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PRIMARY REPAIR WITHOUT IMMOBILIZATION OF FLEXOR TENDON DIVISION WITHIN THE DIGITAL SHEATH

An Experimental and Clinical Study

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In spite of some recent technical improvement in the management of tendon injuries, no real progress has been achieved in avoiding the tendency to adhesion formation around flexor tendons injured, or repaired, within the digital sheath. This situation equally concerns surgeons who tend to repair digital flexor tendons by primary end-to-end suture, as well as those who prefer the secondary repair by free tendon replacement.

As most statistics dealing with the subject indicate, any method regardless of technical refinements unfortunately results in relatively high rates of failure. In an attempt to avoid or at least to diminish the amount of adhesion responsible for the failures, a large series of investigations has been performed, trying mainly to isolate the tendon from the surrounding tissues. Plastic materials such as cellophane, polyethylene, millipore, etc.; vitalium, stainless steel, and even some biological structures have been used as adhesion-blocking artificial sheaths (Ashley et al. 1959, Burman & Umansky 1930, Farmer 1947, Gonsalez 1949, Gueukdjian 1956, Koth & Sewell 1955, McKee 1945, Weckesser et al. 1949). Without dwelling on further details, it is only to be noted that none of the methods or materials mentioned has been accepted in surgical practice, in spite of enthusiastic initial reports. Obviously, healing of the sutured tendon is consequently delayed or even seriously impaired as a result of surrounding cellular activity (Potenza 1962, Skoog & Persson 1954) if an artificial adhesion-blocking sheath is used. Therefore, a more physiologic approach is needed for

preventing or altering the nature of adhesions during the course of healing of the repaired tendon.

With these considerations in mind we examined the early stages following primary repair of divided digital flexor tendons. As has been frequently observed, an almost full range of movement could be demonstrated immediately after an end-to-end anastomosis. Limitation of movement develops later, during the process of healing, when immobilization prevents the normal gliding excursions of the tendon. In this period fibrous tissue proliferation takes place not only between the sutured tendon ends but also between the longitudinal surfaces of the tendon and the surrounding tissues. Finally, adhesions intimately involve the respective structures, resulting in various degrees of limitation of the normal tendon excursion.

The idea of preserving the initial movements of the repaired tendon by early mobilization is not a new one. Lexer (1911) emphasized the importance of avoiding adhesions by careful suturing and early motion, *i.e.*, six days after operation. During the years his outlook was gradually abandoned mostly due to technical failures that often led to separation of the sutured tendon ends and massive fibrotic reaction.

The problem of early motion or rest during the time of healing of digital flexor tendons is still very controversial. Although many hand surgeons strongly recommend immobilization as a prerequisite to any kind of tendon repair (Campbell-Reid 1966, Koch 1946, Littler 1959, McCash 1945, Rank & Wakefield 1960, Verdan 1960), others believe that early motion closely supervised by the surgeon could contribute to reducing adhesions between the tendon and its surrounding tissue (Buchner & Hofman 1959, Bunnell 1956, Lange 1954, Murray 1960, Young & Harmon 1960). It has been the main purpose of the present study to add some details to the data already known on this topic. The clinical part of the study, which covers a very small series of seven cases, should be regarded as preliminary.

MATERIAL AND METHODS

A. Experimental

Twenty-five young adult chickens (weight 1.3 to 1.7 kg) were selected from a single strain. Chickens were chosen as experimental animals because of the anatomical resemblance between their digital flexors and the corresponding flexors of the human hand as reported by Lindsay & Thompson (1960) and Lindsay et al. et al. ((1960). In ten of them the second long digit of the right extremity was operated. The others were operated bilaterally on the same digit. The extremities of the animals were prepared by washing with water and regular soap, followed by a

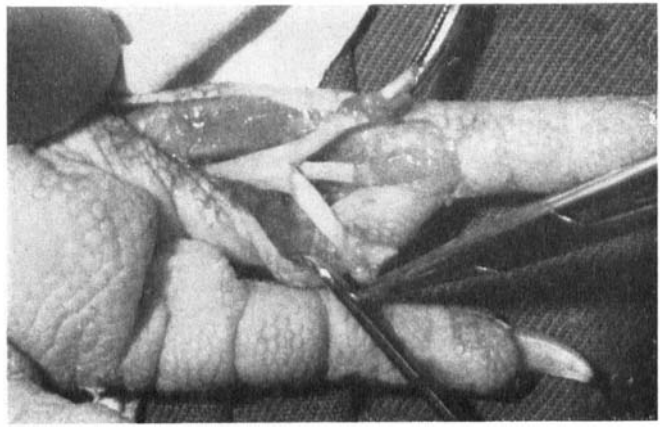
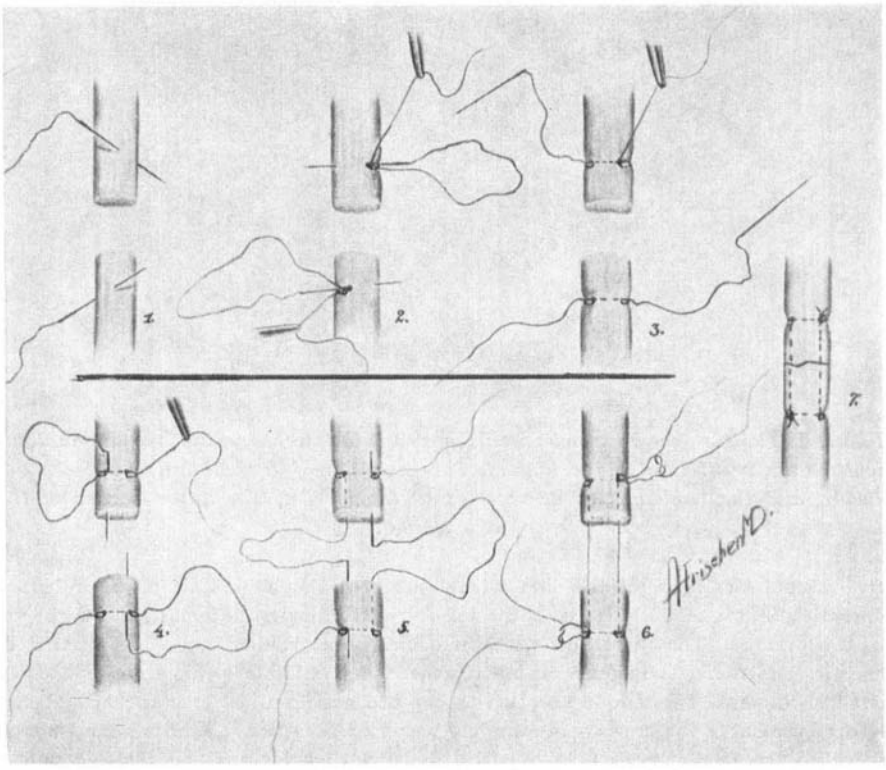


Figure 1. The surgical approach in chickens. A mid-lateral incision reveals anatomical details very close to the human. The insertion of the sublimis has been detached and the tendon is to be resected at the level of the upper border of the skin wound.

five-minute treatment of the skin with 1 per cent Cetablon. Half an hour before operation 20 mg of Pethidin was injected intramuscularly. As anaesthetic agent we used open ether. The operations were performed under rubber tourniquet in strictly aseptic conditions. The skin incision was made in a midlateral plane, as is usually done in humans. The tendon sheath was exposed and the part over the medial and half of the basal phalanges was completely excised. The flexor sublimis tendon was detached from its insertion, then pulled down with a forceps and resected at the level of the upper border of the skin wound (Figure 1). The deep flexor tendon was elevated as atraumatically as possible and the initial steps of the suture were performed before its division. A new type of suture technique was employed in an attempt to achieve an anastomosis strong enough to withstand the tension of the non-immobilized tendon. This suture was developed on the basis of the original Masson-Allen's suture, using twisted wire No. 8/0.008. It consists of four knots grasping the substance of the tendon and forming a regular intratendinous rectangle.

Further details of the suture technique are to be seen in Figure 2.

After completion of the anastomosis, the skin was closed by interrupted silk sutures and a light gauze dressing was applied to the operated digit only. The chickens were injected with 500,000 units of procaine penicillin. In order to check the condition of the suture a roentgenographic examination was always performed at the end of the operation. Then the chickens were placed in cells with a net-covered floor. This arrangement was especially designed to set up conditions under which any attempt at walking would be accompanied by grasping digital motion. It was considered to be the best possible way to obtain some kind of active exercises after surgery. The animals were re-examined in groups at weekly intervals, noting the stages of healing and adhesions. The first group was sacrificed one week and the last group six weeks after surgery. The sutured tendons were exposed and their state carefully examined. The results of these experiments are summarized as follows:



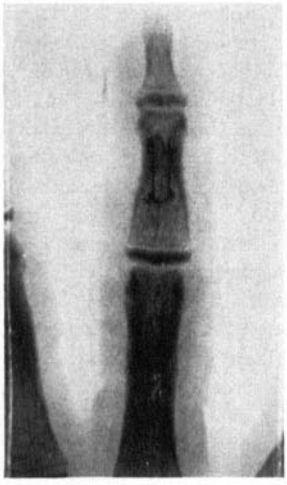


Figure 2. The proposed technique in its different stages. 1 and 2 represent the two diagonally located knots, grasping approximately one-fourth of the tendon substance on each side. Needles pass in the opposite side of the same fragment, grasping a similar part of the tendon (3). The three last stages (4, 5, and 6) represent the intratendinous part of the suture. 7 and the roentgenogram show the rectangular shape of the suture with the repair completed.

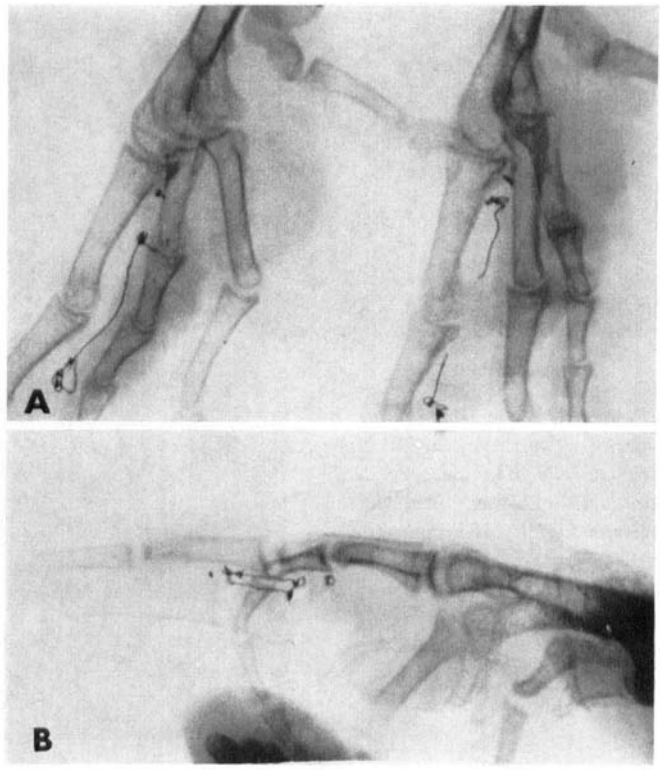


Figure 3. An example of ruptured grasping suture with retracted proximal end (A), and an intact suture (B) for comparison.

In 17 operations the wire suture completely ruptured in its central part and the proximal end of the tendon retracted high into the palm. All the ruptures occurred in the first week after operation and were clearly demonstrated in the roentgenographic control (Figure 3). It is to be noted that not in a single case was the wire separated from its insertion in the tendon. The suture always ruptured centrally and the proximal end of the tendon retracted including its part of the wire.

In 19 operations the suture was found to be intact and in the other 4, the suture ruptured only partially.

The almost equal distribution of ruptured and intact sutures gave us an opportunity to re-examine both conditions at intervals as mentioned above.

In instances with *ruptured* sutures, dissection at the end of the first week revealed slightly thickened yellowish tendon ends and a great gap with marked exudative reaction (Figure 4). Microscopically there were mononuclear cells, much fibrin, and beginning capillary proliferation. At the end of the second week the proximal and distal fragments of the tendon were found to be well surrounded by granulation tissue which also occupied the gap between them (Figure 5). At that stage both stumps showed active proliferation of tenoblasts with a number of mitoses and increasing proliferation of capillaries. Tenoblasts also invaded the gap. Fibroblastic reaction increased gradually to a point at which dissection at the

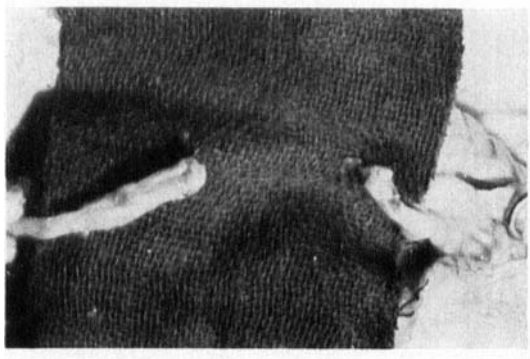
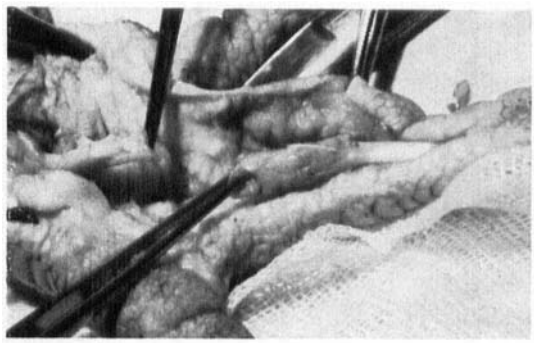


Figure 4. The appearance of a ruptured suture as found after one week. Note the thickness of the tendon ends.

Figure 5. Dissection of an experiment with ruptured suture two weeks after surgery. Note a well-developed granulation tissue which intimately includes the tendon ends.



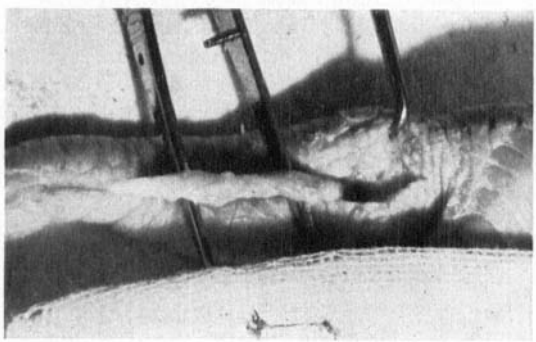


Figure 6. Four weeks after surgery in experiments with intact suture dissection revealed a well-healed smooth and shiny tendon.

end of the fourth week revealed the separated tendon ends to be so intimately included into dense fibrotic tissue that only their more proximal and distal parts could be identified. In instances with *intact* sutures the process of healing developed quite differently. At the end of the first week dissection revealed well-approximated tendon ends, somewhat swollen, and mild exudative reaction. Microscopic examination showed fusion of the stumps by active proliferation of tenoblasts. The sur-

rounding reaction was represented by mononuclear cells and proliferating capillaries. At the end of the second week the inflammatory reaction decreased, the anastomosis was found to be unchanged, and proximal traction produced almost complete flexion of the corresponding digit. A mild fibrotic reaction could be observed after three weeks. Microscopically the stumps showed marked increase in fibroblastic and vascular proliferation and decrease in other cellular reaction. Fibrosis was shown as fine bundles connecting the tendon with the surrounding tissues. These changes were more pronounced at the end of the fourth week and remained almost unchanged afterwards. At this stage dissection revealed a well-healed, smooth, and shiny tendon, slightly thickened at the site of suture (Figure 6). It is to be noted that in all instances with intact sutures, good range of flexion could be demonstrated when traction was placed on the tendon proximal to the anastomosis. These chickens had also shown good *in vivo* function of the repaired digit which joined the rest in grasping the wires of the cells.

In the four instances with partially ruptured sutures, at the end of the second and third weeks dissection revealed moderate to severe fibrotic reaction, mainly in the region of the gap.

B. Clinical

The proposed "grasping" suture was applied in the primary treatment of divided extensor tendons of the hand and wrist in seventeen cases which were not included in the present report. During the same period only seven cases of divided digital flexor tendons happened to be under out treatment. In the evaluation of early movements, those cases seem to be of sufficient interest to justify a report of each one separately.

Case 1

L.J., a seventeen-year-old technician, was admitted to us several hours after he had injured his left index finger with a metal plate. The examination revealed a fresh wound with slightly crushed borders over the proximal interphalangeal joint. Although both interphalangeal joints were passively free, no active flexion could be obtained. Under axillary block anaesthesia, the original wound was extended and the palmar side of the finger exposed. Both flexor tendons were found to be divided and the proximal interphalangeal joint open. After excision of the sheath the sublimis tendon was pulled down and cut as high as possible. The ends of the deep flexor were approximated and sutured in a slightly different manner from the technique described so far. After closing the wound, a light gauze dressing was applied, leaving the hand free. The patient was seen every day in the first week and controlled movements in all the fingers were encouraged starting from the third day. Physical therapy was advised after three weeks because of a mild stiffness of the proximal interphalangeal joint. The patient returned to his work forty-one days after surgery. In the last examination, seven month later, movements were found to be as follows: flexion of the proximal interphalangeal joint to 90 degrees, extension to 170 degrees; flexion of the distal interphalangeal joint to 140 degrees, extension to 170 degrees. The finger was able to touch the palm without any practical impairment of the normal function (Figure 7).

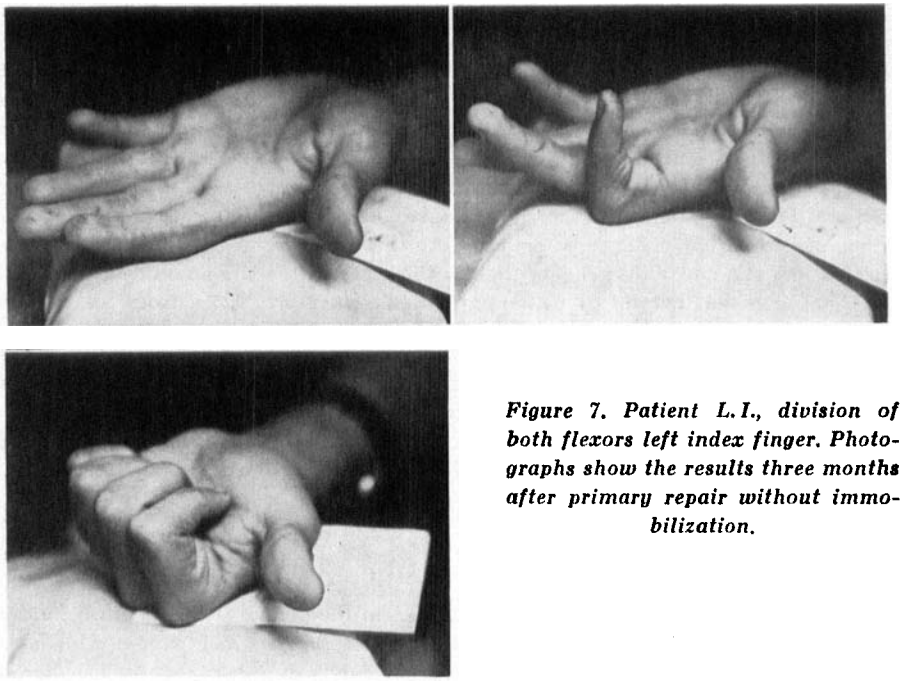


Figure 7. Patient L.I., division of both flexors left index finger. Photographs show the results three months after primary repair without immobilization.

Case 2

B.J., a twenty-two-year-old technician, was examined six hours after injury. He sustained a blow with a sharp instrument causing a small penetrating wound between the fourth and fifth fingers at a point just distal to the distal palmar crease. Passive movements were free but no active flexion was possible. Under ulnar block anaesthesia the flexor sheath was exposed and a complete division of both flexor tendons was revealed. The sublims was pulled down and excised and the cut ends of the deep flexor were anastomosed by "grasping" wire suture. It is to be noted that the proximal pulley was misplaced an insufficient distance to the line of suture; in full flexion the suture line became opposite and at the same level to the pulley. The skin was closed, light dressing applied and active exercises started the next day. Two weeks later the patient was able to flex the proximal interphalangeal joint to 120 degrees and the distal interphalangeal joint to 140 degrees. Extension reached 160 degrees in the proximal interphalangeal joint and could not be increased passively. Any attempt at active overflexion elicited a painful response. Without further improvement in the range of movements he returned to work 34 days after operation. Upon the assumption that incorrect location of the proximal pulley was responsible for the persistent limitation of flexion, a new surgical correction was advised. One month later, through a small lateral incision, the pulley was divided and the patient encouraged to active movements. In the last examination (six months after surgery) movements were noted to be as follows: flexion of the proximal interphalangeal joint reached 90 degrees, extension reached 150 degrees; flexion of the distal interphalangeal joint

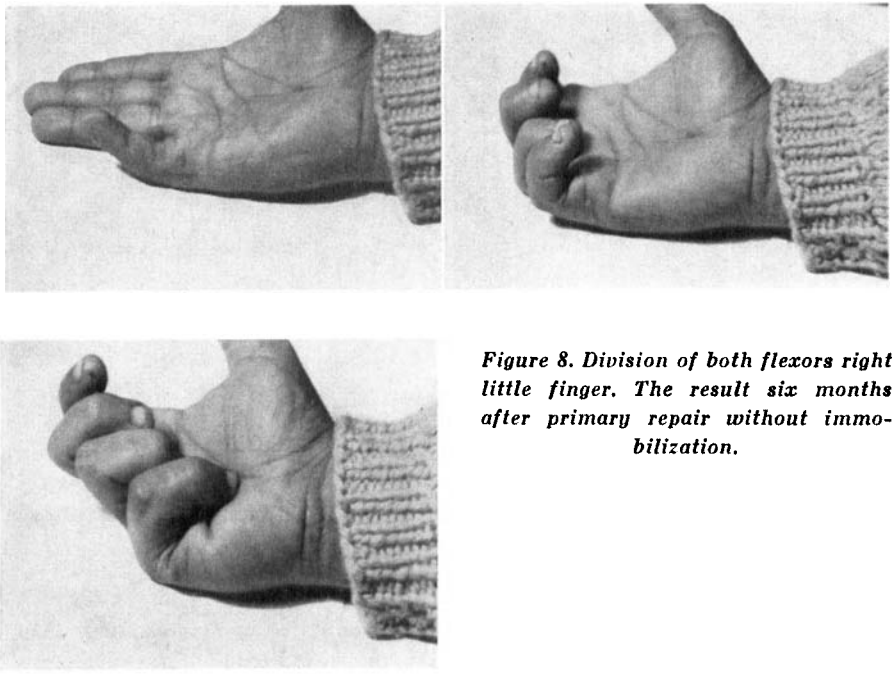


Figure 8. Division of both flexors right little finger. The result six months after primary repair without immobilization.

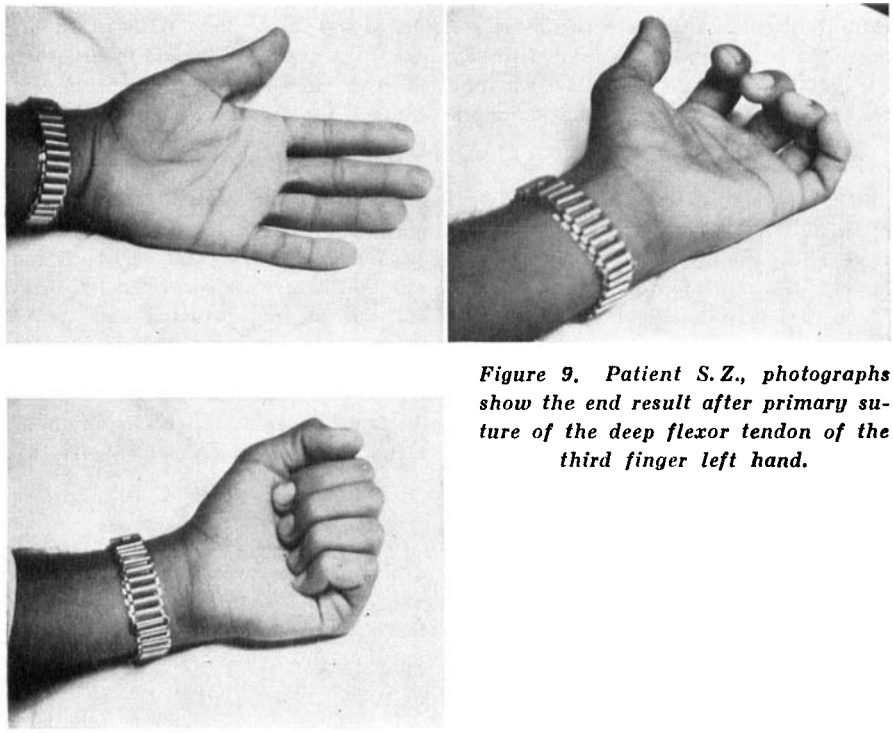


Figure 9. Patient S. Z., photographs show the end result after primary suture of the deep flexor tendon of the third finger left hand.

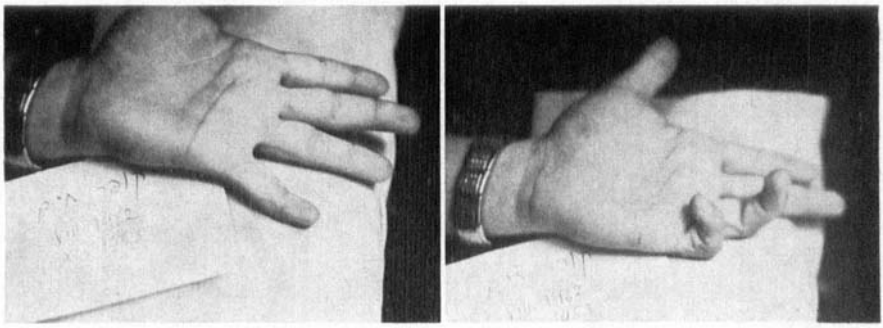


Figure 10. Case K. H., result obtained from an end-to-end anastomosis of a divided deep flexor tendon at the level of the distal interphalangeal joint. Active movements started immediately after surgery.

was noted to be 120 degrees, extension 180 degrees. The finger was able to touch the palmar crease (Figure 8).

Case 3

S.Z., an eighteen-year-old factory worker, was admitted to us about four hours after his left hand was wounded by broken glass. Examination revealed a cut, deep-flexor tendon of the third finger. Under axillary block anaesthesia the flexor sheath was exposed and an additional division of the medial insertion of the sublimis tendon was observed. The medial insertion of the sublimis was re-attached and the cut ends of the deep flexor were identified and anastomosed with "grasping" suture. Active movements started five days later. The patient returned to his work 31 days after operation. The last examination (two months after injury) revealed full range of flexion in the interphalangeal joints of the repaired finger (Figure 9).

Case 4

K.H., a seventeen-year-old student, was admitted to us three hours after he had injured his left little finger in a press. A deep, grease-covered wound with crushed borders over the distal interphalangeal joint was observed. The joint was open and the deep flexor tendon divided. Anastomosis in that case was performed by direct suture of the proximal end into "fish-mouth" opening of the distal end. Active movements started the next day. He returned to his mechanical practice 29 days after surgery. The last examination (14 months later) revealed active flexion of the distal interphalangeal joint to 100 degrees, extension up to 150 degrees (Figure 10).

Case 5

M.A., a thirty-year-old sailor, was seen at our department 24 hours after he had injured his right thumb on a broken glass. Examination revealed a clean wound over the volar surface of the basal phalanx and loss of active flexion in the interphalangeal joint. Under axillary block anaesthesia the wound was extended and the flexor sheath exposed. The distal end of the cut long flexor was found at the depth of the wound. The proximal end was also identified and sutured to the distal by "grasping" suture. Active movements started on the next day. Six weeks later, the

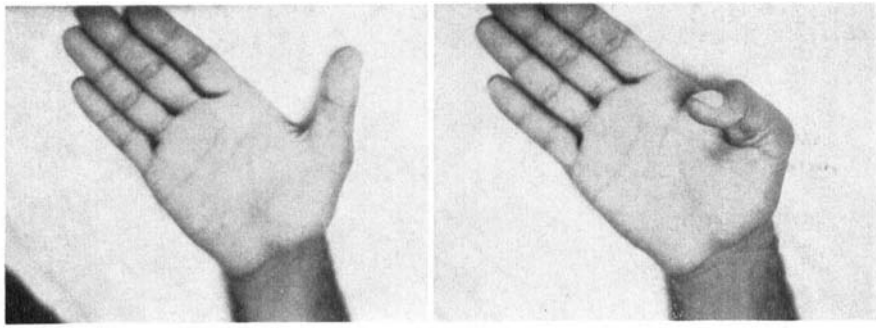


Figure 11. Patient M. A. Result obtained eight months after primary "grasping" suture of a divided long flexor tendon of the right thumb.

active movements were noted to be as follows: extension of the interphalangeal joint to 190 degrees, flexion to 140 degrees. Since no further improvement of the movements was obtained during the next few months, and the patient was not satisfied with the range of motion, surgery was repeated three months later. Through a small lateral incision the suture site was exposed and several fine adhesions connecting the tendon with the surrounding tissues were found and divided. The last examination, eight months after surgery, revealed almost full range of movements of the interphalangeal joint of the right thumb (Figure 11).

Case 6

J.R., a twenty-two-year-old woman, was admitted to us two hours after she injured her third right finger by a sewing machine. In examination, a slightly lacerated wound at the base of the finger with complete loss of active flexion were noted. The flexor tendon sheath was exposed and complete division of both flexors was revealed. The ends of the sublimis were approximated by "U" suture and the ends of the deep flexor by "rasping" suture. It is to be emphasized that although no immobilization was applied, the patient did not exercise the injured finger due to swelling and painful reaction during the first two weeks. One month later, the movements were noted to be as follows: distal interphalangeal joint 180–170 degrees, proximal interphalangeal joint 150–135 degrees. Two months after the injury, in order to further improve the range of movements, the suture site was re-exposed and some adhesions around the flexor tendons were found and divided. Active movements started on the next day. Two weeks later the movements were noted to be nearly normal. The last examination, two months after surgery, revealed full range of movements of the injured finger (Figure 12).

Case 7.

D.R., a seventeen-year-old technician, was admitted to us about five hours after injury. Examination revealed a lacerated wound at the base of the volar surface of the fourth finger and inability to flex the distal phalanx. Under axillary block anaesthesia the wound was extended and the cut ends of the deep flexor identified. They were anastomosed by "grasping" suture. Active movements started on the next

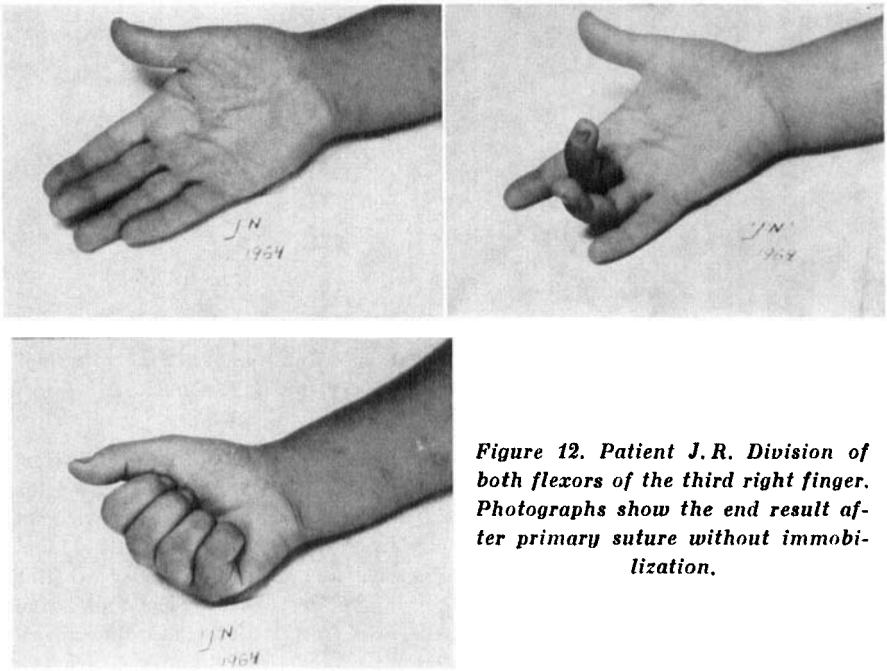


Figure 12. Patient J. R. Division of both flexors of the third right finger. Photographs show the end result after primary suture without immobilization.

day. The case was followed two months after surgery and at the last examination showed a range of active movements of the distal interphalangeal joint between 130 and 180 degrees. Unfortunately no photographs are available.

COMMENTS

It has not been the purpose of the present study to investigate the importance and role of the anatomical appendices of the tendon (sheath, vincula, etc.) in development of fibrosis. This particular subject has been widely elaborated and reported in the past. As stated previously, our study has been limited to an attempt to examine and demonstrate the condition of an injured digital flexor tendon after primary end-to-end suture without immobilization.

For the purposes of the investigation we have not been able to use any of the conventional methods of tendon suturing. As it is known, all of these methods are based on additional support by immobilization in order to keep the sutured tendon ends in contact. We tried at the beginning of our experiments the well-known Bunnell's figure-eight suture. This technique when applied in a non-immobilized tendon invariably causes longitudinal separation of the tendon fibrils and retraction of its proximal end (Figure 13). As noted by Lindsay et al.

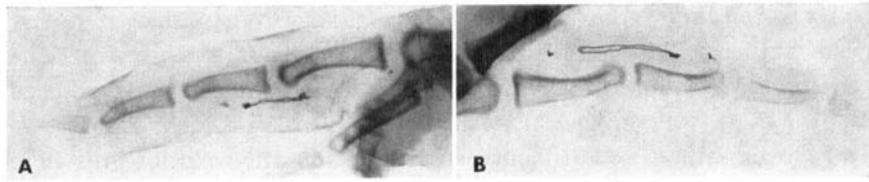


Figure 13. Roentgenographic appearance of the regular Bunnell's figure-eight suture (A). When not immobilized, this suture allows longitudinal separation of the proximal fragment and its retraction into the palm (B).

(1960), even a plaster cast does not appear to be a completely effective means for avoiding a gap between the sutured tendon ends. They found gaps occupied by massive fibrotic formation in some of their cases in spite of immobilization. We have also seen very similar results using some kinds of internal fixation, such as suture at a distance or blocking pins. Obviously, the muscular activity of the immobilized tendon is strong enough to split the fibres under the pin or wire, weakening the fixation and causing either partial or complete disruption of the sutured ends. With the suture proposed, an attempt has been made to withstand the tendency for longitudinal separation. As it is almost intratendinous, this suture has been observed to cause, if intact, only a mild foreign body reaction.

The first observation we made in our experiments was the relatively high incidence of ruptured sutures caused by rupture of the wire we used. This shows the great difference between the tensile strength of the tendon and the tensile strength of the wire. However, whereas the tensile strength of the wire has a simple mechanical attitude, the tensile strength of the intact and repaired tendons presents a number of biological problems. As one of us pointed out on another occasion, the tensile strength of foreign materials as well as the strength of their attachment to biological structures can be quite accurately measured by simple technical means (Kessler, Niebauer & Howard 1967). As far as tendons are concerned, many other factors have to be taken into consideration, such as physiological action of the particular tendon, size, time after repair, etc. We did not elaborate on this particular point, which is a subject for investigation by itself. On the other hand, we do believe that the obviously great difference between the tensile strength of the tendon and the wire is probably not very important in clinical application of the suture, in which gradual and controlled movements replace the voluntary muscle contractions of the animals. In fact, technical details, including type of suture and wire, have been

of only secondary importance (cases 1 and 4). We realize that any type of suture which could withstand the normal muscle contractions and keep the tendon ends well approximated could have been used with the same or even better results. Therefore the most impressive feature brought out by this investigation was the relationship in a significant proportion of instances between intact sutures and fibrous tissue proliferation. It was clearly shown that intact sutures were characterized by highly reduced amount of adhesions, whereas instances with partial or complete ruptures developed massive fibrotic reaction. Moreover, the mild adhesions in instances with intact sutures have even changed their nature; they appeared as fine fibrotic bundles extended in the direction of gliding, with adequate length to allow an almost normal excursion of the tendon.

SUMMARY

A procedure of avoiding massive adhesions around primary repaired flexor tendons by immediate or early movements has been presented. Experiments have shown that a strong anastomosis of an injured tendon without immobilization contributes to the development of mild fibrotic reaction. It is also shown that early movements may change the nature of adhesions and preserve good physiological range of excursion.

In order to obtain a strong and well-adapted anastomosis, a new suture technique that grasps the tendon substance with four knots has been described.

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