Injuries to the Tendons

18

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18.1 Introduction

Tendon surgery only started in the early 16th century when one differentiated between nerves and tendons as, e.g., depicted by Leonardo da Vinci, Andreas Vesalius, and Rembrandt. The breakthrough, however, was only achieved in the 20th century with the advent of improved suturing material. Horsehair, linen, cotton, and silk threads used until then only poorly glided in the tendon sheath, such that as late as 1916 it was recommended to amputate an injured finger so as not to impair the finger or indeed the whole hand. Claude Verdan was the first to demonstrate a primary suture of a severed flexor tendon in 1961. Six years later Harold Kleinert was the first to successfully rejoin tendons in zone 2. In 1973, he furthermore recommended dynamic splinting of the finger generally leading to its full functional restitution. Later the secondary suture of the flexor tendon was abandoned and the delayed primary suture was introduced by Buck-Gramcko et al. (1983).

18.2 Flexor Tendons

18.2.1 Particulars of the Functional Anatomy

Tendon sheaths can be found wherever pressure is exerted on the tendons, such as on the palmar side of fingers and under the retinaculum flexorum and

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extensorum. On the fingers, the tendon sheath reaches over three joints and is held in place by four pulleys ligaments (A1–A4) and by three cruciate ligaments (C1–C3). Damage to annular ligaments, notably A2 (over the base phalanx) and A4 (over the middle phalanx) leads to the "bow-string phenomenon," i.e., a protrusion of the tendon resulting in a reduced glide range and a reduced bending at the interphalangeal (IP) joint. The tendon sheath consists of the epitenon, which lies directly adjacent to the tendon and lines the tendon sheath canal and is also responsible for the blood supply. Vascularization within the tendon sheath is furthermore achieved to a large extent by the vincula tendinea, soft tissue sail-like structures containing arteries and veins, and therefore have to be handled with great caution. If they are destroyed by the injury, the tendons snap back into the palm. If, however, the vincula are preserved, the proximal tendon stumps can be found in the tendon sheath canal. Resection of the superficial tendons to enable the lower ones to glide more easily is considered an outdated method today (Fig. 18.1).

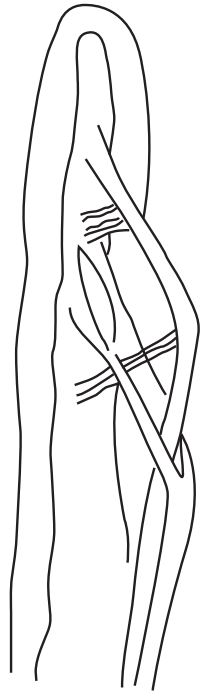

Fig. 18.1 Position of the vincula tendinea

18.2.2 Division into Zones

As with adults, the infantile hand is divided into the same injury zones that determine the required therapy. The most common scheme applied is the one by Verdan and Michon (Fig. 18.2). Bunnell (1944) referred to zone 2 as a "no-man's-land." Due to the tightness in children's' hands in this region adhesion can easily occur.

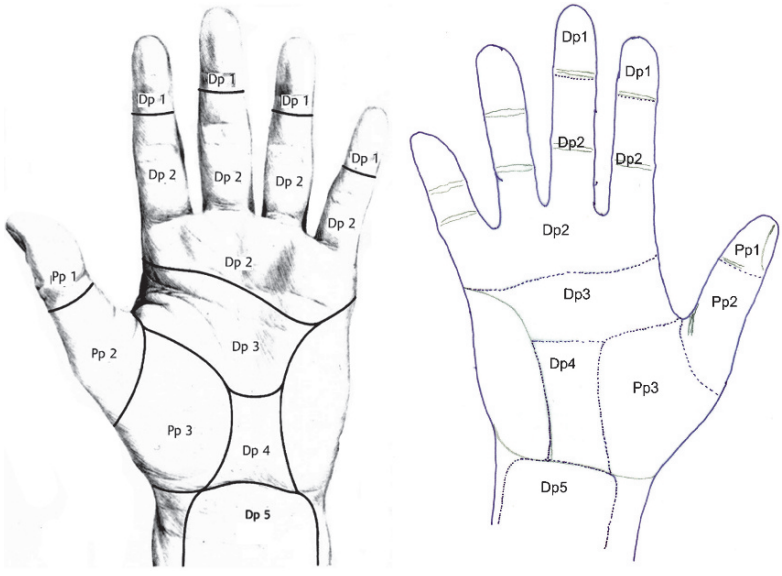

Fig. 18.2 Zone division according to Verdan (left) and Pechlaner et al. (right)

18.2.3 Evaluation

In small children, the function of the tendon cannot usually be tested such that the location of the injury and the position of the hand at rest are often the only clinical signs for a severed tendon. Cut injuries in toddlers are often caused by a fall while carrying a glass or falling into a glass pane, whereas older children hurt themselves while playing with knives.

18.2.4 Inspection of the Hand

If the end phalanx is extended, but not the base phalanx, the tendon of the m. flexor digitorum profundus (or of the flexor pollicis longus) is severed (Fig. 18.3).

Fig. 18.3 Transsection of the tendon of the m. flexor digitorum profundus

Fig. 18.4 Transsection of the tendon of the m. flexor digitorum superficialis

If the finger is only slightly bent, the tendon of the m. flexor digitorum superficialis is severed (Fig. 18.4).

If the finger is extended at the central and distal joints, both tendons are severed; this leads to a bending in the base joint caused by the mm. interossei and mm. lumbricales (Fig. 18.5).

Even if a flexor tendon is only partly transected, it must be surgically repaired (sutured) in order to pre-empt secondary ruptures.

18.2.5 Informative Dialogue

Before the operation, the child should be informed about the necessity of post-operative exercise therapy either by the doctor or by his/her parents. Most patients find it hard to believe that a 1 cm long injury can have such consequences and requires dedicated finger exercises for several months. But beyond subtle surgical techniques, only consistent training can ensure full recovery.

18.2.6 Surgical Management

A *primary* flexor tendon suture is one that is applied within 24 h; a *delayed primary* suture is one that is

Fig. 18.5 Transsection of both tendons

done within 2 weeks, or after the skin wound has healed. After the injury has healed, one refers to the flexor tendon suture as *secondary*, whereas operations in weeks 3–6 (*early secondary*) pose a high risk of complications. There is no rigid space of time for performing secondary sutures, but the chances for a successful reconnection of the tendon stumps—without an intermediary transplant—diminishes with time. For the operation under anaesthesia, a tourniquet and surgical loops and/or microscope are required. Duration of tourniquet inflation must not exceed 2 h. Beside general anaesthesia, a hand block or plexus anaesthesia is applied in order to keep the child free from pain during the first post-operative day which also helps with the occupational therapy.

18.2.7 Incision

In order to assess the extent and severity of the injury, the wound usually has to be opened on both sides to avoid any buttonhole surgery. To this end, one applies a Bruner incision (zigzag widening cut) as well as arc- and L-shaped palmar incisions. Longitudinal cuts on the finger should be avoided in children because they can lead to stringent scar formation and growth disturbances such as axial deviations. The skin flaps produced by the Bruner incision must not be too small to avoid problems with the blood circulation.

18.2.8 Suturing Technique

The more delicate the tendon, the more carefully the operation must be carried out: for example, the tendons must never be held with tweezers on the surface. A *Kirchmayr–Zechner* suture has turned out to be tear proof for children (Fig. 18.6). For the core suture, one uses a non-absorbable suture with a straight needle, doubly re-enforced. For the circular epitendinal adoption suture, an absorbable thread of gauge metric 0′7 (6-0) should be used in order to prevent bulging of the tendon stumps. The same suture can be used for the tendon sheath.

18.2.9 The Kirchmayr–Zechner Suture

After fetching the stumps, a core suture is applied for which the thread is pierced four times. Moreover, one

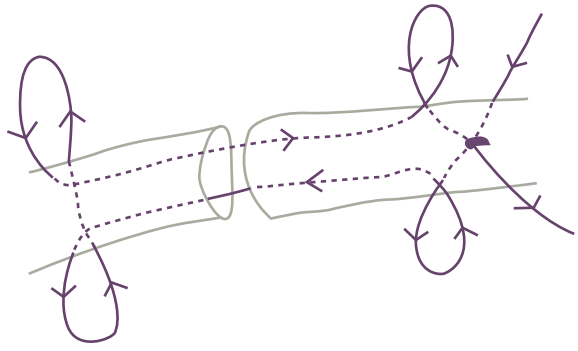

Fig. 18.6 Kirchmayr–Zechner suture

should also try to countersink the knots in children (according to Zechner) which may not always be possible due to the tiny diameters of the tendons. The circular adaptation suture should be a continuously overlapping helix-type suture. One has to pay attention to the pulleys ligaments A2 and A4; if they were to be damaged, they would have to be reconstructed so as to avoid the "bow-string phenomenon." Severed tendons often coincide with severed blood vessels and nerve bundles. If at all possible, not only the finger nerves, but also the arteries should be reconstructed. With only one finger artery, there is often a cold sensation of the finger.

18.2.10 Post-Operative Therapy

At the end of the operation, a forearm plaster or cast longuette is applied. For smaller children, one has to use an upper-arm longuette to ensure they do not become loose and are not stripped off at night. The injured finger is immobilized using a vessel loop, or with an extended rubber string attached to the fingernail with a suitable (first curing) glue. For children, the plaster cast longuette does not need to be in the original 40° position in the metacarpo-phalangeal joint or in the 50–60° position in the wrist joint, because children tend to maintain this extreme bent position after the removal of the plaster, unless they are constantly reminded otherwise. This effect does not occur if the wrist is bent by 5–10°. Furthermore, the longuette only extends to the metacarpo-phalangeal joint which greatly facilitates occupational exercising (Fig. 18.7). Occupational treatment commences on the first post-operative day; only in cases of extensive nerve repair one may begin a day later. The occupational therapist exercises five to six times a day in a playful atmosphere with the little patients and administration of a painkiller may often be helpful. These active and passive exercises are to be demonstrated to the parents so that they can be continued at home. In order not to risk losing the trust of the little patients, removal of the stitches is best done under general anaesthesia. After discharge, the children return two or three times a week for outpatient therapy and follow-ups. Using this modified bandage arrangement, the tendon itself and hence the suture is not under stress; this, of course, leads to synergistic relaxation of the flexor muscles. Adhesions which can occur at the injured area on the surface of the tendon and – in particular—in the tendon sheath can be pre-empted by daily multiple gliding movements to assure that the functioning of the tendon is not impaired. In children, the risk of adhesion is greater than in adults; on the other hand, secondary ruptures are more rare. Immobilization is limited to 5 weeks. Exercise therapy is sufficient if the PIP (proximal interphalangeal) joint is extended on the third post-operative day and if the finger can be fully extended within 10 days. Full recovery and mobility must be achieved within 3 months.

Fig. 18.7 Modified Kleinert plaster

18.2.11 Follow-Up Treatment

Outpatient checks in increasingly larger intervals are strongly recommended and should be maintained until the end of adolescence. This is necessary because the

injured area may not fully participate in a growth spurt; a resulting tendon shortening may require more occupational therapy.

18.3 Extensor Tendons

18.3.1 Functional Anatomy

The extensor tendons are more prone to injuries due to their location directly under the skin. The gliding ability of the extensor tendons is achieved by the paratenon, a loose soft tissue layer at the back of the hand and the distal forearm. In contrast to the flexor tendons, the extensor tendons change their shapes and their courses and consequently have to be attended differently. For this reason the extensor tendons are divided into zones (Fig. 18.8).

18.3.2 Diagnosis

One usually differentiates between open and closed (or subcutaneous) injuries of the extensor tendons; furthermore they may be fully or only partially ruptured. The latter injuries also have to be surgically repaired because poor nutrition and/or degeneration weakens the tendons and makes them prone to complete ruptures.

In adults and children, closed injuries above the distal interphalangeal joint are the most common tendon injuries and most frequently caused by impact with a solid object. Here the straight finger is compressed in its length and pressed in the palmar direction. This injury is also known as hammer-, dropping-, mallet-, or baseball-finger.

Classification of subcutaneous extensor tendon injuries (Fig. 18.9).

1. Rupture of the extensor aponeurosis (from the basis of the end phalanx) (Fig. 18.9a):

   The aponeurosis is avulsed from the Landmeer ligaments, the distal interphalangeal (DIP) joint is tilted by about 30°. The distal phalanx can no longer actively be straightened; clinically there is a slight swelling and redness combined with a moderate locally confined pressure pain.
2. Rupture of the extensor aponeurosis (proximal to the Landmeer ligaments) (Fig. 18.9b):

   This injury leads to a bending of the DIP joint by about 45°. This injury is also named “mallet-finger”. If left untreated it leads to a “swan neck deformity”.
3. Avulsion of the extensor aponeurosis together with a small dorsal bony fragment at the base of the distal phalanx (Fig. 18.9c):

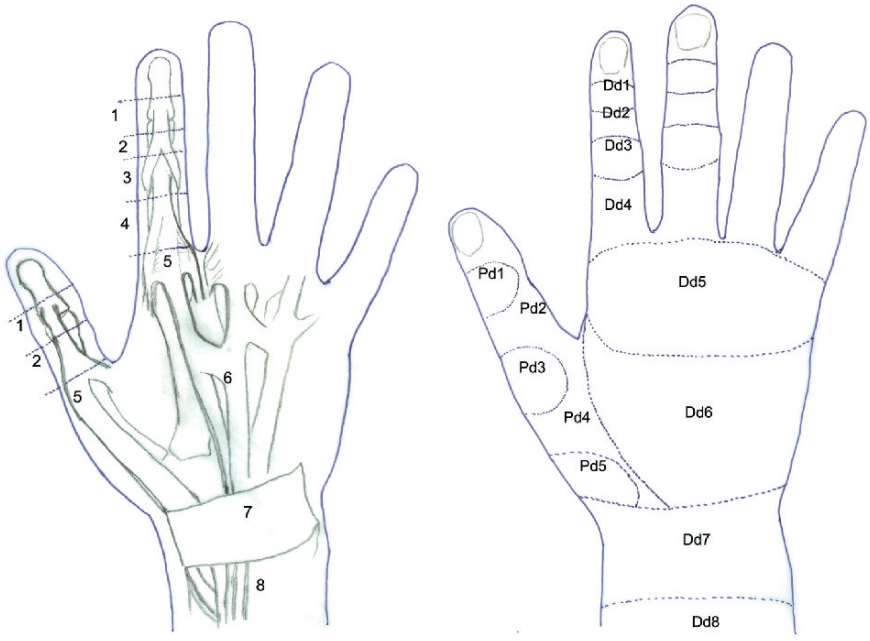

Fig. 18.8 Injury zones according to Verdan (left) and Pechlaner et al. (right)

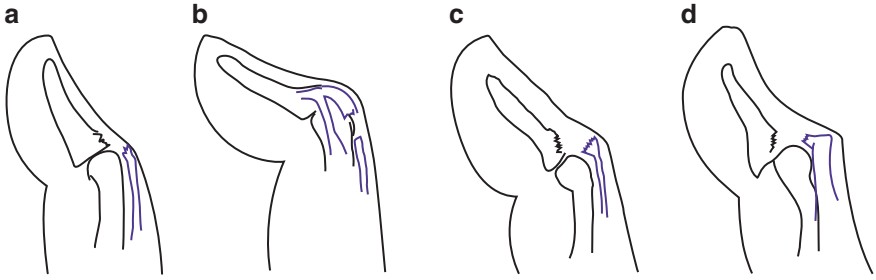

Fig. 18.9 Classification of subcutaneous extensor tendon lesions of zone 1

Here the DIP joint is bent by ~ 30°. Clinically there is a pronounced pressure pain. This chisel-(Busch-) fracture occurs when the end phalanx tends to give way in the dorsal direction.

4. Palmary luxation fracture with shearing of larger dorsal bony fragments from the base of the distal phalanx (Fig. 18.9d):

   The DIP joint is unstable; it is only slightly bent and the end phalanx appears shortened and swollen (hyperextension injury).

18.3.3 History

In children, cuts and stab wounds can affect the extensor tendons. In ballgames or jamming injuries subcutaneous ruptures occur at the end phalanx, and are less frequent at the middle phalanx. Injuries at the proximal phalanx are always ominous for bite injuries; notably human bites – not uncommon in small children—are prone to severe purulent infections.

18.3.4 Physical Examination

Monitoring of the hand functions and the type of the injury can on occasions provide information pertaining to the diagnosis. The indication for a surgical inspection under general anaesthesia has to be generously applied particularly in infants and young and timid children.

18.3.5 Management

As in the case of injuries of the flexor tendon, suspected extensor tendon injuries in children have to be inspected under full anaesthesia, using a tourniquet and surgical loops and/or a microscope. The pressure of the tourniquet sleeve for children is between 180 and 230 mm Hg and the maximum duration of inflation must not exceed 2 h. If longer tourniquet intervals are required, a 20 min spell of blood circulation permits another 1 h of tourniquet use. Alternatively, one can apply "relative" bloodlessness, i.e., only the forearm is unwrapped and thus the residual blood facilitates to differentiate between nerves and blood vessels.

18.3.5.1 Injuries in zone 1 (at the distal interphalangeal joint)

Open Injuries

In children, open injuries need to be attended urgently.

ad a. Here the wound is widened in a zigzag manner and the joint stabilized in not more than 10° hyperextension by a K-wire (gauge 0.6–1 mm). This is to be applied obliquely to reduce the risk of infection. A manual drill or—for older children—an electric drill with low speed (to avoid overheating) is strongly recommended. Multiple trial drillings should be avoided so as not to damage the cartilage. The wire is bent above the skin level and can thus be removed without anaesthesia even in small children. The aponeurosis can thus be reconnected tension-free using interrupted 6/0 sutures. A Lengemann suture may sometimes be necessary for older children. Immobilization is achieved by means of a plaster-attached splint for 6 weeks which may be replaced after 4 weeks by a Stack splint. These splints must be cut to size for the children, but the PIP joint must also be immobilized. Although this is not desirable, it provides better stability for the small fingers. The splint may only be removed when drying the skin (to

Fig. 18.10 Stack's splint

prevent maceration) without moving the end phalanx (Fig. 18.10).

ad b. as above: the aponeurosis is restored by means of a mattress suture line, but special care should be taken because the tendon stumps may easily tear. Again, the hand is immobilized for 6 weeks using a plaster-attached finger splint.

ad c. and ad d. In case of a bony avulsion or luxation fracture, the primary concern must be to carefully reposition the broken parts so that no unevenness remains at the joint surface. Here too the distal phalanx is temporarily stabilized by a K-wire supplemented by a Lengemann suture.

Closed Injuries

A closed, ruptured extensor aponeurosis in zone 1 can primarily be treated non-operatively. Given regular outpatient follow-up check-ups, the outcome is about the same as with primary surgical repair. In children, a plaster-attached splint is recommended initially since it can be better adapted than prefabricated plastic splints. After 4 weeks, the plaster splint has to be replaced by a Stack splint for another 4 weeks. Inadequately reconstructed transsections of extensor tendons will lead to tendon callus formation at the tendon stumps, rendering the tendon too long to fully bend the distal interphalangeal joint. The tendon therefore has to be tightened or doubled. The same non-operative treatment is applied as with a bony avulsion of the extensor aponeurosis. After reducing the fragment into correct position, the quality of the reduction must be checked by X-ray. If the fragment cannot be reduced or held in that position, fixation must be accomplished surgically.

18.3.5.2 Injuries in zone 2 (at the middle phalanx)

As the extensor aponeurosis at the middle phalanx is laminar and thin, the suture may easily cut through the tendon tissue if tightened too hard. The injured distal phalanx can still actively be extended if only one of the side tracts remains. If both lateral ligaments are cut through, the distal phalanx can only partially be extended. If completely destroyed, a hammer-finger deformity develops. To check the extensor aponeurosis, the finger must be extended against a resistance applied at the level of the DIP joint. In case of doubt a surgical inspection is recommended.

Open Injuries

If only one side tract is affected, it must be restored using an absorbable suture (5/0 to 6/0). If both side tracts are affected they need to be adapted by some U-type sutures; in addition a temporary transfixation of the distal interphalangeal joint is required. Immobilization for 6 weeks in intrinsic-plus position is recommended (Fig. 18.11).

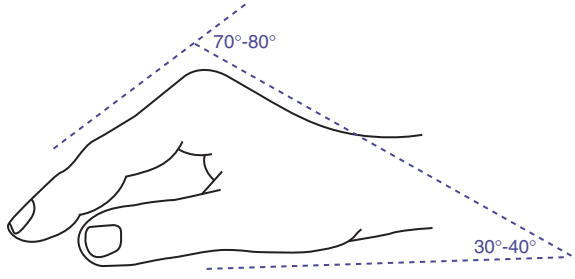

Fig. 18.11 Intrinsic-plus position

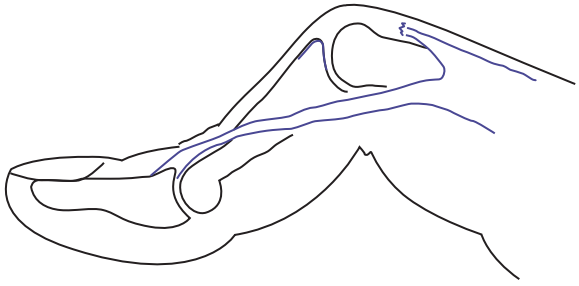

Fig. 18.12 Buttonhole deformity

Closed Injuries

In children closed injuries can also be treated non-operatively, but the injured finger must be immobilized for 8 weeks (3 or 4 weeks with a plaster-attached finger splint—in slight hyperextension of the DIP joint—and another 4 weeks with a Stack splint).

18.3.5.3 Injuries at zone 3 (at the proximal interphalangeal [PIP] joint)

The extensor aponeurosis at the PIP joint consists of a distal part of the tractus intermedius of the two side tracts of the musculi interossei and the musculus lumbricalis, as well as the fibres between the two. If the pars triangularis is affected, the PIP joint is bent. Tearing of the tractus intermedius is often overlooked as long as the side tracts and the ligamentum triangulare are intact. At the PIP joint, one finds a minor, pressure-sensitive spot and the joint cannot fully be extended. If left untreated the tractus intermedius retracts, the side reigns gradually slip down and the heads of the proximal phalanx protrudes as through a buttonhole (buttonhole deformity, boutonniere or, simply, buttonhole) between 10 and 14 days after the trauma (Fig. 18.12). In case of a full transsection of the extensor mechanism, the injured finger remains bent.

Open Injuries

In case of an injury directly above the PIP, a dorso–latero arch incision is used for surgical repair. After rinsing the joint thoroughly using sterile saline solution, the joint is closed using an absorbable suture (5/0 to 6/0 single-knot or U-sutures). A complete transsection of the tractus intermedius is treated similarly; conceivably, in older children an additional Lengemann suture may be necessary. Smaller defects of the tractus intermedius are repaired after detaching it from the side tracts. This is achieved by temporarily transpositioning the tractus intermedius in distal direction and re-inserting the side tracts. In addition a 5-week immobilization is always required. For injuries in adults, a buttonhole splint is used, but this is not available for children. For repair of larger extensor tendon defects, there are several tendon replacement techniques available with the dip-over graft plasty technique being the most established.

Closed Injuries

The same surgical procedure is applied for closed injuries as with open injuries. Provided the side tracts are not affected, a rupture of the pars medialis of the tractus intermedius can be treated conservatively. In this case, it is necessary to maintain activity of the finger while the middle phalanx is passively extended.

18.3.5.4 Injuries at zone 4 (at the proximal phalanx)

In this rather rare case of a full transsection of the complete extensor apparatus, bones are always also affected. If only the central part is concerned, its function is compensated by the side tracts.

Open Injuries

Even if there is no functional deficiency, the severed central section of the extensor apparatus should definitively be surgically repaired in order to improve the results (similar arguments apply to severed side tracts). A Lengemann suture—as applied in adults—is generally not required for children. The tendon sheath must be carefully reconstructed to prevent adhesions. A severed tendon of the m. extensor pollicis longus tendon in a thumb renders it impossible to fully extend the interphalangeal joint. The tendons are joined using an U-suture, possibly with an additional semicircular absorbable suture (6-0) for adequate adaptation of the tendon stumps.

Closed Injuries

Injuries in zone 4 are rather rare in children, but should be surgically treated to ensure full functional restoration; the surgical intervention is to be followed by immobilization for 4 weeks using a plaster-attached finger splint in intrinsic-plus position.

18.3.5.5 Injuries in zone 5 (at the metacarpo-phalangeal joint)

In this case, the extensor tendons and/or the extensor caps are severed. The affected finger cannot be extended in the metacarpo-phalangeal joint, but both the proximal interphalangeal and the distal interphalangeal joints can be extended due to the unaffected palmar muscles (drop finger). If the tendons of fingers 2 and 5 are affected, extension is still possible by activation of the corresponding tendons of the m. extensor indicis proprius and m. extensor digit minimi, respectively. The cap of the extensor tendon is most commonly injured on the radial side leading to a slippage of the tendon towards the ulna when attempting to flex the fingers; this leads to a "snapping" phenomenon when clenching one's fist. The restoration at the radial aspect of the index finger is very important to provide a two-finger grip.

Open Injuries

Open injuries need to be repaired immediately, particularly if the joint is opened. After generous rinsing the joint is closed by fine absorbable sutures. Completely cut-through tendons are reconnected by U-sutures using a non-resorbable thread and an additional circular running type suture for adaptation. The post-operative therapy includes a molded plaster cast finger splint for 4 weeks.

Closed Injuries

Closed injuries are treated in the same manner as open injuries. Untreated injuries lead to the formation of tendon callus above the metacarpal heads resulting in a reduced range of motion of the joint and this should therefore be removed.

18.3.5.6 Injuries in zone 6 (at the back of the hand)

Owing to the intertendineous connections, these injuries only lead to partial loss of extension at the metacarpo-phalangeal joint.

Open Injuries

In children, the very thin and flat tendons at the back of the hand can be repaired using U-type sutures or, as in flexor tendon surgery, by modified Kirchmayr sutures. The surgical treatment is followed by 4 weeks of immobilization by a palmar plaster longuette. The same procedure is applied for the tendons of the mm. extensor pollicis longus and brevis; the proximal stump may retract so much so that it can only be reached by a proximal additional incision.

Closed Injuries

Long extensor tendons of the thumb, as seen in adults—as a result of a radius fracture or a progressive-chronical polyarthritis, for example—practically never occur in children.

18.3.5.7 Injuries in zone 7 (wrist)

Due to the absence of a intertendineous connections, the proximal stumps of fully severed tendons slip far in a proximal direction, such that the affected finger can no longer be extended. On the other hand, adhesions occur more easily in the extensor sheath compartments of the wrist than at the at the distal forearm region.

Open Injuries

The flattened stumps of the extensor tendons of the long fingers should be adapted using U-type sutures; the rather more round tendons of the m. extensor carpi radialis and ulnaris, as well as the extensor pollicis longus allows to apply the flexor tendon surgery techniques for suturing. Post-operative treatment includes immobilization by a palmar plaster longuette for 3–4 weeks.

18.3.5.8 Injuries in zone 8 (distal forearm)

Severing of extensor tendons does not lead to a complete deficiency of the extensor function, but injury to the intertendineous connections may result in reduced strength.

Open Injuries

In this region, the tendon stumps are reconnected by U-sutures followed by 3–4 weeks of immobilization using a forearm-plaster cast longuette.

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