right ring finger and hand.

After five days, the finger broke down and discharged spontaneously through a sinus on the lateral side of the ring finger just proximal to the proximal interphalangeal crease. A few days after this a "long white thing like a worm, and an inch long" sequestrated through the sinus.

After about three weeks the finger healed, but since then she has been unable to flex the terminal interphalangeal joint or extend the proximal interphalangeal joint fully.

On examination, she had a healed scar at the site of the old sinus. The finger lacked profundus action, but had full passive flexion of all the joints. Extension of the proximal interphalangeal joint was passively limited, due to joint and not tendinous cause. (Fig. 104 and 105). There was no associated nerve injury. Prior to ppe#ation, the movements were:-

PASSIVE MOVEMENTS OF RING FINGER PRIOR TO OPERATION.

Joint.	Extension.	Flexion.
Distal I.P.	Full	80°
Prox. I.P.	30° short of full.	110°
M.P.	Full	90°

Under general anaesthesia, a "plastic replacement" repair was performed.

In addition through half inch mid-lateral incisions opposite the proximal inter-phalangeal joint, the lateral ligaments of the joint were divided allowing immediate full extension of that joint to occur.

Post-Operatively:-

1st post-operative day: Movements within the limits of the bandages possible. Hand kept elevated.

5th post-operative day: Heavy dressings removed and active movements encouraged. Patient discharged home with arm in a sling.

10th post-operative day: Stitches removed and Tinct. Benz. Co. dressing applied. Active movements encouraged.

Fig. 104: Case No. 19 B.W. Degree of flexion present prior to operation.

Fig. 105: Case No. 19 B.W. Degree of extension present prior to operation.

CASE NO. 19. B.W. MOVEMENTS OF RING FINGER.

Post Operative Date	Joint	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
10th day.	Distal I.P.	Full.	80°	$\frac{1}{4}$ inch.	Comfortable. No pain.
	Prox. I.P.	15° short of full	90°		
	M.P.	Full	90°		
14th day.	Distal I.P.	Full	80°	Full	Incisions well-healed. No induration.
	Prox. I.P.	10° short of full	90°		
	M.P.	Full	90°		
4 weeks.	Distal I.P.	Full	90°	Full	Patient well satisfied, says she can do all her work well.
	Prox. I.P.	10° short of full	90°		
	M.P.	Full	90°		

Fig. 106: Case No. 19 B.W. Degree of flexion present 10 days after operation.

Fig. 107: Case No. 19 B.W. Degree of extension present 10 days after operation.

CASE NO. 20.

D.M. EUROPEAN FEMALE. AGED 45 YEARS.

Ten hours prior to admission the patient cut her index finger on a razor blade, just proximal to the proximal interphalangeal joint, dividing both profundus and sublimis tendons, without any associated nerve injury.

Under general anaesthesia a "plastic replacement" repair was performed.

Operating time being forty-five minutes.

Post-Operatively:

1st post-operative day: Hand kept elevated. Patient discharged home as she had an invalid husband to look after.

10th post-operative day: Stitches removed. Incisions and laceration well healed. Tinct. Benz. Co. dressing applied.

CASE NO. 20. D.M. MOVEMENTS OF INDEX FINGER.

Post Operative Date	Joint.	Extension.	Flexion.	Distance to Distal Palmar Crease.	Remarks.
10th day.	Distal I.P. Prox. I.P. M.P.	Full. 10° short of full. Full.	45° 90° 90°	$\frac{1}{2}$ inch.	Patient well satisfied. No swelling or discomfort. Says she has to do all her housework.
14th day.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	50° 100° 90°	$\frac{1}{4}$ inch.	Patient doing full housework. Says she can cook and sew. No limitations. Power slightly weak.
3 weeks.	Distal I.P. Prox. I.P. M.P.	Full. Full. Full.	60° 105° 90°	Nil.	Power of finger better, now almost normal. Able to lift 3 lb.weight with finger.

AN EVALUATION OF THE RESULTS OF THE 20 CLINICAL CASES REPAIRED BY PLASTIC REPLACEMENT.

In this study all cases can be classified into one of four groups, depending upon the repair performed. These four groups are as follows:-

Group 1: In this group the tension of the implanted nylon was adjusted so that the relevant finger was held in its normal degree of flexion in relation to the other fingers of the hand, as they lay relaxed under anaesthesia.
Secondly, all cases in this group were immobilised post-operatively in a flexed position. This group consists of 6 of the 20 cases operated upon.

Group 2: In this group the tension of the nylon was again adjusted so that the relevant finger was held in its normal degree of flexion in relation to the other fingers of the hand as they lay relaxed under anaesthesia. Post-operatively, however, the fingers in this group were all immobilised in extension. This group consists of 6 of the 20 cases treated.

Group 3: This group consists of a miscellaneous group of three cases.

In the first, Case No.5, the nylon was sutured to the profundus tendon in the palm of the hand.

In the second, Case No.13, the tension of the nylon was so adjusted that the relevant finger was held, not in its normal degree of flexion, but extended, relevant to the other fingers as they lay relaxed under anaesthesia.

The third, Case No.14, was the only case in this series in whom the flexor pollicis longus tendon was severed, and was replaced by nylon.

Group 4: In this group, consisting of the last 5 cases in the series, the nylon in each case was covered with polythene tubing.

The tension of the nylon in each of these cases was adjusted so as to hold the relevant finger in its normal degree of flexion in relation to the other fingers of the hand as they lay relaxed under anaesthesia.

Post-operatively no immobilisation was practised, movements being permitted immediately post-operatively.

Each of these four groups will be discussed separately as a separate series, since the results in each group vary greatly, depending on the method used, and comparisons would be falacious and misleading.

GROUP I.

In this group, 10 fingers (in all of which both profundus and sublimus tendons were severed) were repaired in a total of 6 patients, of which 2 patients had more than one finger injured. The one had two fingers cut and the other four fingers cut respectively.

The following table summarises the results in the group:

SUMMARY OF RESULTS IN GROUP 1.

Case No.	Finger.	Lack of Extension	Distance to distal palmar crease on flexion.	Post-operative date.
1	Ring	55°	nil	10 weeks
	Little	90°	nil	
2	Little	50°	nil	7 weeks
3	Little	15°	$\frac{3}{4}$ inch	6 weeks
4	Little	85°	$\frac{1}{2}$ inch	10 weeks
6	Little	10°	$\frac{1}{2}$ inch	12 weeks.
	Ring	30°	$\frac{1}{2}$ inch	
	Middle	10°	$\frac{1}{2}$ inch	
	Index	5°	$\frac{1}{4}$ inch	
15	Middle	110°	nil	6 weeks.

Thus the degree of flexion possible in this group is as follows:-

<u>Degree of Flexion Obtained:</u>

4 fingers regained full flexion, (40%)

1 finger regained flexion to within ¼ inch of the distal palmar crease (10%)

4 fingers regained flexion to within ½ " " " distal palmar crease (40%)

1 finger regained flexion to within ¾ " " " distal palmar crease (10%)

In the series of 104 cases published by J. H. Boyes (11) he accepted a degree of flexion better than within one and one half inches of the distal palmar crease as satisfactory. In his series 64.3% of cases obtained this degree of flexion, but only 48%, however, obtained a degree of flexion within 1 inch of the distal palmar crease.

In Group 1 of this present series, it will be seen that 100% have flexion to within ¾ of an inch of the distal palmar crease.

At first sight, therefore, these results appear remarkably good, especially in that the average time required for this degree of flexion to be regained was only eight and one half weeks.

However, when this degree of flexion is compared with the degree of flexion deformity present in all cases, the true range of movement regained is manifestly not satisfactory.

<u>Degree of Flexion Deformity.</u>

Within 10° of full extension	...	...	3 fingers (30%)
Within 30° " " "	...	...	2 fingers (20%)
Beyond 30° " " "	...	...	5 fingers (50%)

If further comparisons are made it will be seen that the fingers with full flexion are also the fingers with the most marked flexion contractures.

Of the six patients included in Group 1:

3 patients stated that they were satisfied and were not appreciably limited functionally or economically by their fingers;

2 patients stated that they thought their fingers were more useful than before the operation, but they were not completely satisfied.

1 person was dissatisfied and demanded amputation.

GROUP 2.

In this group 9 fingers were repaired, all of which had had both their profundus and sublimus tendons severed. These 9 fingers occurred amongst 5 patients, of which 2 patients had more than one finger injured. The one had the tendons of all four fingers severed, whilst the other had the tendons of two fingers severed.

The following table summarises the results in the group.

SUMMARY OF RESULTS IN GROUP 2.

Case No.	Finger	Lack of Extension.	Distance to distal palmar crease on flexion.	Post-operative date.
7	Little	Full	1 inch	by 9 weeks.
8	Index	Full	1½ inches	by 8 weeks.
	Middle	Full	1¾ inches	
	Ring	Full	1¼ inches	
	Little	Full	1½ inches	
9	Index	Full	1 inch	by 12 weeks
10	Index	60°	1½ inches	by 6 weeks
11	Little	Full	¾ inch	by 12 weeks
	Ring	Full	¾ inch.	

An analysis of the degree of flexion present in this group reveals:

Degree of flexion regained in Group 2.

2 fingers had flexion within ¾ of an inch of the distal crease (22%)

6 fingers had flexion within 1½ inches of the distal crease (67%)

1 finger had flexion beyond 1½ inches of the distal crease (11%).

Therefore, in this group 89% of the results would, in most centres (using the methods of free tendon grafting or primary suture), have been considered satisfactory, whilst only 11% failure would be recorded.

It is, however, also necessary to analyse the flexion deformities present before any conclusions can be drawn.

Degree of Flexion Deformity in Group 2.

Full extension	(89%)
Beyond 30%	(11%)

It will further be seen on analysis that the single case (No.10) in which a flexion contracture of more than 30% was present did not regain flexion beyond one and one-half inches from the distal flexion crease. The apparently good results are, therefore, a genuine reflection of the actual degree of movements regained.

By most criteria this group would, therefore, be considered as being one of "fair" results and would be classified as "satisfactory".

In actual fact, this was not the case. As has been discussed before (Chapter II), any lack of flexion is a handicap. Any finger which does not regain full movement, or almost full movement, should not be considered satisfactorily repaired. If this is our criterion and our aim, our results will eventually approach this standard.

In this group, although, as shown above, the results by most standards would be considered "satisfactory", 78% were unable to flex to nearer than three-quarters of an inch to the distal palmar crease. In actual fact the majority lacked a far greater degree of flexion than this.

Of the six patients included in this group:

One patient stated that he was satisfied with the repair, and was not appreciably limited either functionally or economically by his finger.

Four patients stated that they considered that their fingers and hand were more useful to them than before the operation, but they were not completely satisfied.

One patient was dissatisfied with the result and requested further treatment.

In criticism of this questionnaire method of analysis of results may be offered the fact that the single patient in this group who stated that he was fully satisfied with the result and was not appreciably limited, either functionally or economically, by his finger, was the patient with the flexion deformity of 60° and lack of full flexion by one and one-half inches !

In evaluating this method of analysis, therefore, the finger involved (whether index, middle, ring or little), the type of work performed and the patient himself, as well as many less tangible factors, have all to be considered.

GROUP 3.

In this miscellaneous group of cases, no analysis as a group is possible, and each case has already been individually discussed.

GROUP 4.

In this group 5 fingers were repaired. In three of these both the profundus and the sublimus tendons were severed, whilst in the remaining two only the profundus tendons had been divided.

The 5 fingers in this group were amongst 5 patients, none of the 5 having had more than one finger injured.

Two of the cases were repaired as emergencies, one ten hours after the injury and the other twenty-four hours after the injury. The remaining three cases were repaired between four months and three years after the injury.

One of the five cases prior to the repair had a flexion deformity of 30^{o} due to limitation of movement at the proximal interphalangeal joint.

The following table summarises the results in the group.

SUMMARY OF RESULTS IN GROUP 4.

Case No.	Finger	Lack of Extension	Distance to distal palmar crease on flexion	Post-operative date.
16	Little (Profundus and sublimus tendons severed).	Full	nil	6 weeks
17	Little (Profundus and sublimus tendons severed)	Full	$\frac{1}{4}$ inch	2 weeks
18	Ring (Profundus tendon only severed).	Full	nil	2 weeks
19	Ring	10^{o} short of full	nil	2 weeks
20	Index (Profundus and sublimus tendons severed).	Full	nil	3 weeks.

An analysis of the degree of movements present in this group reveals:

Degree of flexion regained in Group 4.

4 fingers regained full flexion ... ... (80%)

1 finger regained flexion to within ¼-inch
of the distal palmar crease.. ... ... (20%)

Degree of Extension regained in Group 4.

Full extension ... ... 4 fingers. ... ... (80%)

10° short of full extension 1 finger ... ... (20%)

The single case which failed to regain full extension was the case which, prior to repair, had a flexion deformity of the proximal interphalangeal joint. The degree of extension was, however, improved by the lateral capsulotomy of the joint, which was performed at the same time as the tendon replacement.

Of the 5 cases in this group, therefore, 3 cases (60%) regained full movement within an average period of 3½ weeks. The remaining 2 cases (40%) regained almost full movement, the one flexing to within a quarter inch of the distal palmar crease, whilst the other lacked 10° of full extension (due to extra tendinous pathology).

All five cases, therefore, fulfil the criteria of movement which had been laid down in this series as necessary to a satisfactory result.

Of the five patients in this group, all stated that they were completely satisfied with the result. They were all able to perform hard work and felt no limitations, either functionally or economically from their hands. They all stated that power and movements seemed normal and none had noticed any unusual or abnormal sensations in their finger or wrist.

It is noteworthy that the results in the cases in which the profundus tendon alone was divided were no different from the results in those cases where both the profundus and the sublimus tendons were severed.

Whether the tendon was replaced as an emergency or years later also appeared to bear no relationship to the final result, provided that the passive joint movements of the finger, prior to the operation, were normal.

Finally, it should be noted that none of the five patients in this group had any form of organised physiotherapy at any time, and were purposely never exhorted to perform rigorous or regular exercises, but were rather, on the whole, in this respect left to their own inclinations.

A P P E N D I X.

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APPENDIX.

The work which developed into this thesis was commenced with the aim of improving the results obtained in the treatment of severed flexor tendons within the digital theca.

It was only after the plastic replacement technique had been evolved that it was realised that the principle of artificial tendons might eventually be extended to the field of tendon transplantations and the rehabilitation of the paralysed.

If artificial tendons can function along anatomical pathways, there appears to be no reason why they should not function along artificial pathways and, if so, there is no limitation to the possibilities of the rehabilitation of any patient with a localised paralysis.

A tendon transplantation is commonly not practicable due to the anatomical lack of a suitable nearby tendon to reposition. If this limitation disappears there is no theoretical reason why a suitable muscle far removed from the paralysed area, should not provide the motor power to that area via a long artificial tendon.

The field for plastic tendons in surgery may only be commencing. The plastic replacement of severed flexor tendons of the fingers may be only one paragraph in a chapter still to be written.

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