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TECHNICAL NOTE

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Some technical tips to improve two stages flexor tendon grafting

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Abstract Two-stage reconstruction of the profundus tendon with a tendon graft is a technically demanding procedure. Results from a series of 16 cases demonstrate the importance of a good soft tissue bed, as well as pulley reconstruction. The accumulation of technical experience, together with early mobilisation protocols, has helped to improve the functional results. The first operative procedure employs a silicone rod, which has an oval cross section and a conical shape, which adapts to the volumetric variations of the digital canal. Pulley reconstruction should be generous, including A1, A2, A3, and A4. Attachment of the profundus tendon to palmaris longus at the first stage guarantees a sound repair, which permits early tendon mobilisation after the second stage. Attachment of the tendon graft to the distal phalanx is carried out using an absorbable mini-anchor, and is reinforced with a fingernail suture. A series of 12 Stage 1 and Stage 2 patients had an average total active motion (TAM) of 223° with a residual interphalangeal joint flexion of −15°. In Stage 3 patients (four cases) one early rupture and two tenolyses resulted in TAM of 160° and 165°. For Stage 1 and 2 patients, the Strickland active rehabilitation protocol gives the best functional results.

Keywords Flexor tendon · Graft · Hand

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Quelques astuces techniques pour améliorer la greffe en deux temps du fléchisseur profond

Résumé La greffe en deux temps du fléchisseur profond est exigeante sur le plan technique. Les résultats évalués à partir d'une série de 16 cas montrent l'importance de la qualité du lit tissulaire environnant et de la restauration des poulies. L'accumulation de détails techniques associés à un protocole de mobilisation précoce de la greffe contribue à l'amélioration des résultats fonctionnels. Le premier temps opératoire utilise une tige de silicone ovalaire et tronconique afin de s'adapter aux variations volumétriques du canal digital. La reconstruction des poulies doit être généreuse: -A1 -A2 -A3 -A4. L'anastomose du fléchisseur profond avec le petit palmaire est réalisée dès le premier temps opératoire ce qui garantit sa solidité à l'issue du second temps opératoire pour autoriser une mobilisation précoce. L'attache de la greffe tendineuse sur la phalange distale est facilitée par les mini-ancres résorbables et renforcée par une suture unguéale. La série de 12 patients au stade I et II montre un total avtive motion (TAM.) .moyen de 223° avec un flexum résiduel de l'IPD de −15°. Au stade III (4cas) une rupture précoce et deux ténolyses produisant un TAM de 160° et 165°. Au stade I et II le protocole de rééducation active selon Stickland donne les meilleurs résultats.

Mots clés Tendon fléchisseur · Greffe · Main

Introduction

Technical improvements in primary repair of flexor tendons in Zone 2 of the hand, together with repair of neurovascular structures and the contribution of various early postoperative rehabilitation protocols have significantly reduced the number of two stage tendon grafting procedures [2, 8]. Between 1970 and 1985 numerous series consisting of small numbers of two stage tendon grafts were published [1, 4, 17, 21–24]. Nowadays the

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number of series is limited, and new generations of hand surgeons only occasionally carry out such surgery, which remains technically demanding. The technical details described below, when carried out painstakingly, should help make these procedures more reliable.

Historical perspective

Basset and Carroll [2] in 1963 were the first to report their experience with artificial tendons and temporary tendon implants which led to a tendon pseudo-sheath, which allowed placement of a tendon graft 2 months later. Hunter [8] described poor results with active tendon implants made from Silicone–Dacron, but did observe after removing ruptured implants, the formation of a pseudo-sheath around the implants which could accommodate a tendon graft. Ten years later together with Salisbury [9] he reported his experience using this technique, which has become known internationally as "Hunter's two stage technique" [18].

Classification of lesions

Boyes [3] produced a classification of five preoperative stages, which described the condition of the local tissues, taking account of the importance of scar tissue, nerve injury, joint stiffness, previous infection, and involvement of multiple digits. Merle [14] amended the classification into three stages (Table 1), which takes into consideration the state of the vascularity of the tissues.

Incorporation of the tendon graft is dependent on the vascularity of the digit, but the functional result also depends on the nerve repair. The better the quality of the vascular bed the lower will be the likelihood of recurrent scar formation. The same applies in producing a functional outcome after arthrolysis of the interphalangeal joints. One can see that two stage tendon grafting is indicated in Stages 1 and 2, and in specific cases to repair injuries in Zone 2 or T2, depending on the state of the local vascularity. In contrast, Stage 3 injuries will only obtain partial functional results, as the state of the surrounding tissues does not guarantee the success of arthrolysis, nerve repair, and integration of the tendon graft.

Technical tips

Carrying out a two stage tendon graft procedure involves placement of a silicone rod, pulley reconstruction, as a minimum A2 and A4 when these have been damaged or lost during previous surgical procedures, the preparation of the proximal anastomosis between the tendon and the graft, and at the second stage, distal fixation of the tendon graft in Zone 1.

Universal one size tendon rod

The digital canal is not made up of a tunnel of constant diameter, and the works of Strauch demonstrate the perfect congruity existing between the pulleys and the passage of the underlying superficialis and profundus tendons, particularly at the level of the A1, A2, A3, A4 and A5 pulleys. It is apparent that the dimensions of the digital canal are not the same during the passage of the superficial and profundus tendons through the A1 pulley, then after the chiasma of the superficialis at the level of the A2 pulley, and at its flattening during the passage through the A3 pulley. The profundus lies alone deep to the A4 and A5 pulleys. The use of a silicone rod of constant diameter throughout the length of the digital canal does not meet the anatomical and biomechanical demands of the digits. For the last three years we have been using a universal conformable tendon rod developed by AREX following studies carried out on fresh anatomical specimens. This has an oval cross section and its two axes vary in thickness from 1.5 to 3 mm and in width from 3 to 6 mm over a total length of 49 cm (Fig. 1).

The advantage of this conformable tendon rod with its conical shape is that it occupies completely the space left around the pulleys. The pseudo-sheath produced by a silicone rod is suitable for accommodating a tendon graft from the eighth week onwards, but it has a tendency to develop a fibroblastic contraction, which causes a reduction in the gliding space available.

With the four widths of silicone rod currently available to create a pseudo-sheath, the surgeon attempts to introduce the largest possible rod into the digital canal. Frequently this becomes stuck at the point of introduction into the A3 and A4 pulleys, and the surgeon is obliged to settle for a rod with a smaller diameter. The one size conformable tendon rod resolves this problem and allows the 'contents' to fit the "container" precisely.

The device is introduced into the digital canal via the most proximal pulley and advanced until it abuts against the most distal pulleys, at which point it is very gently withdrawn. The proximal end of the universal conformable tendon rod must be completely free of

Table 1 Classification of flexor tendon injuries of the fingers treated by secondary repair [14]

Stage 1	Stage 2	Stage 3
Minimal scarring without neurovascular injury	Significant scar tissue with tissue bed damage: ± pulley damage ± joint stiffness. At least one intact neurovascular bundle in each digit	Significant scar tissue with following injuries: both neurovascular pedicles in each finger and/or principal vascular axes of the hand

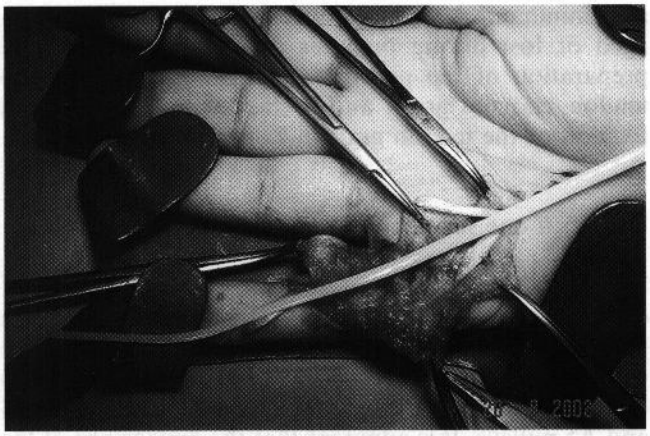

Fig. 1 Universal tendon spacer (UTS) AREX®, 49 cm long, due to its conical shape will fit all digital canal configurations

obstruction in order to avoid a "serpentine" effect occurring during passive mobilisation exercises.

The one-sized conformable tendon rod is made from high resistance silicone and its elasticity allows its extraction from proximal (large diameter) to distal (small diameter). The distal end of the implant is attached to the stump of the FDP tendon in Zone 1 using a Tsuge PDS loop [20] (Fig. 2).

When the profundus graft is carried out in the presence of an intact superficialis tendon it is advisable to pass the universal tendon rod above the superficialis, and not through Camper's chiasma.

The remaining ends of the single width conformable tendon rod can be sterilised again to be used to extract the ends of flexor tendons from fresh wounds, described by Merle [13] (Fig. 3). As part of good operating theatre management this universal tendon rod provides solutions to all surgical problems encountered, and avoids the need to stock four widths of silicone rod which do not in any case get round the 'container–contents' problem.

Pulley reconstruction

This must be carried out at the time of the first operation (Fig. 2D). In the most severe cases it is advisable to restore the A2 and A4 pulleys as a minimum. However, if the tissue environment is favourable it is preferable to reconstruct the A1 and A3 pulleys too. The greater the length of digital canal restored, the better the amplitude of movement of the PIP and DIP joints, which help to reduce a bowstring effect which impairs the comfort and function of the patient. As the reconstructed pulleys are subjected to the sole constraints of the silicone tendon rod for a period of 8 weeks, we prefer the pulley reconstructions described by Kleinert [11], which make use of a strip of superficialis tendon to act as C2, A3, and A2 pulleys. This pulley reconstruction is sutured laterally on to the remnants of the original pulleys. When direct suture is not possible we use the absorbable 1.6 mm diameter micro anchors implanted into the lateral sides of the phalanges (MicroFix®, Mitek). Bowstringing can become apparent in the palm of the hand after tendon graft placement when there is no further pulley action due to the absence of the carpal ligament and the A1 pulley; it is for this reason that we systematically repair the latter.

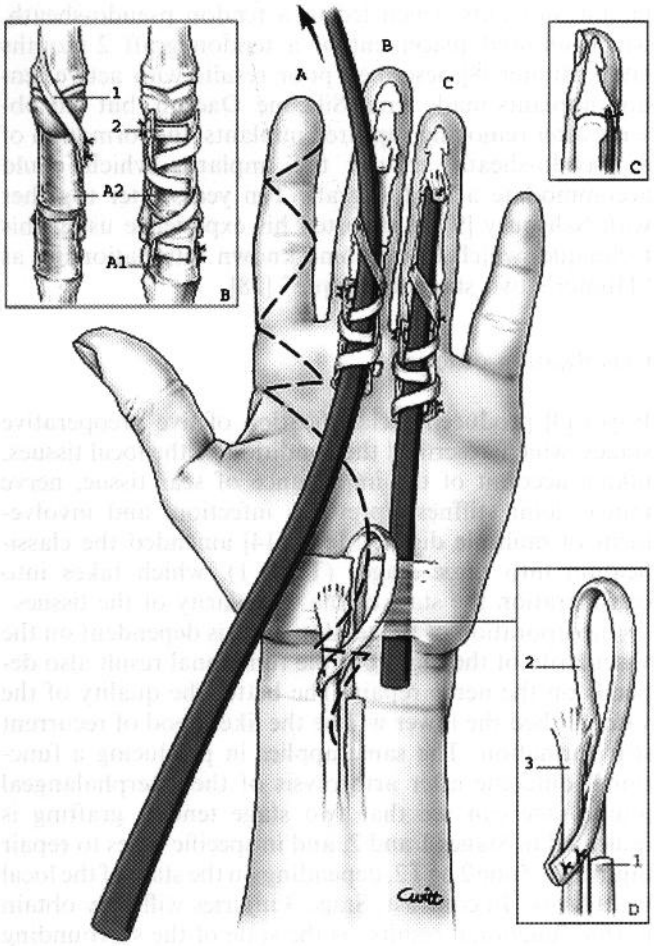

Fig. 2 Two stage graft of flexor digitorum profundus (FDP) *A*. The area to be grafted is approached by a volar zig-zag incision. *B* One centimetre of the distal insertion of FDP is preserved in order to facilitate fixation of the UTS. One strip of the FDS is used to reconstruct the A3 pulley (B1) taking purchase on the edge of *A2* pulley. *A2* and A4 pulleys are reconstructed according to Kleinert technique (B2) using a strip from FDS passed through the edges of the remaining pulleys. The UTS is introduced into the digital canal from the palm of the hand (*B*). *C* The distal end of the UTS is inserted between the palmar plate of the distal phalanx and the stump of the FDP. PDS 3/0 will be used to fix it; *U* shape suture will be sufficient to lock them together until Stage 2. In case of a "long graft" the proximal end of the UTS should be in the forearm distal part before the wrist palmar fold. A passive motion test is performed on the repaired finger, one should get a nice gliding of the UTS through the reconstructed digital canal, without any kinking effect of the UTS during this test. *D* The FDS is resected in zone V (D1). The deep flexor tendon (FDP) is turned back on itself and its free end sutured with a fish mouth anastomosis obliquely onto the distal end of the palmaris longus

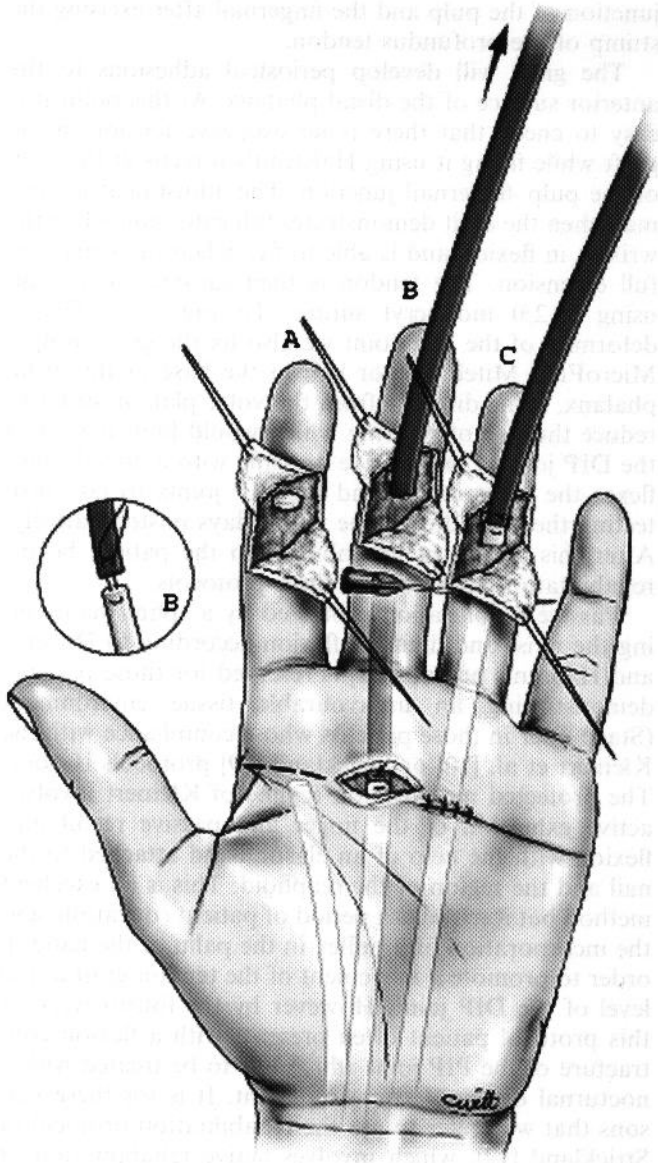

Fig. 3 A non-traumatic method to extract ruptured flexor tendons *A*. The remaining ends of the UTS can be sterilised and used to extract the retracted proximal end of flexor tendon. *B* UTS remaining end will be introduced through the opening of the causing wound, it will bump against the cut end of tendon(s). A counter incision is performed; both ends are sutured together. *C* Extraction will be done with no trauma. An intradermic needle will fix the tendon while it is repaired

Tenorrhaphy of profundus tendon with the tendon graft

Paneva-Holevich [16] proposed primary anastomosis of the superficialis to the profundus tendon. By the time of the second procedure the proximal anastomosis is completely sound and well vascularised, thus allowing the incorporation of the graft and its early mobilisation. We have however noticed that the superficialis graft is very bulky and this does not allow its excursion within the pseudo-sheath. Foucher and colleagues [6] prefer to use the palmaris longus as a tendon graft when available. The technique of anastomosis is straightforward: the profundus tendon is freed from all of its attachments as far as the inferior border of the carpal ligament, then turned on itself, it runs between the anterior surface of the ligament and the subcutaneous tissue, to anastomose with the palmaris longus in fish mouth fashion. The anastomosis is carried out using interrupted 3/0 PDS, the palmaris longus remaining attached to the carpal ligament (Fig. 2D).

Passive rehabilitation

This begins in the very first postoperative days, especially if arthrolysis of the MP and/or IP joints has been carried out. The rehabilitation is active for the MP and IP joints when the superficialis is intact and functioning, and passive when the superficialis and profundus tendons have been injured. The use of dynamic flexion and extension splints promotes the return of maximal range of movement to the digit. The functional result of tendon grafting will not exceed the passive range of movement achieved at the time of insertion of the universal tendon rod.

Second operative procedure (Fig. 4)

Eight weeks later a limited incision is made along the border of the carpal tunnel, extended in a zig-zag fashion proximal and distal to the wrist crease. The palmaris longus is dissected, and is found to have an increased diameter, probably due to mechanical reasons. An olive-shaped scar has formed at the level of the anastomosis of the palmaris longus with the profundus tendon, and this should be separated from the carpal ligament and thinned out. Through a 1 cm counter incision the palmaris longus is divided at the level of its musculotendinous junction (on average 12 cm from the distal wrist crease). Using a 3/0 vicryl suture the free end of the palmaris longus is attached to the proximal end of the one size conformable tendon rod.

Extraction is carried from proximal to distal through a Brunner incision at the distal interphalangeal crease. It is necessary to make a preliminary 2–3 cm longitudinal incision in the neosheath, to allow gliding of the proximal anastomosis of the graft. At this point, having checked the full excursion of the tendon graft within the neosheath using the tenodesis effect from wrist extension, the remaining incisions are sutured.

Adjustment of tension in the graft and its distal attachment

The wrist should be in the neutral position; the uninjured digits are left free in order to check the correct physiological cascade. The injured digits must be overcorrected by approximately 15° of flexion at the PIP and DIP joints, compared with the adjacent digits.

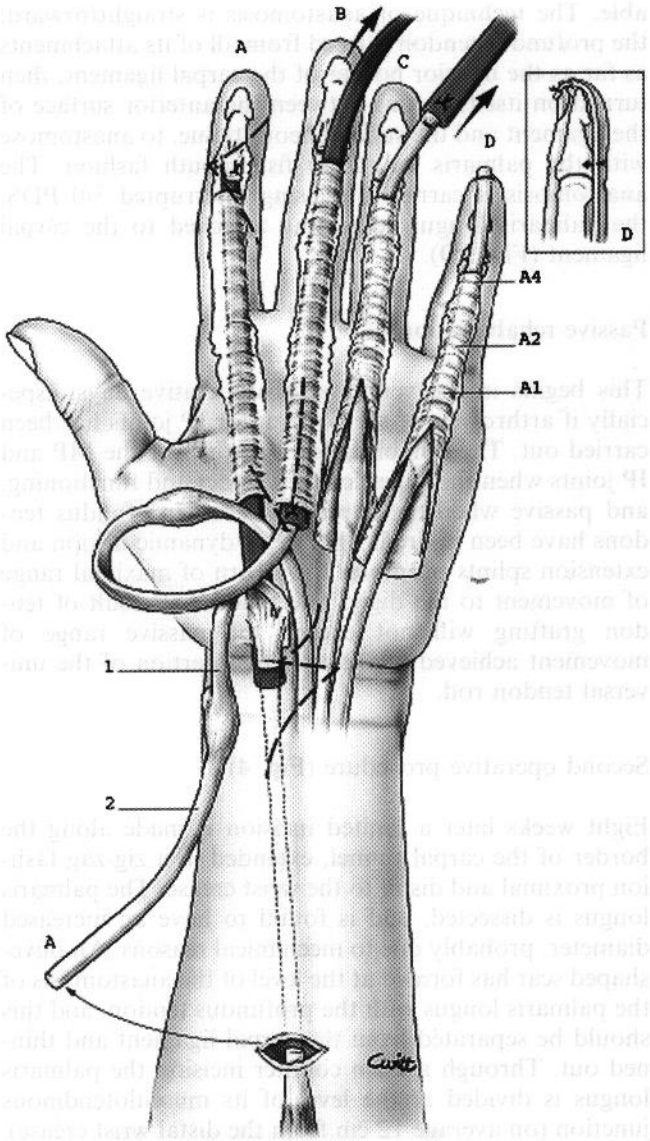

Fig. 4 Second Stage *A*. The palmaris longus is released at the level of the musculo-tendinus junction in the forearm. A scrupulous dissection of the anastomosis of palmaris longus and FDP is conducted. Distally a short incision is made to detach the UTS from the stump of the FDP. *B* The proximal end of the palmaris longus tendon is securely fixed to the UTS. The neo sheath induced by the silicone spacer is split to prevent anastomosis jamming in the canal. *C* The elasticity of the UTS, even though it is truncated, permits the tendon graft extraction by the pulpar distal end. *D* To adjust graft tension one has to over correct by adding 15° flexion to PIP and DIP joints, taking into account the physiological cascade of the uninjured digits. This will be done in order to answer muscular atrophy due to lack of function. Distal fixation of the tendon graft will be done with Microfix Mitek anchor to the base of the distal phalanx and to the nail with resorbable sutures. The FDP stump is cut off to prevent an over thickness that could limit DIP flexion

Distal fixation of the graft must be precise and sound, in order to permit early mobilisation of the digits, and at the same time avoid a fixed flexion deformity of the DIP joint (Figs. 5, 6, 7). At the same time we extract the tendon graft through a 4 mm incision situated at the junction of the pulp and the fingernail after excising the stump of the profundus tendon.

The graft will develop periosteal adhesions to the anterior surface of the distal phalanx. At this point it is easy to check that there is no excessive tension in the graft while fixing it using Halstead's forceps at the level of the pulp–fingernail junction. The adjustment is optimal when the digit demonstrates full extension when the wrist is in flexion and is able to flex when the wrist is in full extension. The tendon is then sutured to the nail using a 2/0 monocryl suture. To prevent a flexion deformity of the DIP joint we also fix the graft using a MicroFix® Mitek anchor [15] to the base of the distal phalanx, some distance from the volar plate in order to reduce the risk of scarring which would limit flexion of the DIP joint. Compressive dressing with a dorsal splint flexes the wrist to 30 and the MP joints to 60 , protecting the graft during the first 3 days postoperatively. After this period of immobilisation the patient begins rehabilitation according to three protocols.

Passive mobilisation protected by a splint maintaining the wrist and digits in flexion according to Duran's and Hausen's protocol [5] is reserved for those patients demonstrating an unfavourable tissue environment (Stage 3) or in those patients whose compliance with the Kleinert et al. [10] or Strickland [19] protocols is poor. The protected mobilisation regime of Kleinert involves active extension of the finger and passive recoil into flexion with the help of an elastic band attached to the nail and the region of the scaphoid. This is an excellent method but it requires a period of patient education, and the incorporation of a pulley in the palm of the hand in order to promote a movement of the tendon graft at the level of the DIP joint. However by the fourth week of this protocol patient often presents with a flexion contracture of the PIP joint which has to be treated with a nocturnal dynamic extension splint. It is for these reasons that we prefer to use the rehabilitation protocol of Strickland [12], which involves active rehabilitation of the graft of the profundus tendon, but which gives the

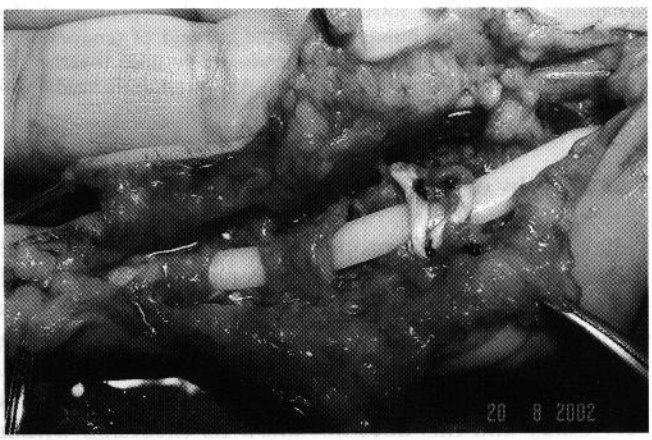

Fig. 5 First stage of two stage graft of FDP A2 pulley reconstruction. The UTS, thanks to its conical shape fits the digital canal

Fig. 6 Functional results, 9 months later. There is no pulpo palmar distance, the remaining flexum of the DIP is due to the weakness of the fifth digit

Fig. 7 Functional results, 9 months later. There is no pulpo palmar distance, the remaining flexum of the DIP is due to the weakness of the fifth digit

patient a good perception of the forces he is applying to the graft.

Results

The accumulation of these technical details has enabled us to achieve very good functional results when applied to Stage 1 and Stage 2 cases (12 cases). By contrast, in Stage 3 we have found in a series of four patients rupture of the graft at the second month, probably due to absence of revascularisation of the graft due to a poor vascularised bed. In two cases we had to re-operate at 6 and 7 months, carrying out tenolysis, to provide useful range of motion in the digits (TAM, total active motion: 160° and 175°).

In the 12 Stage 1 and Stage 2 cases we did not observe any ruptures, but we had to carry out on average six months later in two patients a tenolysis of the graft, which produced an active motion of 210° and 215° respectively. It is interesting to note that these two patients had been rehabilitated following Kleinert's protocol. After tenolysing these cases the twelve cases in Stage 1 and Stage 2 taken together demonstrated a mean range of active movements (TAM) of 223° (range 200°to –245°). We note that the mean residual flexion deformity of the DIP joint is –15° (range –5°to –35°). The best functional results were seen in those patients having a profundus tendon graft with an intact superficialis, not requiring pulley reconstruction and having rehabilitation according to Strickland's protocol.

Conclusions

Grafting the profundus tendon is technically demanding and all devices capable of improving tendon function in the digital canal will be reflected in improved function clinically. The addition of a universal conformable tendon rod, preparation of the proximal anastomosis to the palmaris longus, and the best possible reconstruction of the damaged pulleys are all requirements of the first operative procedure.

The second operative procedure begins with the passage of the graft in the pseudo-sheath produced by the universal tendon rod. Distal fixation 8 weeks later to the base of the distal phalanx and at the level of the fingernail allows early mobilisation. The rehabilitation protocol yielding the best results is the active protocol of Strickland, which need not be restricted to those patients who have an awareness of the tension exerted on the graft. Since the definitive functional outcome is dependent on the vascular status of the finger it is important, at the time of emergency treatment, to perform vascular repair of the digital and main vessels of the hand, regardless of the coexisting associated injuries.

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