Traumatic Extensor Tendon Injuries to the Hand: Clinical Anatomy, Biomechanics, and Surgical Procedure Review

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Abstract

The extensor apparatus is a complex muscle-tendon system that requires integrity or optimal reconstruction to preserve hand function. Anatomical knowledge and the understanding of physiopathology of extensor tendons are essential for an accurate diagnosis of extensor tendon injuries (ETIs) of the hand and wrist, because these lesions are complex and commonly observed in clinical practice. A careful clinical history and assessment still remain the first step for the diagnosis, followed by US and MR to confirm the suspect of ETI or to investigate some doubtful conditions and rule out associate lesions. During last decades the evolution of surgical techniques and rehabilitative treatment protocol led to gradual improvement in clinical results of ETI treatment and surgical repair. Injury classification into anatomical zones and the evaluation of the characteristics of the lesions are considered key points to select the appropriate treatment for ETI. Both conservative and surgical management can be indicated in ETI, depending on the anatomical zone and on the characteristics of the injuries. As a general rule, an attempt of conservative treatment should be performed when the lesion is expected to have favorable result with nonoperative procedure. Many surgical techniques have been proposed over the time and with favorable results if the tendon injury is not underestimated and adequately treated. Despite recent research findings, a lack of evidence-based knowledge is still observed in surgical treatment and postoperative management of ETI. Further clinical and biomechanical investigations would be advisable to clarify this complex issue.

Keywords

- extensor tendon injuries
- hand and wrist
- surgical treatment
- tendon repair
- tendon reconstruction

Introduction

Extensor tendon injuries (ETIs) to the hand and forearm are frequently seen in clinical practice; nonetheless, these kinds of lesion are sometimes underestimated compared with those of flexor tendons. Extensor and flexor tendon systems contribute together with a complex arrangement to give a

precise balance of force and positioning of the fingers; therefore, an optimal repair and reconstruction of extensor tendon should always be attempted to avoid functional sequelae.¹ ETI and the mallet finger represent the 16.9% and the 9.3% of orthopedic soft tissue injuries, with an estimate incidence of 17.9 and 9.9 cases per 100,000 of population per year, respectively.²

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The old treatment protocol for ETI included static splinting and immobilization for a mean of 6 weeks, followed by a standard rehabilitation. In the last decades, biomechanical evidence urged on a surgical approach using strong and more effective suture methods.³⁻⁷ Because of this operative approach, surgical outcomes have significantly improved over the time in most cases.⁶⁻⁸

In this review we describe the current literature evidence on the physiopathology, diagnostic imaging, and treatment options of acute and chronic ETI, including conservative treatment and surgical procedures.

Clinical Anatomy

The extension of the hand and fingers is provided by a complex muscle-tendon system, which is used to be classified in an extrinsic and intrinsic apparatus cooperating to allow the whole range of movements of this specific district.^{9,10}

The extrinsic system is composed of musculotendinous units that arise from the lateral aspect of the elbow, radius, ulna, and interosseous membrane of the forearm. The muscular components can be divided into deep and superficial groups of layer. The deep group belongs to the abductor pollicis longus (APL), extensor pollicis brevis (EPB) and extensor pollicis longus (EPL), and extensor indicis proprius (EIP). The superficial group includes the extensor carpi radialis brevis (ECRB) and extensor carpi radialis longus (ECRL), extensor digitorum communis (EDC), extensor digiti minimi (EDM), and extensor carpi ulnaris (ECU). All these muscle are innervated by the motor branch of the radial nerve. When the tendons reach the dorsal aspect of the wrist, they pass through six well-delimited compartments. The first compartment includes the APL and EPB tendons. At this level a septation occurs in 20 to 60% of patients.¹¹ The second compartment contains the extensor carpi radialis longus radially and extensor carpi radialis brevis ulnarly, which inserts on the base of the second and third metacarpal bone, respectively. The EPL fills alone the third compartment and ends on the dorsal aspect of the base of the distal phalanx of the thumb, after passing around the ulnar side of the Lister's tubercle. The fourth compartment contains the EDC and extensor indicis proprius, which reach the finger exten-

sor apparatus as the EDM is situated in the fifth compartment over the distal radial-ulnar joint. Finally, the extensor carpi ulnaris runs through the sixth compartment and inserts on the base of the fifth metacarpal. The extensor tendons of the index, long, ring, and small fingers are interconnected by fibrous bands called juncturae tendinum proximally to the metacarpophalangeal joints. Anatomical variations regarding extensor tendons and juncturae have been well described in the literature and their knowledge may be very important during reconstructive and transfer procedures.^{12,13} The intrinsic system includes three palmar and four dorsal interossei and four lumbrical muscles. The interossei muscles originate from metacarpal bones and are all innervated by the ulnar nerve, whereas the lumbricals arise from the flexor digitorum profundus tendons and are of competence of the median and ulnar nerves. From the metacarpophalangeal joint to distal, the finger extensor apparatus becomes a more complex structure, in which the extrinsic and intrinsic systems intersect. Extrinsic tendons run over the metacarpophalangeal joints, then trifurcate in a central slip that inserts at the base of the middle phalanx, and in two lateral slips that finally conjoin at the dorsal base of the distal phalanx as a terminal extensor tendon. The intrinsic muscles form lateral bands on each side of the digits all around the metacarpophalangeal joints, which finally reach the lateral slips of the extrinsic extensor tendons at the level of the proximal interphalangeal joints. From the physiologic point of view, the intrinsic muscles contribute to metacarpophalangeal joint flexion and interphalangeal joints extension.

Many additional structures concur to stabilize and coordinate the finger extensor apparatus, and include the sagittal bands, transverse retinacular ligaments, triangular ligaments, and oblique retinacular ligaments^{9,12-14} (→Fig. 1). The sagittal bands connect the extrinsic extensor tendons to the volar plate at the metacarpophalangeal joint to centralize the extensor tendon over the midline and prevent the hyperextension of the joint. The transverse retinacular ligaments connect the lateral bands to the volar plate at the proximal interphalangeal joint and prevent dorsal luxation. The triangular ligaments connect the lateral bands over the middle phalanx and prevent their volar subluxation. The oblique retinacular ligaments run from the A3 pulley to the dorsal

Fig. 1 Extensor tendon apparatus. DIP, distal interphalangeal; MP, metacarpophalangeal; PIP, proximal interphalangeal.

aspect of the distal phalanx in correspondence of the terminal extensor tendon and concur to coordinate the flexoextension of the proximal and distal interphalangeal joints. At the thumb, the intrinsic system that contributes to thumb extension is constituted by the abductor pollicis brevis, flexor pollicis brevis, and adductor pollicis, via attachments to the extrinsic extensor apparatus.

Biomechanics

Tendons, juncturae, and intratendinous fascia together allow stability during grip and finger mobility when fine finger movements are requested.¹² Full extension of fingers is allowed by activation of both extrinsic forearm extensor muscles and intrinsic hand muscles. These muscles groups have different anatomy and complementary function at metacarpophalangeal and interphalangeal joints.¹³ Fully independent finger extension is not possible because of connections among extensor tendon, but index finger has a greater range of movement in extension compared with other finger due to the activity of two separated tendons and the mobility of the second metacarpal bone.¹³ Grip strength is provided by firm positioning of the wrist in slight extension due to activation of extensor radialis carpi brevis and longus and extensor ulnaris carpi. The former tendon with its sheath contributes to the dynamic stability of the wrist acting to the distal radioulnar joint (DRUJ) as part of the triangular fibro cartilage complex (TFCC).¹⁵ Any lesions of additional structures of extensor tendon apparatus may lead to specific dysfunction, including extensor tendon instability and finger deformity. Swan neck deformity is caused by insufficiency of transverse retinacular ligaments allowing dorsal migration of lateral band with unbalanced proximal interphalangeal joint hyperextension and distal interphalangeal joint flexion.¹⁴ Boutonniere deformity is caused by insufficiency of sagittal band or triangular ligament at the proximal interphalangeal joint allowing volar migration of the lateral bands with unbalanced proximal interphalangeal joint flexion and distal interphalangeal joint hypextension.¹⁴ In case of ETI, the maintenance of an appropriate tendon length and gliding are also essential for an optimal extensor function. Limitation of tendon excursion due to adhesions at the fracture site or after tendon repair may cause reduction in mobility of adjacent tendons with a so-called quadriga effect.¹⁶ Deformities of the DRUJ or ulnar head position may alter the gliding extensor mechanism and affect specifically the EDM and EDC tendons.¹⁷ On this regard, it has been shown that the gliding resistance of EDM tendon is significantly higher than that of EDC tendon. Wrist ulnar deviation, ulnar dorsal dislocation (> 9 mm), and ulnar lengthening (> 6 mm) increased the gliding resistance of the EDM tendon.¹⁷ In patients at risk for EDM rupture, such as those with rheumatoid arthritis (RA) or DRUJ osteoarthritis, avoiding such positions may be advantageous.

Similarly, the gliding resistance of EPB and APL are affected in pathologic conditions including septations and wrist position at 60 degrees; these factors that may contribute to the development of de Quervain disease can induce tendon weak-

ness, making the tendon more susceptible to ruptures.¹⁸ Extensor tendon also affects the stability of wrist ligament, as demonstrated by inadequate extensor carpi ulnaris muscle function that is an important destabilizing factor in lunotriquetral (LTq) ligament deficiency of the wrist.¹⁹ Every tendon length variance should be avoided because tendon repair or healing with overlengthening may result in extensor lag while overstrengthening induces limitation of finger flexion.¹⁴

Zone Classification of Extensor Tendon Injuries

According to the site of lesion, ETIs may be classified into anatomical zones (→Fig. 2). This classification is very helpful to address the correct management.²⁰

Fingers and Wrist

Zone 1. This zone corresponds to the distal interphalangeal joint. Injuries at this level may lead to the mallet finger. The typical mechanism that causes the rupture of the terminal part of the extensor apparatus derives from a forced flexion of the joint during active extension. According to Doyle's classification, it is possible to describe four types of injury¹⁴: type 1 is closed, with or without avulsion fracture, which is the most common pattern; type 2 is an open injury with tendon discontinuity; type 3 involves loss of soft tissue coverage and tendon substance; and type 4 is characterized by a phalanx base fracture of 20 to 50% of the articular surface.²¹

Zone 2. Lesions over the middle phalanx are often lacerations and the tendons can be partially or totally sectioned.

Zone 3. The disruption of the central slip attachment, as well as the involvement of the triangular ligament over the dorsal aspect of the middle phalanx, results in the Boutonniere deformity. The finger, if untreated, assumes a flexed posture of the proximal interphalangeal joint with

Fig. 2 Kleinert and Verdan zones of extensor tendon injuries.

hyperextension of the distal interphalangeal joint, because of the volar migration of the lateral bands.

Zone 4. As in the zone 2, injuries at the level of the proximal phalanx result from lacerations. Frequently these lesions are incomplete, because the extensor apparatus is large and flat, wrapping around the phalanx.

Zone 5. Injuries over the metacarpophalangeal joint are commons and can involve the extensor tendon or the sagittal bands. Blunt trauma is the main mechanism of lesion. The complete rupture of the extensor tendon is rare, but more frequent are the lacerations of the radial sagittal band that lead to extensor tendon subluxation. Rayan and Murray defined three types of injuries, in which type 1 is a simple contusion, type 2 involves tendon subluxation with still contact with the dorsal aspect of the metacarpal head, and type 3 shows a dislocation of the tendon between the metacarpal heads.²² Clinically type 2 lesions are characterized by snapping of the tendon during flexion-extension movements of the metacarpophalangeal joint, whereas type 3 pattern shows weakness in extension of the finger from a full-flexion position and a ulnar deviation of the involved finger.

Zone 6. Proximally to the metacarpophalangeal joint, lesions of the tendons can be masked by an intact junctura if the damage occurs distally to this structure. When the injury is proximal to junctura, retraction of the proximal stump may occur making the management of these lesions challenging. However, the prognosis is often better than in more distal injuries because the position of lesion is far from the joints and the risk of adhesions and tendon imbalances is reduced.

Zone 7. Tendon injuries at the wrist often involve the extensor retinaculum. Tendons may be also lacerated secondarily to wrist fracture treated by internal fixation.

Zone 8 and 9. Injuries at this level occur to the musculotendinous junction or to the muscle belly, consequent to open trauma or prominence of internal hardware used for bone fixation. Closed ruptures at the musculotendinous juncture are rare and may be a consequence of violent-resisted wrist or finger extension.

Thumb

Zone T1 and T2. This group includes closed tendinous and small avulsion fractures that characterize the mallet thumb, similar to that observed in long fingers.

Zone T3 to T5. Injuries at these levels can involve avulsion or lacerations of EPL, EPB, and APL. T3 injuries involve the tendon at metacarpophalangeal joint, T4 at metacarpal level, and T5 at wrist level.

Clinical Assessment

Evaluation of a tendon injury requires a detailed knowledge of the anatomy of the extensor apparatus, as well as the functional characteristics of each segment. An accurate anamnesis is essential and should include the traumatic mechanism, the position of the hand at the time of injury, and the eventual comorbidities. Normally when trauma occurs with the finger

extended, the tendon damage corresponds to the level of injury, while tendinous retractions can be observed in case of fist trauma. In general, it is possible to divide injuries into two main categories: open wounds and closed rupture.²³ Open injuries can appear as avulsions, sharp lesions, or lacerations. In this last condition, a significant damage to the surrounding tissues often occurs and a careful neurovascular examination is mandatory. Closed ruptures may result from morbid conditions that weaken the tendon structure, such as RA, crystal deposition diseases, and attrition by internal hardware used for bone fixation.^{24,25} Inspection should consider the location of the injury, the size of the wound, the presence of any loss of tendon substance or retraction, and the associated damages. Furthermore, a careful observation of the hand may suggest an underlying tendon injury when the finger flexion cascade is abnormal at rest or when the wrist is flexed and extended with the tenodesis effect. Then, examination of each single finger with and without resistance should be done, to exclude the action of the juncturae tendinum that could mask the real entity of the damage. In presence of weakness of extension against resistance, a partial tendon injury may be suspected. For detecting an acute rupture of the central slip of the extensor tendon, in presence of a boutonniere deformity, Elson described a test that evokes an hyperextension of the distal interphalangeal joint when the proximal one is held passively in the maximal flexed position.²⁶ This test is based on the fact that an injury to the central slip eliminates the slack in the lateral bands that occurs when the proximal interphalangeal joint is passively flexed, allowing extensor tension at the distal interphalangeal joint.²⁷ Sometimes pain does not allow an appropriate examination and diagnosis, so in certain cases a local anesthesia may help the diagnostic.¹⁴

Imaging

Radiographs may play a useful role in the investigation of ETI. In case of trauma, X-rays may rule out or confirm bone injuries associated with ETI; furthermore they may reveal pathologic conditions such as malunion of wrist and hand fractures and/or RA responsible for chronic ETI. Diagnostic imaging for direct visualization of ETIs is primarily based on ultrasound (US) and magnetic resonance (MR). Computed tomography (CT) has been sometimes reported²⁸ for detection of tendon injuries, but this application in clinical practice is limited and commonly used only when there is a suspect of associated fractures to be investigated.

High-resolution US has been used for the evaluation of tendon injuries of the hand since the 90s.^{29,30} Along their course, from the forearm to the hand, extensor tendons may be examined by means of US showing a typical fibrillar structure that reflects the orientation of collagen bundles. Partial tendon ruptures are characterized by hypoechoic-anechoic image of the tendon or by tendon swelling and sheath effusion. Complete ruptures are diagnosed by the absence of the tendon in the physiologic anatomical site or by identification of tendon discontinuity with a gap.³¹ Ultrasonography is noninvasive, low-cost, and sensitive method for the confirmation of complete lesions and the detection of

particular tendon injuries such as partial tendon tears or distal zones ETIs, and at present it is considered a reliable and useful diagnostic tool in such field of study.^{8,32}

MR has high diagnostic value to assess tendon injuries of the hand.^{33,34} In a cadaveric study by Clavero et al who examined the MR findings of extensor tendon apparatus of the hand,³³ it was reported that this technique allowed accurate identification and depiction of most tendinous and retinacular structures, describing similar findings to those obtained with macroscopic dissection. For this reason they concluded that this specific knowledge of MR imaging (MRI) has a fundamental diagnostic value for the evaluation of extensor tendon lesions of the hand. Similar conclusions were reported by Bencardino.³⁴ Swen et al demonstrated that in patients with RA, US has a better diagnostic value than MR in detecting partial extensor tendon tears and that this technique could be useful in surgical decision making about tenosinovectomy.³⁵ Furthermore, US has been successfully used in the diagnosis of mallet finger and in cadaveric study for the detection of central slip lesion at proximal interphalangeal joint.^{36–38} Additionally, a dynamic US evaluation could detect specific tendon injuries such as extensor tendon instability due to sagittal band injuries of the extensor cuff at metacarpophalangeal joint.³⁹ Overall, both US and MR techniques may be helpful in the diagnosis of ETI, not only for visualization of complete lesions but also for the detection of asymptomatic partial tendon tears.^{33,40,41}

Treatment Options

The characteristic of ETI, including mechanism of trauma, site of injury, involvement of soft tissue and/or nerve and vascular bundles, and the characteristic of patient, including age, work, comorbidities, and functional requests, should be considered to offer the appropriate treatment.¹⁴ Conservative treatment can be indicated for subcutaneous lesions occurring at finger-level joint in zones 1 and 3 and for sagittal band injuries to extensor tendon cuff in zone 5. Partial lacerations involving less than 50% of tendon structure in zones 2, 4, and 5 can be treated conservatively¹⁴ or sutured according to surgeon's preference. Surgical repair is always indicated when open ETIs involve greater than 50% of tendon structure, and surgery is also advised when tendon injuries are associated with soft tissue damage, neurovascular lesions, and in contaminated wounds when debridement and irrigation are mandatory.¹⁴ The tourniquet, loupe magnification, fine instruments, and appropriate surgical techniques are always recommended. The correct management of open wounds includes deep cleaning of the site of injury, exploration of anatomical structures, and repair of lesions. The administration of antibiotic prophylaxis is required for wounds that have remained open for more than 24 hours or in case of largely contaminated and crushed lesions.¹⁴ In general, extensor tendon repair should be performed as soon as possible and generally within 1 week from trauma. The anatomical characteristic of tendon in the site of injury should be considered to plan the appropriate method and configuration of suture.⁴² The thickness of the tendon may allow a core suture at the

wrist and at the dorsum of the hand, but distal to the metacarpophalangeal joint the tendons become narrow and this suture may be difficult to perform. A running suture technique can be chosen in such conditions (►Fig. 3A). Biomechanical studies performed by Newport et al demonstrated that Kleinert and modified Kessler techniques with a 4-0 polypropylene (Prolene) were the strongest core suture methods of extensor tendon repair in zone 4 and 6 (►Fig. 3B, C).⁶ In subsequent studies the modified Becker technique has also been tested for zone 4 extensor tendon lesions, demonstrating that it is a reliable and biomechanically effective method of suture⁵ (►Fig. 3D). In a cadaveric study the modified Becker suture showed one cross-stitch superior mechanical properties for loads compared with the two and three cross-stitch techniques.⁴³ Recently Lee et al compared the resistance of the modified Bunnell and Becker suture technique with a running interlocked suture, combining a running and an interlocking mattress extensor tendon suture⁴ (►Fig. 3E). This technique is performed rapidly and allows an early mobilization, thanks to the favorable biomechanical properties suggesting that this suture may be an ideal configuration for extensor tendons repair.^{4,8}

A specific problem is represented by complex ETI, where significant bone and soft tissue lesions following major hand trauma are usually associated. These injuries require more complex techniques for tendon reconstruction, soft tissue coverage, skeletal repair, and eventual treatment of concomitant vascular and nerve injuries. Carty and Blazar defined three keys of interventions in complex injuries, including (1) restoration of reliable vascularity, (2) stabilization of the wound bed, and (3) reestablishment of skeletal continuity.⁴⁴ All devitalized and macroscopically contaminated tissues should be removed from the wound obtaining a clean vital wound bed. When necessary, microsurgical procedures are performed for revascularization or replantation of the injured segment and for nerve repair or reconstruction. In such cases immobilization is usually prolonged at least for 3 weeks. Fixation of metacarpal and phalangeal fractures associated with ETI may be performed by means of different devices. Single or multiple K wires, lag screws, plates and screws, or external fixation may be used according to the type of fracture and the characteristics of hand injury. K wires do not provide immediate stabilization and may not allow early mobilization; external fixation is indicated in case of open fractures or extensive soft tissue injuries leaving the possibility of the control of wound healing and the progression of soft tissue repair. Finally, screws and plate fixation may provide maximum stability of skeletal fractures.⁴⁴ During last two decades many devices dedicated to hand trauma have been introduced in the commerce, including anatomically designed micro-plates and conventional and locking screws. These surgical devices allow a stable fixation even in some difficult cases allowing early mobilization and functional recovery.⁴⁴ Traumatic injuries to the dorsal aspect of the hand causing loss of substance with extensor tendon involvement may require tendon reconstruction by means of tendon graft. The most common donor tendon used in such conditions are the palmaris longus and the plantaris longus, but

Fig. 3 (A) Running suture. (B) Modified Bunnell suture. (C) Modified Kessler suture. (D) Modified Becker suture. (E) Running interlocking mattress suture.

extensor indicis proprius and EDM have also been used as a valid graft option for tendon reconstruction⁴⁴. Subsequent soft tissue coverage of the dorsal aspect of the hand may be managed with local forearm flaps such as radial perforator forearm flap, radial flap, posterior interosseus flap, or dorsoulnar flap.⁴⁴ In particular conditions local composite perforator flaps with preservation of major vascular axis can be performed addressing both tendon reconstruction and soft tissue coverage.⁴⁵ Instead, in case of multiple extensor tendon loss, the free composite dorsalis pedis flap, based on the dorsal pedis artery, can be used to incorporate extensor tendons of the foot, reconstruct extensor tendons, and to cover the loss of substance of the dorsal aspect of the hand.⁴⁴

Surgical Approach by Zones (1–9)

Zone 1

Lesions of extensor tendon at the base of distal phalanx correspond to the mallet finger or baseball finger. It was first reported by Segond in 1880 who described ETI associated with fracture of the base of distal phalanx and by Schoening in 1887 who reported a case of subcutaneous rupture of extensor tendon at the same level.^{46,47} Closed tendon avulsion and small dorsal phalanx avulsion fractures, reducible with distal interphalangeal joint extension, can be conservatively treated with an extension splint for at least 6 weeks.¹⁴ After this period, further immobilization with a nocturne splint is

recommended for 4 to 6 weeks. Whatever the type of splint adopted, the patient's compliance is essential to ensure the best outcome.^{48,49} According to Doyle's classification of mallet finger, open tendon injuries (types 2 and 3) and fractures of the base of distal phalanx involving greater than 30 to 50% of the joint surface with subluxation of the distal phalanx (type 4) are indications for surgical repair.¹⁴ Direct tendon suture with nonabsorbable suture is the treatment of choice for types 2 and 3 even if debridement skin closure and tendon splinting with hyperextended distal interphalangeal joint is an accepted solution for type 2 lesion. Several techniques have been described for operative of type 4 mallet finger, including open fixation by means of plate, pullout, and anchors even if the size and the comminution of the bone fragment may preclude the effective stabilization.¹⁴ For this reason, extension block pinning may be performed by percutaneous insertion of two K wires acting as a block after reduction in hyperextension of the distal bony fragment.⁵⁰ In such case the proximal blocking wire is kept in site for 4 weeks whereas the distal wire fixing the interphalangeal joint in hyperextension is removed after 6 weeks. Conservative treatment with splint may be attempted in chronic injury until few months. Skin and tendon scar excision with subsequent suture (tenodesis) and temporary fixation of the distal interphalangeal joint in hyperextension with K wire is the preferred operative procedure for chronic resistant mallet finger, whereas arthrodesis should be limited to mallet finger with fixed and/or painful arthritic distal interphalangeal joint.¹⁴

Mallet thumb can be managed following the same criteria for long fingers in case of the injuries located in zone 1.

Zone 2

Tendinous injuries to zone 2 are often subsequent to open wounds. When the damage involves less than 50% of the tendon width, surgical repair may be performed. Nonsurgical treatment may be attempted with an extension splint according to surgeon's preference if the active extension is preserved.¹⁴ Primary repair is always suggested for lesions involving greater than 50% of extensor apparatus and is mandatory in case of complete tendon injuries. Direct repair can be performed using several suture techniques, with supplemental K-wire stabilization in extension of the distal interphalangeal joint. Direct suture with nonabsorbable 5-0 suture is the preferred technique because core suture cannot be performed due to minimal thickness of the extensor tendon.¹⁴ The duration of the treatment is similar to that described for the mallet finger, with 6-week full-time immobilization, followed by nocturne extension splint for additional 6 weeks.

ETI to the thumb in zone 2 can be managed following the same criteria for similar lesion located in long fingers.

Zone 3

Trauma to extensor tendons in zone 3, where tenderness and swelling at the proximal interphalangeal joint are associated with weakness of the joint extension against resistance, should not be underestimated because of the risk of a central

slip lesion. In this case the deficit of the central slip action and the subsequent volar subluxation of the lateral bands may induce a boutonniere deformity several weeks after trauma. In closed injuries conservative management with splint in extension of proximal interphalangeal joint should be adopted for 6 weeks and prolonged for further 6 weeks during the night. Exercise program can be associated during the immobilization period including passive extension of proximal interphalangeal joint and active flexion of distal interphalangeal joint to avoid stiffness and relocate the lateral bands of extensor tendon apparatus.

Zone 4

Lesions in zone 4 that involve less than 50% of the tendon width can be treated conservatively or repaired surgically according to surgeon's preference. Conservative management requires an extension splint of the proximal and distal interphalangeal joints and metacarpophalangeal joint for 3 to 6 weeks, followed by rehabilitation. In all the cases in which a loss of active extension of the proximal interphalangeal joint is evident at the clinical evaluation, surgical exploration and tendon repair is always required.¹⁴ Many biomechanical studies have compared different suture techniques at this level, and now it is commonly accepted that the sutures have to be strong enough to allow early mobilization.^{4-6,51} A core single or double 4-0 suture placed on the thicker area of the lateral bands with a 5-0 dorsal cross-stitch is recommended, followed by an early motion program to prevent adhesions. Similar management can be applied at the thumb, with a 3-0 or 4-0 core suture and 5-0 dorsal cross-stitch. The safe range of movement of the proximal interphalangeal joint from which the rehabilitative protocol can start is determined intraoperatively assessing the tension on the site of repair.¹⁴ When a proximal phalangeal fracture is concomitant, a solid synthesis is recommended to facilitate early motion program.⁹

Zone 5

Wounds over the metacarpophalangeal joint due to punch directed on the teeth are frequently characterized by partial laceration of the tendinous apparatus and can be contaminated by saliva.¹⁴ Because of the high risk of infection, the correct management should involve X-ray to exclude fractures or foreign bodies, then irrigation, exploration, and antibiotic prophylaxis. The wound should be left open and only secondarily a tendinous suture may be performed. A single or double 3-0 or 4-0 core suture is recommended, with 5-0 cross-stitch. The metacarpophalangeal joint should be immobilized in an extension cast for 4 weeks, with free active motion of the proximal interphalangeal joint.¹⁴

Blunt trauma may involve the rupture of the radial sagittal bands with subsequent subluxation of the extensor apparatus. The first management of an acute lesion diagnosed within 3 weeks from the trauma also is conservative, using an extension metacarpophalangeal splint and free interphalangeal joints for 4 to 6 weeks. For the long and ring finger, a custom-made splint, called *sagittal band bridge*, that connects the injured joint to the adjacent one with a relative

hyperextension of 25 to 35 degrees has been proposed by Catalano et al.⁵² Surgical treatment is recommended in case of failure of conservative management and consists in direct repair with 4–0 or 5–0 simple sutures or reconstruction of the radial sagittal band by means of juncturae flap.⁵³ To centralize the extensor apparatus, a partial release of the ulnar sagittal band may be helpful.¹⁴ Various techniques for reconstruction of the radial sagittal band have been reported in literature, including a dynamic lumbrical muscle transfer proposed by Segalman.⁵⁴

According to Kleinert and Verdan,²⁰ tendon injuries at thumb metacarpophalangeal joint, metacarpal, and wrist level correspond respectively to zone 3, 4, and 5 in the first digital ray. Injuries involving the APL, EPL, and EPB can be repaired by core sutures and cross-stitches following the same surgical criteria indicated for tendon reconstruction of long fingers at the corresponding anatomical level.

Zone 6

Injuries over the dorsal aspect of the hand have often favorable prognosis for many reasons: associated joint injuries are uncommon, the great tendon excursion does not lead to joint motion limitation after repair, the increased subcutaneous tissue reduces the risk of adhesions, the width of the tendon allows easy 3–0 core sutures with or without 5–0 cross-stitches, and dynamic splinting is manageable.¹⁴ However, diagnosis is not always immediate because of the presence of the juncturae tendinum. The EIP and EDM tendons could hide a lesion allowing a certain degree of extension, so surgical exploration is recommended. In chronic injuries, when direct repair is not possible, side-to-side tendon transfer or the use of tendon grafts could be valid options, as well as two-stage reconstruction with silicone rods in cases of great loss of substance.⁵⁵

Zone 7

Injuries in zone 7 occur at the wrist where extensor tendons run underneath the retinaculum. At this level the tendons, which are surrounded by synovial sheath, can be surgically approached by means of partial retinaculum incision without risk of bowstringing. Acute tendon injuries may result in tendon retraction requiring surgical exploration prolonged to the distal forearm to recognize and suture tendon stumps. Surgical reconstruction should be performed with 2–0 or 3–0 nonabsorbable core suture eventually reinforced with cross-stitches.¹⁴

Chronic ruptures may occur in patients with inflammatory arthritis such as RA or as posttraumatic complication. In case of surgical fixation of distal radius fractures, ruptures may occur due attrition of extensor tendons with fixation hardware or with the dorsal malunited surface of the distal radius.¹⁴ Frequently such injuries involve the EPL tendon. In these cases a primary repair is often precluded by tendon disruption or secondary reconstruction by means of graft; therefore a reliable solution is the extensor indicis proprius tendon transfer.¹⁴ Nonetheless, this procedure alters normal biomechanics of the thumb reducing the adduction moment during extension that is physiologically produced by EPL

tendon.⁵⁶ An adequate time of immobilization of 4 weeks in splint or cast is required after the procedure before starting active mobilization.

Zone 8

Lesions at the musculotendinous junction are quite challenging to repair because of the consistence of tissues. Sometimes it is possible to find a quote of tendon tissue within the central part of the muscle that allows a firmer suture. In other cases a side-to-side tendon transfer could also be indicated.^{9,14,57}

Zone 9

At the proximal half of the forearm, injuries to the muscular components are almost always the consequence of wounds. These lesions need surgical exploration systematically, to detect any possible associated nerve damage. In particular the posterior interosseous nerve, because of its deep position in the muscle substance, is challenging to find and repair. The muscle must be repaired by means of multiple figure-of-eight sutures. Botte et al described the use of tendon grafts, such the palmaris longus or toe extensors, in cases of lacerations of more than 50% of two or more muscle bellies.⁵⁸ In case of chronic nerve lesions, tendon transfers can be performed to regain partial functionality.¹⁴

The indications for ETI treatment have been summarized in ▶Table 1.

Overview

An accurate diagnosis and optimal treatment of ETI of the hand and wrist are essential, because these lesions are commonly observed in clinical practice. A careful clinical history and assessment still remain the first step for the diagnosis, followed by US and MR to confirm a clinical suspect of ETI or to investigate some doubtful conditions. Particularly, US highlights some lesions that may require specific splinting to prevent extensor tendon instability at metacarpophalangeal joint, boutonniere, and mallet deformities. Conversely, there is lack of literature concerning the use of US and MR in the assessment of extensor tendon healing after a conservative treatment or surgical repair; furthermore, the interpretation of US images requires knowledge of the mechanism of injury, surgical technique, and the physiopathology tendon healing that includes tendon thinning, tendon fluid collections, persistent hypervascularity, tendon calcifications, and adhesions.⁵⁹

During last decades the evolution of surgical techniques and rehabilitative treatment protocol led to gradual improvement in clinical results of ETI treatment and surgical repair. Injury classification into anatomical zones and the evaluation of the characteristics of the lesions are considered key points to select the appropriate treatment for ETI. Both conservative and surgical management can be indicated in ETI depending on the anatomical zone and on the characteristics of the injuries. As a general rule an attempt of conservative treatment should be performed when the lesion is expected to have favorable result with nonoperative procedure.

Table 1 Treatment of extensor tendon injuries according to anatomical site of lesion (Kleinert and Verdan)

Zone 1 (Doyle, Hishiguro)
Type 1: extension splint DIP joint
Type 2: surgical repair 5–0 running suture + splinting
Type 3: surgical repair 5–0 running suture plus soft tissue covering + splinting
Type 4: extension splint DIP joint or extension K-wire block
Complete closed chronic rupture: tenodesis DIP joint ; central slip tenotomy ; spiral retinacular ligament reconstruction
Zone 2 (Doyle)
Partial open rupture < 50%: suture and/or extension splint PIP joint
Partial open rupture > 50% and complete open rupture: running suture repair 5–0 and cross-stitch 5–0
Zone 3 (Doyle)
Partial closed rupture: extension splint PIP
Partial open rupture: suture and/or extension splint PIP
Complete closed rupture central slip: extension splint PIP
Complete open rupture central slip: surgical repair
Zone 4 (Doyle)
Partial open rupture < 50%: Suture and/or conservative treatment extension splint
Partial open > 50% and complete open rupture: core suture 4–0 and cross-stitch 5–0
Zone 5 (Doyle, Catalano, Arai)
Extensor cuff radial sagittal band rupture without tendon subluxation: extension splint MP
Extensor cuff radial sagittal band rupture with tendon subluxation: extension splint or surgical repair
Partial open clean rupture: suture and/or conservative treatment extension splint MP
Partial open and contaminated rupture: debridement and extension splint MP
Complete open clean tendon rupture: surgical repair core suture 3–0 or 4–0 and cross-stitch 5–0
Complete open contaminated rupture: debridement and surgical repair core suture 3–0 or 4–0 and cross-stitch 5–0
Zone 6 (Doyle)
Complete open rupture: core suture 3–0 and cross-stitch 5–0
Complete closed chronic rupture: tendon transfer; reconstruction with tendon graft
Zone 7 (Doyle)
Complete open rupture: core suture 2–0 or 3–0 and cross-stitch 5–0, extensor retinacular reconstruction
Complete closed chronic rupture: tendon transfer; reconstruction with tendon graft
Zone 8 (Doyle, Takami)
Good tissue quality: direct suture muscle-tendon junction
Poor tissue quality: side-to-side tendon transfer
Zone 9 (Doyle)
Multiple figure-of-eight muscular sutures

Abbreviations: DIP, distal interphalangeal; MP, metacarpophalangeal; PIP, proximal interphalangeal.

Clinical results of extensor tendon function may be assessed according to Miller's criteria based on total extension lag and total flexion loss.¹ Following those criteria is a common opinion that ETIs in zones 1 to 4 have worse results than those in zones 5 to 8.^{8,14,60} Long-term results of extensor tendon repair have been described by Newport et al⁶⁰ who observed a significant positive trend in patients with isolated tendon injuries compared with those having associated bone, joint, and flexor tendon lesions. Moreover, the same authors

reported 63 to 83% of favorable results in the proximal zones (5–8) compared with less than 50% of good results in the distal zones (1–4). Proximal extensor tendon repair is facilitated by the large thickness of tendons that may accommodate a core suture reinforced by dorsal cross stitches. Conversely, the reduced thickness of extensor tendon in distal zones can make the suture difficult. Moreover, at this level minimal variation in tendon length and tension may cause significant extension and flexion lag after tendon repair.^{61,62}

Recently a new running interlocking tendon suture technique has been developed showing optimal biomechanical properties and reliability for such tendon sutures.⁴ We do not have so far long-term clinical results, but good and excellent results have been observed in preliminary reports for digital zones 4 and 5 and thumb zones 1 to 4 in case of ETI repair with this technique in association with a postoperative controlled active motion regimen.³ Platelet-rich plasma (PRP) preparations have been shown to effectively treat acute and chronic tendon injuries in other anatomical sites, such as Achilles tendon or rotator cuff, and could be considered as supplement therapy in patients treated for chronic ETI; nevertheless, there is a current controversy over PRP's efficacy that may be best addressed by basic science studies performed on cellular and animal models.⁶³

Conservative treatment is recommended in closed injuries involving extensor tendons at metacarpophalangeal and interphalangeal joints. Recently Peelman et al reported satisfactory results with splintage in the treatment of acute and subacute extensor tendon subluxation due to sagittal band incompetence, with resolution in 95% of all traumatic cases.⁶⁴ For closed proximal interphalangeal joint injuries with central slip lesions, a splintage with extended joint for 6 weeks is commonly suggested. A Cochrane revision performed by Chalmer et al observed that there is insufficient evidence from trial testing about the duration and the extent of immobilization of proximal interphalangeal joint after hyperextension trauma.⁶⁵ Splintage with extended distal interphalangeal joint for 8 weeks is the treatment commonly suggested for acute type 1 mallet finger injuries. Another Cochrane revision performed by Handoll and Vaghela⁶⁶ examined the evidence for the relative effectiveness of different treatment method for mallet finger injuries. The conclusions were that there was insufficient evidence to establish the effectiveness of different splints in the treatment of mallet finger and to establish the indication for surgery.

In conclusion, despite recent research findings, a lack of evidence-based knowledge is still observed in the treatment of ETI. Further clinical and biomechanical investigations may give additional informations about the timing and the rationale of surgical approach, the operative technique, and the postoperative management. These data, deepened and shared by orthopedic surgeons, should help ensure the best prognosis and restrict the functional sequelae.

Conflict of Interest

None.

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