Flexor Tendon Reconstruction

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L. Paul van Minnen and Thybout M. Moojen

Keywords
Flexor tendon • Reconstruction • One-stage • Two-stage • Tendon graft • Pulley reconstruction • Silicone rod • Adhesions • Tenolysis

Introduction

Primary or delayed primary flexor tendon repair followed by early guided motion rehabilitation protocols are considered the gold standard treatment of flexor tendon injuries. Ideally, prompt end-to-end repair follows early diagnosis of an acute flexor tendon laceration. In general, primary repair can be attempted up to 3–6 weeks after zone I–V injuries in uncomplicated cases.

However, not all patients with flexor tendon injuries are eligible for primary repair. In these cases a one- or two-stage tendon reconstruction should be considered. A delay longer than 3–6 weeks often makes primary repair impossible due to retraction of the proximal tendon stump and scarring in the flexor tendon sheath. This is also often the case if a previous primary tendon repair fails. Other indications for reconstructive alternatives to primary repair are in patients with significant associated soft tissue (crush) injury, wound infection, segmental tendon loss or destruction of the flexor tendon sheath.

In general, the term flexor tendon reconstruction includes (1) tenolysis of flexor tendon adhesions, (2) one-stage tendon grafting or (3) two-stage tendon repair. Indications and reconstructive options vary both per injured flexor tendon and per zone and are directed by the associated problems of the involved digit.

For example, limited range of motion in a previously injured, and repaired, digit may be caused by simple adhesion formation around an otherwise intact or repaired tendon. Surgical exploration may reveal an adequate pulley system, but flexor tendon adhesions and a PIP joint flexion contracture. This particular case may be treated adequately by tenolysis, release of the PIP joint and vigorous post-operative hand therapy. On the other hand, if extensive damage to the pulley system and segmental tendon scarring or undiagnosed tendon rupture post-operatively are

L.P. van Minnen, MD, PhD (✉)
T.M. Moojen, MD, PhD
Xpert Clinic Nederland,
Landgoed Zonnestraal, Loosdrechtsebos 15,
1213 RH Hilversum, The Netherlands
e-mail: lpvminnen@gmail.com

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encountered, a more elaborate two-stage reconstructive strategy including pulley reconstruction is warranted.

In the present chapter, flexor tendon tenolysis and one- and two-stage tendon reconstruction for zone II to V flexor tendon injuries of the fingers and thumb will be discussed.

Tenolysis

Background

Any injury to the tendon initiates the classic healing response of inflammation, proliferation, collagen synthesis and apoptosis. The cellular response to injury occurs within the tendon itself and its surrounding synovial tissue. The tendons become surrounded by a fibrin rich inflammatory exudate which may later convert to scar tissue [1–3]. Adhesions primarily form at the original site of injury and repair, but often spread to involve a much larger segment of the tendon.

Surgical manipulation also plays an important role in added tissue damage and adhesion formation. For this reason Bunnell reported the importance of minimal, atraumatic tissue handling, a bloodless field, strict asepsis and preservation of pulleys [4, 5]. He also addressed the importance of postoperative hand therapy. Indeed immobilization after injury allows for collagen depositions to form between the tendon and the synovial tissue, shaping the adhesions [1]. Therefore early mobilization programs are essential in the prevention of adhesion formation.

Presentation and Investigation

Patients with flexor tendon adhesions typically present with complaints of limited range of motion (ROM) of the involved digit. The digit has been subject to previous damage to the flexor tendon or its sheath caused by trauma, infection or previous surgery [6].

On examination, active excursion (active ROM) of the flexor tendon is incomplete despite a palpable, powerful muscle belly contraction and the passive ROM of the digit is significantly greater than active ROM [6–8]. Passive flexion is greater because the examiner can exert more power on the joint than the muscle-tendon unit which is being limited by the tendon adhesions. Typically, extension of the involved digit is also limited, but the passive and active extension deficits are often equal. The active and passive deficits are both caused by the adhesions on the flexor tendon blocking further extension [8]. Adhesions in the forearm can usually be easily identified by puckering of the skin on contraction of the muscle. In the hand, locating the exact site of adhesions can be more difficult. Careful adjustment of the surrounding joints can help to determine the location of the adhesion. Also, tenodesis of the wrist and/or metacarpophalangeal joints will also help to exclude intrinsic joint contractures as a cause of diminished ROM.

Thorough history and physical examination are often sufficient to adequately diagnose the presence of adhesions, but some surgeons value the help of additional imaging techniques such as ultrasonography or MRI. Ultrasonography can detect the presence of an intact tendon in its sheath, which helps to distinguish between adhesions and a tendon rupture [9]. MRI has been demonstrated to be 100 % accurate in distinguishing between a rupture or adhesions at the site of primary flexor tendon repair [10].

Treatment

Flexor tendon tenolysis should not be thought of lightly. Strickland once described it as the most demanding of all flexor tendon procedures [11]. Therefore, careful patient selection is essential. Criteria that must be met before an attempt at successful flexor tendon tenolysis can be done are listed in “Clinical pearls: prerequisites for successful flexor tendon tenolysis” below [6, 7]:

Clinical Pearls: Prerequisites for Successful Flexor Tendon Tenolysis [6, 7]

All fractures should be healed in anatomic alignment
Wounds must have healed with soft, stable scars and skin cover
Joint contractures have been mobilized to near normal passive ROM
Tendons systems should be intact Muscle strength should be good
Muscle strength should be good
The patient is compliant and motivated
An experienced hand therapist should be available

Preceding tenolysis, at least 3 months of intensive hand therapy is recommended to obtain as much passive ROM as possible. As long as hand therapy improves ROM, tenolysis should be postponed. If no progress has been seen during the previous 4–8 weeks, tenolysis can be planned [11]. Tenolysis earlier than 3 months after primary flexor tendon repair or tendon grafting is considered potentially dangerous to tendon blood supply. This could put the tendon at risk for rupture during postoperative hand therapy exercises [12].

Any additional procedure that requires postoperative immobilization such as tendon grafting, free skin grafts or corrective osteotomies should not be planned concomitantly. In these cases reconstruction in multiple stages is advised.

Ideally, flexor tendon tenolysis is performed under local anesthesia with intravenous analgesia and a sedative [13]. Active involvement of the patient is helpful to fully judge the active ROM of the digit when the tendons have been freed of adhesions. Additional tenolysis at a more proximal or distal level may be required if ROM is still found to be limited. Another advantage of local anesthesia is that the patient can directly observe the progress made during the procedure. This helps the patient's motivation to preserve the results during the postoperative hand therapy program [6]. If the procedure will take longer than 1 h or the patient does not tolerate the local anesthesia with sedation, general anesthesia or axillary block should be used.

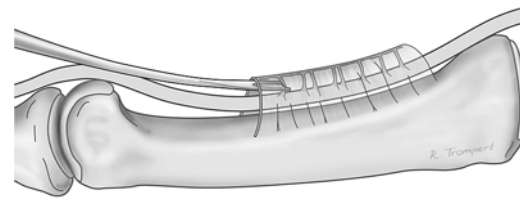

Fig. 4.1 A tenolysis knife is used to disrupt adhesions under the pulleys that are otherwise difficult to reach

Azari et al. described a step by step technique of flexor tendon tenolysis [6]. First, wide exposure of the entire flexor tendon sheath is obtained by Bruner type zigzag incisions or a mid-lateral approach. The flexor tendon is exposed proximally and distally to reach unaffected tissue. Then, both the flexor tendons are freed en-bloc from their surroundings proceeding from an unaffected area through the affected area. The pulley system, especially the A2 and A4 pulleys, is carefully spared as far as possible. Access to the tendons can be obtained through minimal transverse windows in the cruciate pulleys or, if need be, by sacrificing the A3 pulley [14]. Specially designed tenolysis knives are available to get to adhesions under the pulleys that are otherwise difficult to reach (Fig. 4.1).

When the flexor tendons have been freed from the tendon sheath, adhesions between the FDP and FDS tendons should be addressed by separating the tendons from one another [6]. If the tendons appear very frail or heavily scarred, the tenolysis procedure is stopped and one- or two-stage tendon reconstruction should be considered.

All adhesions are dealt with until the tendons glide adequately. At this stage, the patient can be asked to actively flex and extend the involved digits to assess the gliding. If the patient has general or axillary block anesthesia, gliding of the freed tendons can be assessed by the "traction flexor check", as proposed by Whitaker et al. [15]. In this maneuver, proximal traction on the involved tendons through a palmar or volar distal forearm

Fig. 4.2 The traction flexor check. To assess the presence of remaining adhesions, proximal traction on the involved tendon through a volar distal forearm incision is used to passively flex the digit

incision is used to flex the digit passively (Fig. 4.2). Additional tenolysis may be required if tendon gliding is still unsatisfactory.

Several techniques have been tried to prevent adhesion formation after tendon surgery. Local deposition of steroids at the end of the procedure has been suggested, but has also been hypothesized to have adverse effects on tendon healing [6]. Various interposition materials have been tried experimentally and clinically from as early as the 1940's. Materials included silicone sheets, gelatin sponge, and more recently Seprafilm, hyaluronan gel or hydrogel containing biocompatible phospholipid polymer [16–18]. Most however, prefer the use of early active mobilization programs to prevent tendon adhesions [19]. As early as the same day of tenolysis, hand therapy can be initiated. The hand therapist should be advised on the peri-operative findings so therapy can be adjusted to the individual patient's needs.

Outcome

In most, carefully selected patients, improvement of ROM after flexor tendon tenolysis is to be expected. Complete, unrestricted ROM however, is infrequently obtained. In 1989 Jupiter et al. reported an increase of ROM from 72 to 130 ° after tenolysis in replanted fingers [20]. In a series of 72 patients with flexor tendon tenolysis, Foucher et al. obtained an improvement in active ROM from 135° to 203° in 84 % of the fingers and from 65° to 115° in 78 % of the thumbs [21]. Tenolysis also improved ROM with 107 ° in a series of patients with flexor tendon adhesions after a phalangeal fracture [22]. More modest results were obtained in 19 patients with zone II flexor tendon adhesions, reported by Riccio et al. In this group tenolysis improved ROM by 28 % [18].

Complications

Tenolysis does not always improve digital function. In one series the large majority of patients had benefit of tenolysis, but no change or reduced ROM was observed in 16 % of the fingers [21]. So insufficient effect, or deterioration due to surgery are complications that need to be considered. The main cause for these complications is recurrence of adhesions again emphasising the importance of early postoperative active mobilization programs.

Tendon rupture is another known complication of tenolysis. In a series of 23 patients, flexor tendon rupture occurred after tenolysis in 16 % of the cases [23].

Other, less specific complications after tenolysis include would healing problems, cold intolerance or neurovascular injury. These complications are mainly due to the repeated surgical insult to the already compromised digit. Careful patient selection to meet the above mentioned selection criteria can avoid these problems.

One- and Two-Stage Tendon Reconstruction

Background

Potential candidates for flexor tendon reconstruction can present early or late. A patient seen immediately after injury has a completely different subset of problems to be addressed than a patient presenting weeks or months after the initial injury or after undergoing earlier surgical attempts at tendon repair.

In acute cases, crush or blast injury is often the cause of a mangled digit or hand. Injuries are often extensive and involve multiple digits, levels or soft tissue structures. This often makes primary tendon repair impossible. In these cases, problems such as inadequate soft tissue cover, infections or fractures need to be dealt before the flexor tendons can be reconstructed.

Patients that present late usually had less extensive initial injuries. Their causes of functional problems include tendon bed scarring, adhesions, joint stiffness or trophic changes due to associated nerve injury. Alternatively, impairment of flexor tendon function recurred after earlier attempts at primary repair. In these secondary cases, tendon adhesions, failure of the tendon repair or both require attention.

The classification system published by Boyes in 1950 is a useful tool in surgical planning, Table 4.1 [24]. In the most favorable cases, a single involved digit is in otherwise optimal condition (Grade 1). Presence of scar tissue renders the case more complicated (Grade 2). Stiffness of the interphalangeal joints requires additional hand therapy or capsulectomy (Grade 3). Associated digital nerve damage causes trophic changes making successful functional outcome less likely (Grade 4). Finally, "multiple damage" can be interpreted in two ways: multiple injured fingers or multiple lesions (*e.g.* bone, skin and neurovascular injury) in a single digit (Grade 5) [25]. In general, primary repair can be attempted in grade 1 injuries without significant delay. Tendon reconstruction in one or two stages should be considered in grades 2 to 5 [26].

Table 4.1 Boyes classification [24]

Grade	Condition
1	Minimal scar, mobile joints, optimal condition
2	Scarring
3	Joint damage/stiffness
4	Digital nerve damage
5	Multiple digits/lesions per digit

Tubiana has refined the indications for tendon reconstruction of injured digits since Boyes' publication [25]. In addition to assessment of associated injuries, timing of presentation (early, intermediate or late) is also considered in the decision making process. According to Tubiana, the indication for one- or two-stage tendon reconstruction arises if (1) the case presents late and significant scarring is present, (2) an addressed associated fracture remains unstable, (3) there is inadequate skin cover or 4) in case of multiple injuries (*i.e.* nerve, bone, joint or skin). In the latter, outcome of tendon reconstruction is poor and salvage procedures such as arthrodesis or amputation should be considered.

In short, flexor tendon reconstruction should only be considered if issues of soft tissue cover, joint stiffness, bone injuries and neurovascular damage can be or have been adequately addressed. It is essential that functional, passive ROM is present or restored before tendon reconstruction procedures are initiated. Pulvertaft summarized these conditions for successful tendon grafting (See "Clinical pearls: Pulvertaft's conditions for successful tendon grafting" below) [27].

Clinical Pearls: Pulvertaft's Conditions for Successful Tendon Grafting

The involved hand is in overall good condition
There is no extensive scarring of the tendon bed
Passive ROM is (nearly) full
Circulation of the digit is satisfactory
At least one digital nerve is intact
The patient is cooperative

The state of the involved digit or hand cannot always be judged completely by history and physical examination alone. In the acute situation conventional radiography is often required, but there is no place for other diagnostic imaging modalities [12]. Imaging techniques such as ultrasound, CT or MRI can be helpful in secondary cases. It can be difficult to distinguish between a tendon rupture or adhesion formation after earlier flexor tendon repair. In these cases ultrasonography is a useful, non-invasive imaging technique [12]. CT is capable of detecting pulley ruptures. MRI is expensive, but superior in diagnosing flexor tendon problems such as adhesions, partial or complete tendon ruptures or pulley damage.

Surgical exploration however, remains the only method to fully assess the amount of scarring, presence and location of tendon adhesions, the state of the tendon sheath and the tendon stump. Based on physical examination, imaging and operative findings a definitive reconstructive plan can be made.

In all cases a clear understanding of the patient's wishes, expectations and – very importantly – motivation, are of paramount importance when deciding if the patient is a good candidate for flexor tendon reconstruction. Thorough preoperative counseling is needed to discuss the options, the potential results, risks and complications of all reconstructive efforts. A multidisciplinary hand clinic is ideal to council patients seeking flexor tendon reconstruction. The involved hand surgeon and therapist can consult the patient together to guide decision making by all parties involved. Decisions should not be made hastily. If the patient has reservations or second thoughts, a follow-up appointment should be arranged for more counseling.

Flexor Tendon Reconstruction of Zone I Injuries

Presentation

In flexor tendon zone I, the FDP tendon is damaged distal to the insertion of the intact FDS tendon by avulsion from its insertion, laceration or failure of a previously performed primary FDP repair.

In 1977 Leddy and Packer categorized closed avulsion injury of the FDP insertion from the distal phalanx into three types [28]. A few years later, a fourth type was added [29, 30] (Fig. 4.3).

Type I injury involves rupture of the FDP tendon from its insertion on the distal phalanx. Vinculae are also ruptured, allowing the tendon to retract into the palm. Rupture of the vinculae causes a hematoma in the flexor tendon sheath. If not treated urgently, fibrosis in the flexor tendon sheath and fixed muscular contraction make primary repair impossible.

Type II FDP avulsions are more forgiving. The tendon ruptures from its insertion, but the intact vinculae only permit limited retraction of the tendon to the level of the PIP joint. Hematoma formation is less pronounced and limited retraction is unlikely to cause fixed contraction of the muscle. Type II injuries are therefore often eligible for delayed primary repair with good results. Successful primary repair of type II injuries after 3 months delay have been described [31].

Type III lesions are much like type II injuries to the extent that retraction is limited and the vinculae remain intact. In these lesions, a bony avulsion fragment of the distal phalanx prevents tendon retraction into the flexor tendon sheath. Type III lesions are therefore also more often suitable for delayed primary repair.

In 1981 Smith suggested adding a type IV FDP avulsion injury. In this fairly rare type of injury not only does the FDP tendon retracts into the finger or palm bit it also ruptures from an

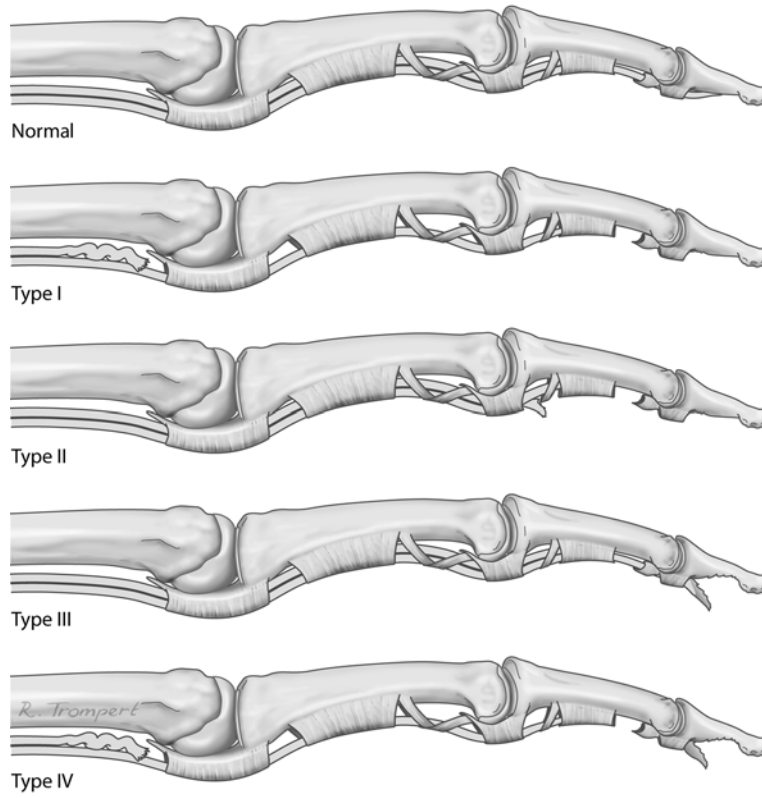

Fig. 4.3 Types I to IV avulsion injuries of the FDP insertion

avulsed bony fragment [30]. Other than the presence of a bony avulsion fragment, this is much like a type I injury and should be addressed in an urgent fashion.

In summary, flexor tendon grafting or two stage flexor tendon repair is usually indicated in type I and IV injuries. However, significant delay or associated injuries may require more this type of treatment in types II and III injuries.

Open lacerations of the FDP tendon in zone I have similarities to type II closed avulsion injuries; the FDP tendon usually remains tethered to its vinculae and retracts no further than the PIP joint or proximal phalanx.

Unfortunately, rupture of a previously repaired zone I primary tendon injury is not uncommon. If recognized within two to three days, ruptured primary tendon repairs can be successfully treated with a repeated attempt at primary repair. If delayed longer, one- or two-stage reconstruction should be considered.

Treatment

The indication for reconstruction of FDP function with an intact FDS remains controversial. The reasons for this debate are twofold.

Firstly, impairment caused by loss of FDP function is limited to inability to actively flex the DIP joint and reduced strength in the involved digit. It must be noted that particularly in the ulnar two fingers, loss of power grip can be quite restrictive. Also, active flexion of the DIP joint may be needed in particular cases (*e.g.* musicians). But if the DIP joint does not hyperextend during pinch and the patient does not have particular need for active DIP joint flexion, conservative treatment is a viable option. Alternatively, tenodesis or arthrodesis to stabilize the DIP joint are functionally valuable options.

Secondly, good outcome of FDP reconstruction with an intact FDS cannot be guaranteed. Some authors go as far as limiting reconstruction

to patients of 10–21 years of age [32]. If the wish for reconstruction is outspoken, the patient should be clearly informed that results can be disappointing or, in some cases, may even be functionally worse.

Clinical Pearls

Isolated loss of FDP is often functionally unimportant

More conservative options: – no surgical treatment, tenodesis procedure or arthrodesis are usually more appropriate

Consider one-stage reconstruction in younger and well motivated patients

One Stage Tendon Grafting

One stage tendon grafting can only be performed if the flexor tendon sheath is intact, there is minimal scarring and joints are supple. The tendon graft chosen should be thin enough to fit in the flexor tendon sheath together with the intact FDS tendon slips. In the majority of cases, fingertip-to-palm grafts suffice for zone I FDP tendon reconstructions with an intact FDS. The palmaris longus tendon or the extensor digitorum communis tendon to the index finger have been reported to be suitable grafts [11]. These tendons have sufficient length for tip to palm grafting. Characteristics and harvesting technique of available grafts for one- or two-stage reconstruction are described later in this chapter.

Bruner type zig-zag incisions or a mid-lateral approach to the flexor tendon system is obtained. Choice of approach depends on preference of the surgeon and on pre-existing scars. The zig-zag incisions provide the best exposure, but the mid-lateral approach reduces the amount of scarring directly over the flexor tendon sheath [33]. Exposure of the flexor tendon sheath is obtained from the FDP insertion at the distal phalanx to the mid palm. Remnants of the FDP tendon should be excised from the fingertip to the lumbrical origins. If possible a 1 cm stump of the distal FDP at its insertion on the distal phalanx should be preserved for attachment of the graft. The annular pulleys should be spared as much as possible.

Ideally, the graft is threaded carefully through the chiasma of the FDS tendon. But the chiasma is often obliterated by scarring. If so, the graft can be routed around the FDS tendon slips. Under no circumstance should the functional FDS insertions be sacrificed. Some authors however, have suggested a resection of one of the FDS tendon slips [34]. This is usually considered unnecessary [35].

The distal junction of the graft to the distal FDP stump or distal phalanx should be fixed first. Multiple techniques for the fixation of the distal juncture have been described. If the distal FDP tendon stump is of sufficient length, a graft-to-tendon suture technique is used. Otherwise, graft-to-bone fixation is warranted [34]. The same techniques apply for fixation of the distal graft junction as described previously for primary flexor tendon repair. Options include pull-out sutures through or around the distal phalanx that place the tendon end into small transverse trough in the volar distal phalanx, or alternatively the use of a small bone anchor. The decision on which fixation to use is largely based on surgical preference. Pull out sutures have the advantage of being non-permanent. They also allow for accurate placement of the distal tendon end into the bony trough. If the sutures are placed through the nail plate, deformities of the nail may result. The bone anchor has de advantage of a strong fixation without the need of suture removal or the risk of nail plate deformities. The downside is the use of a permanent implant, which some surgeons prefer to prevent if possible.

Skin can be closed distally before the proximal juncture in the palm or distal forearm is made. This facilitates skin closure before tensioning at the proximal juncture places the digit into a flexed position.

Typically for zone I injuries, the FDP motor is still intact and its proximal tendon is available in the palm. Proximal fixation of a slender graft such as the plantaris or palmaris tendon can be done by interlacing the graft through the FDP

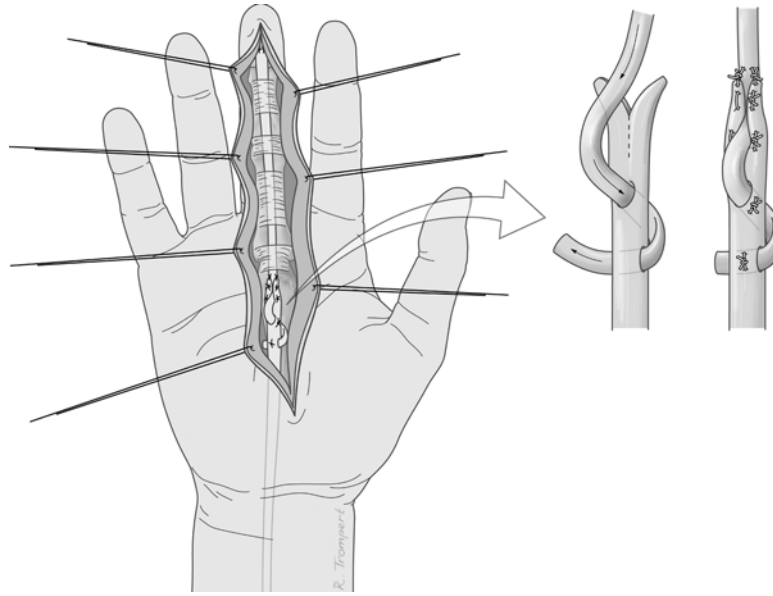

Fig. 4.4 The tendon graft is tunneled trough the flexor tendon sheath and attached proximally. If sufficient space is available, the attachment is made by interlacing the graft through the FDP tendon as described by Pulvertaft

tendon as described by Pulvertaft [36]. Care should be taken to place this fairly bulky connection sufficiently proximal to the A1 pulley to allow for unimpeded tendon gliding, if needed the A1 pulley can be vented to create additional gliding room (Fig. 4.4). Alternatively, an end-to-end juncture can be fashioned if the graft and FDP tendon are of similar caliber. If the proximal juncture is placed in the distal forearm, the Pulvertaft weave is recommended. With the wrist, MCP joint and PIP joint straight, tensioning of the graft should put the DIP joint in approximately 40° of flexion [35].

Strickland recommends postoperative immobilization of the hand with a dorsal splint for 3.5 weeks [11]. More recently, others allowed for gentle short-arc active extension and flexion within the first postoperative week, supervised by an experienced hand therapist [19].

Two Stage Tendon Grafting

A two-stage tendon grafting procedure is needed if scarring of the flexor tendon sheath does not allow for supple gliding of the future graft. Also, if the A4 pulley needs to be reconstructed or a stiff DIP joint needs release, this can be done at the first procedure together with placement of a silicone rod.

Stage One

Exposure of the entire flexor tendon sheath is obtained from the insertion of the FDP tendon on the fingertip to the site of the planned proximal juncture in the palm or the distal forearm. Previous incisions must be respected to ensure viability of the skin flaps. The state of the sheath and FDS tendon are evaluated. Any scarring of the sheath or pulleys is excised. Joint contractures are released at this stage if needed.

The A4 pulley is reconstructed if it is considered dysfunctional and irreparable. The remainder of the FDP tendon is excised to the origin of the lumbricals in the palm. If possible, the distal 1 cm of the FDP at its insertion on the distal phalanx should be spared for attachment of the silicone rod and the tendon graft in the first and second stages respectively. Also, the (healthy) proximal end of the FDP can be sutured to the A1 pulley in the first stage. This maintains length and prevents retraction.

Depending on the planned future tendon graft and the available space, a properly sized silicone implant is threaded through the (reconstructed) pulley system and fixed to the distal FDP stump. If the distal FDP stump is not available through- or around-the-bone suture techniques or screw fixation of the silicone implant can be used [37].

If the plantaris tendon is to be used at the second stage, a 3 mm silicone rod will usually suffice [12]. A future palmaris tendon graft requires a larger size implant: 4–5 mm, but space is usually limited due to the proximally intact FDS tendon. The implant can be placed trough or around the chiasma of the FDS and threaded proximally enough into the palm to allow for unimpeded gliding of the proximal end. If the palm is scarred or the lumbricals are damaged, these should be bypassed by a longer silicone rod to the distal forearm. In the distal forearm the proximal end is placed between the FDS and FDP tendons. The proximal end of the silicone rod is left unattached. Free gliding of the rod must be tested before closure of the wounds. The proximal tendon end in the forearm can be marked with an non-resorbable monofilament suture to make subsequent identification easier during the second stage. The hand is covered in a bulky compressive dressing with the wrist in slight flexion.

After stage one, post-operative hand therapy is aimed to keep the joints supple and the tendon sheath open. Passive guided motion exercises are started at 7–10 days. After sufficient time for the soft tissues to heal and the pseudosheath to form, the second procedure is scheduled. This is usually 3 months after the first procedure.

Stage Two

In the second procedure, only minimal exposure of the silicone rod and the newly formed pseudosheath is necessary at the fingertip and at the site of the proximal juncture. Distally, the silicone rod is released from its insertion. The tendon graft can then be attached securely to the silicone rod and very gently pulled proximally trough the pseudosheath into the proximal wound. Characteristics and harvesting technique of suitable grafts are described later in this chapter. With the tendon graft in place, the rod is detached and discarded. The distal juncture of the graft is secured as described above before closure of the distal wound.

Attachment to the original FDP motor is preferred. The combined FDP motor of the third to fifth digit is usually available and in good shape if only one digit had been injured initially. The individual FDP motor of the second digit is often contracted if the palmar tendon and lumbricals have been excised at the first stage. Contracture can be prevented by attaching the musculotendinous juncture of the FDP motor of the second digit to the periosteum of the radius under tension at the first stage so the motor can be used in the future The alternative of attachment of a tendon graft of the second digit to the combined motor of the third to fifth FDP is preferred by most. Alternatively, the FDS can also be chosen as a motor to the tendon graft if multiple digits need to be grafted, or if the FDP motors are of insufficient quality.

Enough tension is placed on the graft at the proximal juncture to place the DIP joint in 40° of flexion with the PIP and MCP joints in extension and the wrist held straight. Tenodesis testing at wrist level ensures proper tensioning and cascade of the digits. Depending on the caliber of the graft and the motor tendon a Pulvertaft weave or end-to-end tenorrhaphy is used for the proximal juncture. At the end of the procedure, the hand is put in a bulky compressive dressing with the wrist in slight flexion, the MCP joints in approximately 70 ° of flexion and the interphalangeal joints in extended or slightly flexed position [35].

Early mobilization under supervision of an experienced hand therapist can be initiated in the first postoperative week. If the graft and junctures are not considered to be strong enough, immobilization for 3–4 weeks can be chosen [11]. This does increase the risk of adhesion formation [19].

Outcome

In 1988 Ipsen et al. published a series of one-stage tendon grafts through or around an intact FDS tendon [38]. They concluded that early mobilization is safe with only one tendon rupture in 25 cases. All but one had increased total ROM at long term follow up. On the other hand, six fingers lost an average of 16° of PIP joint flexion.

Older series of one-stage tendon grafting for isolated FDP lesions also reported favorable results [39, 40]. In 1969 Goldner et al. demonstrated good

functional outcome but stressed that detailed preoperative assessment, meticulous surgical technique, careful selection of patients and surgical experience are necessary.

Wilsen et al. reported a series of delayed, two-stage tendon grafting in a series of twelve fingers with flexor profundus avulsions or lacerations. Total active motion improved 78°. Grip strength significantly improved in 8 of the 11 patients. One graft rupture occurred and in two cases secondary tenolyses were necessary [41]. Sullivan reported disappointing results of staged flexor tendon grafting for isolated FDP injuries. Only 7 of the 16 cases achieved satisfactory results [42].

Complications

Complications associated with repeated surgical interventions to the digits include skin flap necrosis, wound healing difficulties, scar contractures, cold intolerance and neurovascular damage. Careful selection of cases with the Boyes classification in mind reduces occurrence of these problems.

More specifically, damage to the intact FDS tendon or added scarring due to repeated surgeries need to be considered. Potentially, the patient could have no benefit or reduced function due to failed reconstructive efforts [42].

Suboptimal tensioning of the graft causes problems. If the FDP graft from the fingertip to the palm is kept too long, a lumbrical plus digit may result. Contracture of the FDP motor causes more tension on the lumbricals than the distal graft, causing paradoxical extension of the interphalangeal joints. Conversely, if a graft is tensioned too tightly a quadriga effect may occur, especially in the third to fifth digits. In this case, further (common) FDP muscle belly contraction is limited by the fully flexed reconstructed digit, leaving the muscle incapable to further flex the other fingers with their less tight/longer tendons.

Complications of two-stage grafting include infection, synovitis around the implant or rupture of the distal juncture between stages one and two. Other reported complications include median nerve neuralgia and carpal tunnel syndrome [42].

In all cases, adhesion formation is the most important reason for disappointing results and the need for additional interventions [43, 44]. If, in the months following reconstruction, active flexion diminishes in the presence of passive flexion, tenolysis should be considered. Reoperation however, should be delayed. If tenolysis is performed within 5 months of tendon reconstruction there is an increased risk of tendon rupture [35].

Flexor Tendon Reconstruction of Zone II Injuries

Presentation

Flexor tendon zone II contains both flexor tendons to the digits in the confined space of the flexor tendon sheath. Injuries in this zone are notorious for their difficulty to manage and poor functional outcome. It is for these reasons that this zone is also referred to as “no man’s land”. Cases become particularly difficult to manage if the opportunity for primary repair of the tendons has passed. In those cases reconstructive procedures such as one-stage free tendon grafting or two-stage reconstructions may be indicated.

Potential candidates for zone II tendon reconstruction often present with one of the following backgrounds:

- Delayed treatment of combined FDP and FDS lacerations
- Significant associated injuries to the soft tissues (*e.g.* crush injury)
- Tendon rupture or adhesion formation after earlier (repetitive) attempts at primary repair
- An injury that included segmental tendon loss

Treatment

The objective of one-stage or two stage tendon grafting in zone II is to excise remnants of the flexor tendons and to reconstruct the FDP. Two exceptions should be noted:

Firstly, if only the FDS tendon is severed and the FDP is intact no attempts at tendon reconstruction should be made [35]. In these cases the

remnant of the FDS is excised out from the flexor tendon sheath.

Secondly, in some cases one can choose to reconstruct the FDS and excise the FDP. For example, if the DIP joint is stiff, the distal phalanx is (partially) amputated or if the only available graft is too short to reach the distal phalanx [35]. Other indications for construction of a "superficialis finger" are tendon reconstructions in multiple digits or the need to reconstruct more than two pulleys [45]. A superficialis finger will avoid DIP problems, usually shows good active PIP flexion and minimal functional impairment [12, 46].

One-Stage Tendon Grafting

The most common indication for one-stage tendon grafting in zone II is delayed presentation. It should only be considered if wounds have healed, the finger has full passive ROM, the flexor tendon bed is not significantly scarred and the annular pulleys are intact. In general, only Boyes grade 1 candidates would be eligible for a one-stage reconstruction (Table 4.1). Otherwise, two-stage reconstruction is indicated.

Exposure of the entire flexor tendon sheath is needed. A volar zigzag incision or mid-lateral approach can be chosen based on the presence of previous incisions or traumatic scars and the preference of the surgeon. A thorough inspection should confirm the presence of a flexor tendon sheath that allows supple gliding and intact annular pulleys. Particularly the A2 and A4 pulleys are essential to prevent functional impairment due to bow-stringing. But the presence of more pulleys, especially the A3 pulley, is favorable [35].

Remnants of the injured FDP and FDS tendons are excised, keeping a 1 cm stump of the FDP at its insertion on the distal phalanx if possible. The FDP remnant is pulled proximally out of the flexor tendon sheath and transected in the mid palm so that only good quality tendon remains. If the lumbricals are scarred or adherent to their surroundings, they should also be excised.

The FDS remnant should be shortened sufficiently to prevent adhesion to the future proximal juncture of tendon graft juncture to the FDP. Tubiana suggested withdrawing the FDS proximally into an additional volar incision in the distal forearm and transecting it there [35]. Strickland advised putting distal traction on the FDS stump, through the palmar incision, and cutting the tendon as proximal as possible [11].

Passive ROM of all joints of the digit can be tested once more and the quality of the flexor tendon sheath and pulley system reassessed. If these are satisfactory, one can proceed with the one-stage tendon grafting. If pulleys require reconstruction or if joints need to be released, it is advisable to convert this to a two-stage reconstruction.

For fingertip-to-palm grafting the palmaris longus tendon is the preferred donor. It can be carefully threaded through the flexor tendon sheath using a tendon passer or paediatric nasogastric tube. The distal juncture to the FDP tendon stump is attached first outside the sheath to prevent added damage by surgical manipulation. Then, the distal portion of the wound can be closed and the proximal juncture to the proximal FDP tendon addressed. A Pulvertaft tendon weave juncture is the strongest option. But if this juncture is too bulky in the palm, and the calibers of the graft and the proximal FDP allow it, an end-to-end tenorrhaphy is chosen. If the proximal juncture is made in the distal forearm, there is usually enough space for the Pulvertaft weave.

The excursion of the motor tendon is tested using a traction suture. Excursion should be sufficient to allow for adequate digit flexion. With a fixed wrist, about 2.5 cm of excursion is necessary to fully flex a digit. However, more available excursion is preferred (*e.g.* >4 cm). It is then immobilized halfway along its course of excursion by a needle or temporary suture to the skin. A single pass of the tendon weave with one suture allows for testing of the digit's position. With the wrist in neutral position, tension should put the involved digit in slightly more flexion than the natural arcade of the digits. Tubiana suggested 15° of additional flexion compared to normal [35]. Then the fixating needle or skin suture is removed. With the wrist put in 40° of flexion it should be possible to fully extend the grafted digit. Full wrist extension should bring the finger's pulp-to-palm distance within 3–4 cm

[35]. If tensioning is satisfactory, the tendon weave is completed and the skin closed.

If the surgeon is confident enough that both junctures can withstand the strain, early passive motion programs such as those of primary flexor tendon repair can be initiated. Tubiana recommended 10 days of immobilization in the relaxed position followed by passive mobilization of the digit with the wrist and MCP joints immobilized by a dorsal splint. However, others prefer to immobilize the digit for 3–4 weeks before movement programs are started [11]. Immobilization should keep the wrist midway between neutral and full flexion, the MCP joints in 60–70° of flexion and the interphalangeal joints extended. Full extension should be prevented for several weeks after the start of mobilization [11].

Two-Stage Tendon Grafting

Joint contractures, extensive damage of the pulley system or scarring of the flexor tendon sheath preclude one-stage reconstructions. A two-stage procedure is a very elegant, but challenging method to restore functional digital ROM. At the first stage an optimal situation for the future tendon graft is prepared. This can include joint contracture release, pulley reconstruction and the preparation of a new flexor tendon bed by creation of a pseudosheath.

Stage One

At the first stage, the flexor tendon sheath is completely exposed as described for one-stage tendon grafting. Contracted joints are released. All scarred tissue is meticulously removed. Remnants of the flexor tendons often are adhered to the sheath and should be excised as far proximally as needed. The FDP tendon is excised as far proximally as the palm or distal forearm depending on the length of the future graft. The remnants of the FDS tendon are excised as far proximally to prevent adhesion to the future tendon graft.

A thorough inspection of the quality of the remainder of the flexor tendon sheath and pulleys follows. Dysfunctional pulleys are identified and the essential pulleys are reconstructed as described later in this chapter. At this stage, the silicone implant can be introduced. For men a 4–5 mm implant is usually chosen, whereas women and children often require a smaller, 3–4 mm implant. The implant is secured distally by connecting it to the FDP stump or to the base of the distal phalanx. It is then threaded proximally underneath the (reconstructed) pulleys into the palm or between the FDS and FDP tendons in distal forearm. The proximal end is placed close to the future motor tendon and left unattached Fig. 4.5).

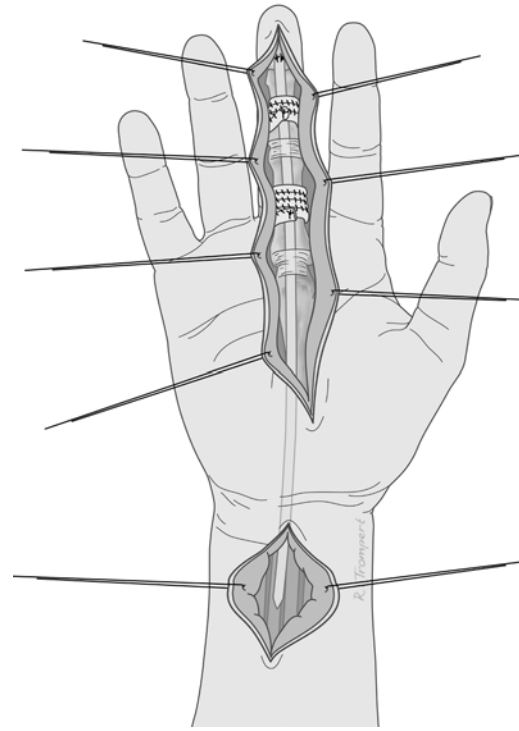

Fig. 4.5 The silicone implant is secured distally and threaded proximally through the (reconstructed) pulleys into the distal forearm. The proximal end is left unattached

The silicone rod should glide without restrictions. If it buckles with passive flexion of the digit, the source of the obstruction should be identified and adjusted (*e.g.* a reconstructed pulley that is too tight).

Then, the skin can be closed and the hand is covered in a bulky compressive dressing with the wrist and MCP joints in slight flexion.

Passive guided motion exercises are started 7–10 days postoperatively. Hand therapy between stages one and two is essential to prevent joint

contractures and to keep the silicone rod gliding in the new tendon sheath.

Stage Two

The second stage is scheduled after sufficient time for the soft tissues to heal and the pseudosheath to form. A 3 month interval between stages is recommended. Ideally, the second stage should only function to harvest, place and tension the final tendon graft in the prepared digit.

For tip to palm grafting, the palmaris longus tendon is a popular choice. If longer grafts are needed, or the palmaris longus is not available, the plantaris tendon or long toe extensors are effective alternatives.

The pseudosheath and the volar scars should be left undisturbed as much as possible. The silicone rod is approached through minimal incisions at the fingertip and the site of the proximal juncture. Distally, the silicone rod is released from its insertion. The tendon graft can then be attached securely to the distal silicone rod and very gently pulled proximally trough the pseudosheath into the proximal wound (Fig. 4.6). The rod is detached and discarded. Again, the distal juncture is fixed before the proximal juncture to the motor.

The original muscle to the excised tendon is the motor of choice. However, if passive excursion of the motor is less than 2–3 cm upon traction, it is advised to use an alternative. An adjacent FDP motor is a good second choice. If multiple tendons are reconstructed, or if the FDP is unavailable, the FDS can also be chosen as a motor to the tendon graft [11].

Tension to the graft is set as described above for one-stage tendon grafting. Also, the postoperative hand therapy program is similar.

Paneva-Holevich

An alternative to free tendon grafting is the pedicled tendon graft described by Paneva-Holevich [47]. A tendon loop is created by connecting the cut ends of the FDP and FDS tendons in the palm in an end-to-end fashion in the first stage of reconstruction after placing the silicone rod as for a conventional graft reconstruction. At the second stage, the FDS tendon is transected at the musculotendinous junction in the distal forearm. By placing distal traction on the FDS in the palm, its proximal end can be pulled into the palmar wound and threaded distally through the flexor tendon sheath to the distal phalanx. The advantages are the lack of donor site morbidity and the fact that after stage two, only the distal juncture needs healing since the proximal end-to-end juncture has healed from the first stage.

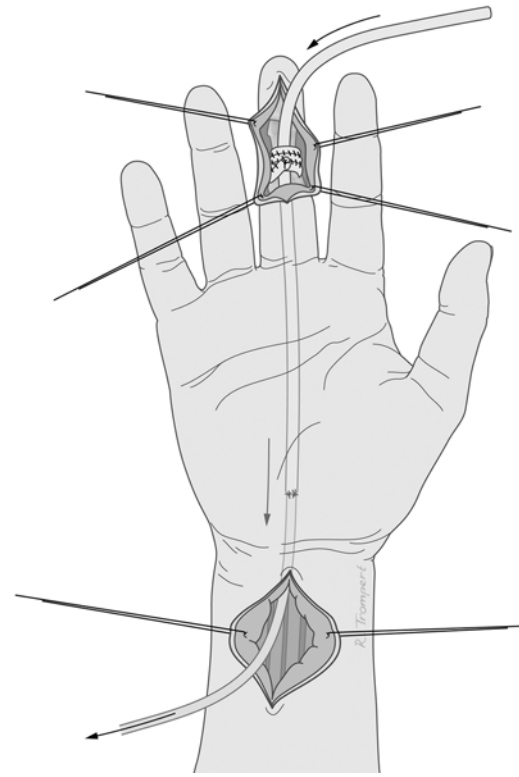

Fig. 4.6 The tendon graft attached to the distal silicone rod is very gently pulled proximally trough the pseudosheath into the proximal wound

Pulley Reconstruction

A functional, intact pulley system effectively transforms longitudinal tendon excursion into angular motion of the MCP and interphalangeal joints [48]. Disruption of the pulley system causes reduced efficacy of tendon excursions, resulting in reduced ROM and power grip. Intact A2 and A4 pulleys are the minimum necessary for near normal function [49–51]. Addition of an intact A3 pulley improves function further [35].

Damaged pulleys are primarily repaired if possible [52]. But as often is the case in flexor tendon reconstruction candidates, the possibility of pulley repair has passed and reconstruction is indicated. At least the A2 and A4 pulleys need to be reconstructed. In addition, the A3 pulley can be reconstructed if it seems suitable.

Location and width of the pulleys should be reconstructed as close to normal as possible for maximum efficacy. Also, careful tensioning of the pulleys and sufficient strength to allow for early mobilization are required [35, 52].

Most popular techniques for pulley reconstruction are the Okutsu triple loop, the Kleinert/Weilby tendon weave, the Lister extensor retinaculum wrap and the Karev belt-loop techniques. Each of these has their own advantages and disadvantages. What they do have in common is the use of autologous tissue only. Some studies suggest using synthetic materials, but this seems only rarely indicated.

The Okutsu triple loop technique uses a tendon graft (*e.g.* a resected FDP or FDS tendon) to encircle the proximal or middle phalanx for reconstruction of the A2 or A4 pulleys respectively [53]. The use of three loops is recommended for maximal strength and efficacy. Originally, the loops around the proximal phalanx were placed under the extensor apparatus dorsally and those around the middle phalanx over the extensor apparatus (Fig. 4.7) Others however, recommended the loops to always be placed deep to the extensor system [19]. The triple loop technique has been proven strong and effective [54].

Lister advised to reconstruct pulley using a strip of extensor retinaculum to wrap around the phalanx [55]. It provides excellent tendon gliding, but is less strong and requires disruption of the extensor retinaculum [52, 56].

The Kleinert/Weilby method uses remnants of the pulleys attached to the phalanges to weave a tendon graft through [57] (Fig. 4.8). Tensioning is considered to be easier with this technique, preventing issues with reconstructions that are too tight (causing synovitis and friction) or too loose (causing bowstringing). It does however, seem to be less strong [52].

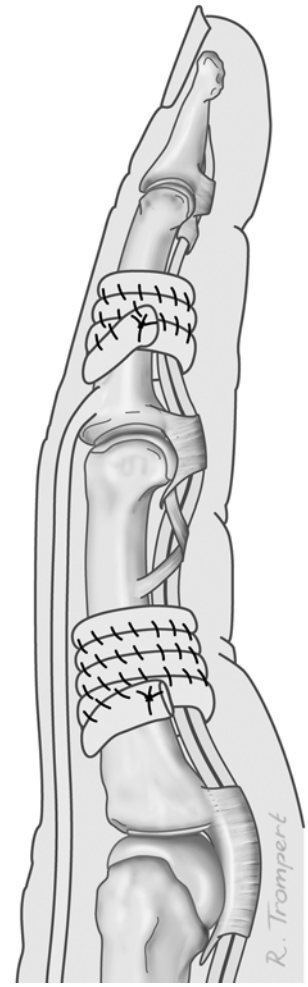

Fig. 4.7 The Okutsu triple loop technique for pulley reconstruction

Finally the Karev belt-loop is worth mentioning. The volar plate at the PIP joint is transversely incised proximally and distally and lifted volarly [58]. The resultant tunnel can be passed through by a tendon graft or repair. The resultant pulley is strong, but is unfortunately located at the A3 position and may be too tight [52].

Outcome

Unfortunately, not many reports on the results of one-stage grafting are available. Künzle et al. reported excellent results in 20 %, good results in

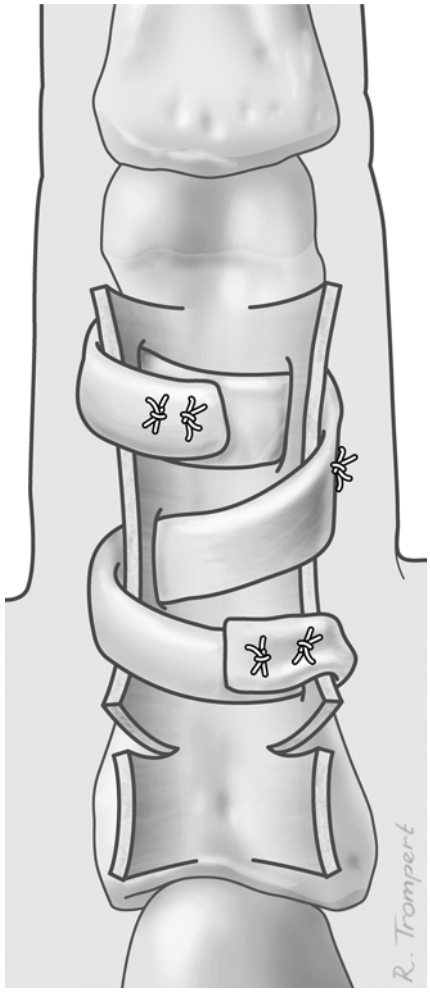

Fig. 4.8 The Kleinert/Weilby method of pulley reconstruction. A tendon graft is weaved through the remainders of the pulleys

36 %, fair results in 32 % and poor results in 12 % of their 25 cases [59].

Despite the notorious reputation of two-stage flexor tendon reconstruction in zone II, results of various large patient series published over the past decades show reasonable outcomes in the majority of their cases.

LaSalle et al. reported excellent and good results in 16 and 23 % of their 43 reconstructions [60]. In a larger series of 130 fingers published by Amadio et al., 54 % had good or excellent results [61] in reconstructions of zone I to V injuries. Coyle et al. achieved good and excellent results in 24 of 35 patients [62].

An average increase of 74° of total active motion and increased power from 20 to 79 % of normal was reported in a series of 150 fingers, 81 % of which were zone II injuries [63]. In another study of 33 fingers and 10 thumbs, the average time away from work was 44 and 101 days after the first and second stage, respectively [64]. In a recent retrospective analysis of 61 patients (106 fingers), good to excellent results were obtained in 84 %, fair in 12 %, and poor in 4 % of patients [65].

The Paneva-Holevich technique of pedicled tendon grafting combined with placement of a silicone rod at the first procedure resulted in good and excellent results in 73–82 % of the cases, depending on the used evaluation scale [66].

Most of these reports conclude that for the unfavorable cases of flexor tendon injury in zone II with poor prognoses, two-stage tendon reconstruction is a most useful therapeutic option.

Complications

Tendon adhesions are the most frequent complication of flexor tendon reconstruction. In fact, tenolysis is sometimes referred to as the "third stage" of tendon reconstruction [12]. Tenolysis rates of 7–47 % have been reported after two-stage tendon reconstructions [12, 60, 61, 67].

Other complications associated with two-stage tendon repair are infection of the implant, rupture of the tendon graft or junctures, migration of the rod, flexion contractures, reflex sympathetic dystrophy and problems associated with tensioning of the graft (quadriga or lumbrical plus) [63, 64].

In many cases, these complications require surgical intervention. In a series of 43 patients, Finsen reported 26 additional surgeries to be required after stage two in 18 of the 43 fingers or thumbs [64].

Flexor Tendon Reconstruction of Zone III to V Injuries

Presentation

As in zone I or II injuries, delay in presentation, failed primary repair or extensive associated soft

tissue injuries present the need for tendon reconstruction in zones III to V. Lacerations or crush injuries to the palm, carpal tunnel or distal forearm are frequently associated with neurovascular damage, contributing to functional impairment.

Non-traumatic, closed flexor tendon rupture can also present an indication for tendon reconstruction. Flexor tendons ruptures caused by attrition to bony prominences associated with carpal disorders (*e.g.* Kienböck disease), malunited distal radius fractures, a hook of hamate fracture or attrition to volar locking plates on the distal radius have been described [68–71]. In these cases often a segment of tendon substance has been damaged, which precludes primary repair.

Treatment

Taras and Kaufmann describe that reconstruction of flexor tendons in zones III to V can be done by placement of an interposition graft, transfer of an FDS tendon or by end-to-side FDP tenorrhaphy [19].

A tendon interposition or "bridging graft" can be placed in isolated defects of the FDP or FDS tendon. If both tendons are involved, usually only the FDP is reconstructed using the FDS remnants for grafting. Bridging grafts can vary in length from only few centimeters to fill a tendinous gap, to the length between the palm and the musculotendinous junction in the distal forearm [72].

Ample exposure is advised, using curved incisions extending from proximal to distal uninjured areas. This also facilitates the identification of nearby neurovascular structures. All affected tendons and surrounding scar tissue are excised. If damaged tendon resides in the flexor tendon sheath distally, the procedure is converted to a zone II tendon reconstruction.

After careful debridement, the gap that needs to be bridged can be measured. Suitable remnants of the FDS tendon or the palmaris longus are the grafts of choice. For a gap of 2 cm or less, sutures can be threaded longitudinally through the graft with Bunnell crisscross sutures placed in the tendon proximally and distally of the graft [72]. Individual tenorrhaphy sutures should be placed at the proximal and distal junctures if the graft is longer than 2 cm. Tensioning can be challenging when using interposition grafts.

Alternatively, an adjacent intact FDS tendon can be sacrificed to construct an end-to-end juncture to the distal segment of the injured tendon [19, 73]. If the juncture is to be placed in zone III, the FDS tendon should be routed dorsally of the neurovascular bundle. In zone IV, it should be passed under the median nerve.

A less invasive technique is the end-to-side juncture of the distal segment of the injured tendon to an adjacent, intact FDP. This method seems most suitable for zone V injuries, but favorable outcomes have also been published for tendon ruptures due to hook of hamate fractures [19, 74].

Passive ROM exercises are allowed from the first postoperative visit. Active ROM can be initiated at 2 weeks after surgery. After 4–5 weeks, resisted exercises can be started.

Outcome

Flexor tendon reconstructions in zones III to V have more favorable outcomes than those in zone I or II. Proximal to the flexor tendon sheath adhesion formation is less likely, and there is more space available for tendon junctures. Published reports of results however, are sparse.

Bridging grafts resulted in satisfactory function in 28 of 37 fingers in a series of Stark et al. [72]. FDS to FDP transfers resulted digital ROM greater than 180° in 10 out of 16 cases in a study published by Scheider et al. [73]. The end-to-side FDP junctures gave satisfactory functional results in a small series of Milek et al. [74].

Complications

Adhesion formation is less likely to occur outside the flexor tendon sheath. But zone III to V reconstructions are not devoid of problems associated with adhesions [73]. Also, ruptures of tendon junctures, problems with tensioning (*e.g.* loss of extension) and the need for additional surgical procedures have been reported [72, 73].

Reconstruction of Thumb Flexor Tendon Injuries

Presentation

The thumb is considered separately because of its unique anatomy. The flexor pollicis longus is the only tendon passing through the thumb flexor sheath. Anatomy of the flexor sheath is also distinctively different from its counterpart in the fingers. Of the three pulleys in the thumb flexor sheath, the oblique pulley has the most functional value. This should be considered if pulley reconstruction is required.

The majority of FPL injuries are caused by lacerations in zone TI or TII. Most of these injuries are eligible for primary repair up to 6 weeks after injury. But similar to the fingers, delay, scarring and extensive injury to multiple surrounding tissues or infectious complications may precipitate the need for one- or two- stage tendon grafting. In other cases, segmental tendon damage may require reconstruction. For example, an FPL tendon ruptures due to attrition against a volar plate on the distal radius, or against bony spurs in the carpal tunnel in rheumatoid arthritis patients (Mannerfelt lesion) may not be eligible for primary repair [75].

Selection of patients eligible for reconstruction of the FPL is based on the same principles as those for patients with flexor tendon injuries to the fingers. Important is the presence of good passive ROM of the interphalangeal joint.

Treatment

Alternative treatments to FPL reconstruction should always be considered. Fusion or tenodesis of the thumb interphalangeal joint often merits good functional results, but does reduce power grip.

Surgical techniques and postoperative hand therapy programs are similar to those described for the fingers [35]. A one-stage tendon graft between the distal tendon stump and the FPL motor is the treatment of choice if the pulley system and tendon sheath are functional. The palmaris longus is a suitable graft [35], but the plantaris or a strip of the flexor carpi radialis tendon have also been used [76]. Placement of the proximal juncture in the carpal tunnel should be avoided [35]. If there is extensive scarring or the oblique pulley needs to be reconstructed, a two-stage tendon reconstruction can be considered. If the FPL motor has contracted beyond function, an FDS tendon transfer from the fourth finger to the thumb can be used to replace the motor and the tendon [77, 78].

When tensioning the reconstruction, the wrist is held straight, the first metacarpal at 30° of anteposition and abduction, and the MCP and interphalangeal joints at 15 and 45° of flexion respectively [12, 35].

Outcome

Good functional outcome has been described for one-stage tendon grafting of the FPL [79]. Also, two-stage reconstruction has gained favorable results. In a series of 16 patients with two-stage reconstructions adequate function was restored in 75 % [76].

In a smaller series Weinstein et al. describes results of 5 Boyes grade 2–5 thumbs. Functional results were fair in two and poor in one thumb requiring pulley reconstruction. Two thumbs without pulley reconstruction had good and fair functional outcome [80].

Transfer of the FDS of the fourth finger had good results in 12 of 14 patients in a study by Schneider et al. [78]. Good postoperative mobility of the thumb interphalangeal joint was obtained after one- and two-stage FDS transfers described by Posner [77]. In the same study, mobility of the donor ring finger was unimpeded in all cases.

Complications

Complications of FPL reconstruction include the need for tenolysis or failures of the reconstruction due to tendon rupture. Also, complications associated with the silicone rod such as implant

migration or infection are conceivable. Sacrificing the FDS tendon for transfer can cause donor finger morbidity such as swan-neck deformity or insufficient finger flexion [81].

Flexor Tendon Reconstruction in Children

General principles and indications of flexor tendon reconstruction also apply to the pediatric patient. However, especially in young children, additional challenges may arise with all facets of care from diagnosis, imaging, consent, surgical technique, pain management to postoperative care.

Closed and open tendon injuries are often diagnosed late in children, resulting in delayed presentations. In injuries such as a jersey finger (closed FDP avulsion) or even in case of a laceration injury, the tendon injury can be missed on the initial presentation. Particularly if the patient is young, uncooperative and anxious, thorough clinical history taking and examination pose a challenge.

Observations of the parents on use and limitations of the child's hand and fingers are very valuable when obtaining a clinical history. Physical examination should evaluate the same aspects as in the adult population, including careful observation, location of scars, position and ROM of joints, including wrist tenodesis. Compression of the muscle bellies in the forearm can be helpful to assess passive digital flexion and thus tendon integrity in the pediatric patient. Ultrasound imaging may be a valuable addition in the diagnostic process.

Principles of operative technique of single and two stage tendon reconstruction are the same as in the adult patient. Dealing with smaller anatomy can present an extra challenge. Appropriately fine instrumentation and silicone rod size selection are warranted. One should be aware of physeal plates in the growing patient when anchoring the distal FDP insertion into the distal phalanx. Bone anchors or trans-osseous pull out sutures can damage the physeal plate [82]. Therefore, passing pull out sutures around the bone is preferred instead.

Postoperative management of children with flexor tendon reconstructions remains a topic of debate. Generally, postoperative immobilization of 3–4 weeks is considered safer than early active motion protocols in (young) children [61]. Pediatric patients are less likely to have long term tendon adhesions requiring tenolysis after flexor tendon surgery. Also, immobilization reduces the risk of morbidity involved with tendon ruptures. Some reports however, demonstrate good results with early mobilization protocols with strict therapist supervision [82].

Tendon Graft Donors

For flexor tendon reconstruction, most popular donor grafts are the palmaris longus and plantaris tendons. But other tendons are available. Each donor tendon has its own advantages and disadvantages making them more or less suitable for specific reconstructions.

The palmaris longus tendon has about 10–16 cm of usable length, making it suitable for fingertip to palm grafting [12, 83]. It is approximately 3–5 mm wide and 1–2 mm thick [12]. It is situated conveniently close to the operative site, but absent in approximately 15–25 % of people [19]. It is harvested using a tendon stripper trough a small, transverse incision at the wrist crease.

The plantaris tendon has 20–35 cm of usable length and has an average diameter of about 2–3.5 mm) [12, 83–85]. This makes it the preferred tendon for fingertip to distal forearm grafting. It is present in 80–97 % of patients [84, 86]. Its presence can be determined by CT scan preoperatively [12]. The plantaris is harvested with a tendon stripper through a 5 cm longitudinal incision anterior to the medial aspect of the Achilles tendon [19].

The extensor digitorum longus tendon to the second to fourth toe averages 35 cm in length and about 2–2.5 mm in diameter [85]. These extensors are always present, but like the plantaris requires surgery to an additional extremity. One or more of the tendons can be harvested with a tendon stripper through a transverse incision over the dorsum of the foot. End-to-side tenorrhaphy of the distal

remainder to an intact adjacent tendon restores extensor function to the donor toe.

The extensor digiti minimi and extensor indices proprius tendons are about 16 and 13 cm long respectively with an average diameter of 3 mm [83, 85]. The proprius tendons are identified ulnar to the extensor digitorum communis tendons of the same finger through a transverse incision over the MCP joint. They are transected and pulled out through a second incision proximal to the wrist. These tendons are close to the operative field, but their use can result in an extension lag in the MCP joints of their respective digits.

Conclusions

Flexor tendon reconstruction can be a very rewarding challenge in hand surgery practice. Careful diagnosis, patient selection and reconstructive planning are of paramount importance to outcome.

One-stage tendon reconstruction is indicated when primary end-to-end tendon repair is impossible. There should be no significant scarring of the tendon bed. Skin cover and the pulley system should be adequate and no additional procedures on bone or joints should be required. In these cases the tendon defect can be replaced in a single procedure by a tendon graft.

A two-stage procedure is needed if one-stage reconstruction cannot be done due to scarring of the tendon sheath, suboptimal state of the joints or the need for pulley reconstruction. In the first stage, pulleys are reconstructed and capsulectomy of stiff joints can also be performed if required. A silicone rod is implanted under the native or reconstructed pulley system. During the following months a pseudosheath forms around the silicone rod. The second stage is planned if scars are matured and a sufficient gliding sheath has formed, usually 3 months after the first stage. The silicone rod is then replaced by a tendon graft that is placed within the newly formed pseudosheath.

Before embarking on a reconstructive path, time should be invested in thorough preoperative patient counseling and patient selection. Generally, results are good but one- and two-stage procedures are far from devoid of complications. These complications can be minimized by careful surgical technique using ample exposure of the operative field, meticulous tissue handling and close cooperation with an experienced hand therapist for post-operative rehabilitation.

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