Diploma Thesis

Management of Extensor Tendon Injuries in Paediatric and Adolescent Patients

submitted by

Sigurd Timotheus Seitz

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under supervision of

Assoz. Prof. Priv.-Doz. Dr.med.univ. Georg Singer

Ass. Prof. Dr. med. univ. Barbara Schmidt

Graz, 17.07.2015
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Graz, am 17.07.2015

Sigurd Timotheus Seitz eh.
Zusammenfassung


Ergebnisse: Wir fanden eine Geschlechterverteilung von 3:1 mit höherer Verletzungsrate unter Jungen (74,13%), sowie passend dazu eine Dominanz von Schnitt- und Ballsportassozierten Verletzungen von 68,53%. Der Verletzungsgipfel lag bei 14 Jahren (14,69%) und das sowohl im gesamten Kollektiv, als auch unabhängig unter Zone I - Verletzten, welche mit 56,10% die größte Subgruppe der Fälle ausmachte. Es konnte keine Seitenpräferenz beobachtet werden. Multiple Sehnenverletzungen waren selten, da in 87,41% nur einzelne Sehnen betroffen waren. Die bevorzugte Nahttechnik waren in 49,83% U-Nähte. Während 39% aller Patienten im Verlauf unerwünschte Nebeneffekte zeigten, betrug die Zahl der persistierenden Defizite nur 14,69%, weshalb sich insgesamt eine Rate von 92,31% exzellenten und guten Ergebnissen ergab.


Schlüsselwörter: Strecksehne, kindliche Handverletzung, Sehnennaht, Kinder, Mallet Finger
Abstract

Objective: Purpose of this study was to show the management of extensor tendon injuries in paediatric and adolescent patients and assess the functional outcomes of injuries to specific Zones as well as various repair techniques. Also general epidemiological factors such as distribution of these injuries in children and teenagers age-wise, typical causes and primary treatment was assessed as details on these parameters are still widely unknown.

Methods: Following a descriptive, retrospective study model we reviewed the data of 143 patients treated for injuries to extensor tendons of the hand at the Department of Paediatric and Adolescent Surgery Graz. Including patients from 2003 to 2012, the age was set to be between 0 to 18 years, with no amputating injuries being included. Using basic documentation and surgical protocols a variety of parameters concerning patient-, injury- and treatment specific factors as well as functional outcome were assessed and compared in a descriptive manner.

Results: We found a gender distribution of 3:1, affecting a higher number of boys (74.13%), and suiting this a dominance of cut and ball sport caused injuries of 68.53%. The age most often affected was in 14 year-olds (14.69%), both in the full collective as well in Zone I injuries which made up the biggest subgroup with 56.10% of all cases. There was no preference in injured side to be seen. Multiple injuries in children are rare as 87.41% suffer single tendon injuries. The preferred suture type were U-sutures in 49.83%.

While 39% of all patients showed complicating factors, lasting deficits were only seen in 14.69% which makes for excellent or good end results in 92.31%.

Conclusions: In comparison to adult studies we could find extremely good functional outcomes relatively soon after repair took place. However, long-term development and its effect on tendon function would be of significant interest, as due to the nature of a child's growth any manipulation will show some degree of influence. Larger, prospective studies on the topic are needed.

Key Words: extensor tendon, paediatric hand injury, tendon repair, children, mallet finger
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<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>A. rad.</td>
<td>radial artery</td>
</tr>
<tr>
<td>A. uln.</td>
<td>ulnar artery</td>
</tr>
<tr>
<td>AP</td>
<td>adductor pollicis muscle</td>
</tr>
<tr>
<td>APB</td>
<td>abductor pollicis brevis muscle</td>
</tr>
<tr>
<td>APL</td>
<td>abductor pollicis longus muscle</td>
</tr>
<tr>
<td>CI</td>
<td>connexus intertendinei</td>
</tr>
<tr>
<td>CL</td>
<td>Cleland's ligaments</td>
</tr>
<tr>
<td>CLW</td>
<td>contused lacerated wound</td>
</tr>
<tr>
<td>DI-V</td>
<td>digitus I-V / 1\textsuperscript{st}-5\textsuperscript{th} digit</td>
</tr>
<tr>
<td>DIP-joint</td>
<td>distal interphalangeal joint</td>
</tr>
<tr>
<td>ECRB</td>
<td>extensor carpi radialis brevis muscle</td>
</tr>
<tr>
<td>ECRL</td>
<td>extensor carpi radialis longus muscle</td>
</tr>
<tr>
<td>ECU</td>
<td>extensor carpi ulnaris muscle</td>
</tr>
<tr>
<td>EDC</td>
<td>extensor digitorum communis muscle</td>
</tr>
<tr>
<td>EDM</td>
<td>extensor digiti minimi muscle</td>
</tr>
<tr>
<td>EIP</td>
<td>extensor indicis proprius muscle</td>
</tr>
<tr>
<td>ESIN</td>
<td>elastic stable intramedullary nailing</td>
</tr>
<tr>
<td>EPB</td>
<td>extensor pollicis brevis muscle</td>
</tr>
<tr>
<td>EPL</td>
<td>extensor pollicis longus muscle</td>
</tr>
<tr>
<td>FDP</td>
<td>flexor digitorum profundus muscle</td>
</tr>
<tr>
<td>FDS</td>
<td>flexor digitorum superficialis muscle</td>
</tr>
<tr>
<td>IP-joint</td>
<td>interphalangeal joint</td>
</tr>
<tr>
<td>K-wire</td>
<td>Kirschner wire</td>
</tr>
<tr>
<td>LL</td>
<td>Landsmeer ligaments</td>
</tr>
<tr>
<td>MRI</td>
<td>magnetic resonance imaging</td>
</tr>
<tr>
<td>MCP-joint</td>
<td>metacarpophalangeal joint</td>
</tr>
<tr>
<td>PIP-joint</td>
<td>proximal interphalangeal joint</td>
</tr>
<tr>
<td>ROM</td>
<td>range of motion</td>
</tr>
<tr>
<td>TAM</td>
<td>total active motion</td>
</tr>
<tr>
<td>TPM</td>
<td>total passive motion</td>
</tr>
<tr>
<td>U-suture</td>
<td>U-shaped suture</td>
</tr>
<tr>
<td>VLC</td>
<td>vulnus lacerocontusum → see CLW</td>
</tr>
<tr>
<td>V. mors.</td>
<td>vulnus morsum, bite wound</td>
</tr>
<tr>
<td>V. sect.</td>
<td>vulnus sectum, cut wound</td>
</tr>
<tr>
<td>Z-suture</td>
<td>Z-shaped suture</td>
</tr>
</tbody>
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1 Introduction

Injuries to the paediatric hand are commonly encountered in emergency departments throughout the world. Due to its exposed position in daily activities, the hand is prone to suffer a variety of injuries to causing damages of its delicate mechanical system. In the thesis the topic of extensor tendon injuries and their role in the developing child will be addressed.

Hand surgery and especially tendon surgery can be a very challenging and at times frustrating field in medicine. Sterling Bunnel, a pioneer in hand surgery once stated in 1948, “My first attempts at repair of tendons in the fingers resulted in immediate success, but as the succeeding days went by motion became less and less, until at the end of a few weeks it was nil.” (1).

This statement by an excellent surgeon of his time, who went on to develop several surgical procedures including a suture technique that is still in use today, showcases the difficulties a physician faces when treating extensor tendon injuries. Setbacks have to be expected, initial successes may turn to disappointment and promising starts can crumble under lack of cooperation.

Yet cases in which therapy is indeed successful do not only offer incredibly rewarding functional results, but also patients who are able to regain part of themselves and their ability to interact with their surroundings.

Injuries to the hand count among the most common work and sports related injuries. In an overview Armstrong et al. were able to show that this high representation in emergency departments does strongly correlate with the use of tools and other heavy machinery, as can be seen, by the higher number of injured patients among the male population. Yet also a large number of patients present with sports injuries and accidental trauma. Amongst these injuries, lacerations have been found to make up almost two thirds, namely 61.5%, of the patients presenting themselves in the hospital (2).

These numbers have been consistent over the last decades making hand injuries, hand surgery and in succession extensor tendon injury an ever present topic, that trauma surgeons have to deal with.

In past medical generations, there have been great hand surgeons, who worked in cooperation and tackled existing, insufficient techniques and over the years were able to build the surgical and anatomical framework for tendon repairs we have today (3). Many of these early classifications and suture techniques are still in use today after having experienced modifications or other
improvement. Especially modern technology with its imaging systems has been able to go one step further and explain pathologies at a microscopic level.

However, with all the progress and excellent therapeutic systems and protocols that we now have at our disposal, still very little is known about how these injuries affect children. Few studies have been published on the epidemiology of extensor tendon injuries in paediatric patients and to our knowledge only one evaluated the outcome of repairs (4).

The following thesis is intended to address some of the major topics of extensor tendon therapy in paediatric patients, including anatomical specifications, surgical approaches and the benefits and drawbacks of conservative treatment. Also typical suture techniques, ways of immobilisation as well as the importance of follow-up care will be discussed.

1.1 Specifics of the Extensor Tendon

1.1.1 Anatomical Attributes

The extensor tendons of the hand hold an important position in function of the hand and forearm, as they are directly or indirectly involved in nearly all motion distally of the elbow joint.

There is an extrinsic and intrinsic system that can be discriminated, meaning a group of muscles reaching from the forearm into the hand as far as the fingers, thus being of extrinsic origin from the hand's point of view. Intrinsic muscles, on the other hand, can be classified as having both origin and endpoint within the hand. These, while not having direct extension as their main function, still play an important role in the fine mechanics of finger motion which will be addressed in the respective Zones or procedural tasks.

The extrinsic hand muscles share the common characteristic that the muscular insertion in the forearm, lies within the proximal half of ulna and radius or, in few cases, on the distal humerus. Starting here the muscle belly courses distally, while slowly changing its aspect within the musculotendinous junction to a strong, fibrous tendon. From there on the tendons continue on their way to the hand, pass below the extensor retinaculum, through the respective extensor compartments to reach the dorsum of the hand (5). In 20-60% of patients a septation of the first extensor tendon compartment as well as multiple slips of the extensor pollicis brevis tendon exists.
At this point a first differentiation takes place, as the tendons, whose primary function lies in wrist movement will now find their insertion points at the base of various metacarpal bones. The remaining tendons continue towards the fingers, changing their shape into the characteristic flat extensor tendon cross-section, as opposed to the round flexor tendons. Also the tendons are sharing the juncturae tendineum at this stage. These are fibrous bundles connecting the separate tendon strands of the extensor digitorum communis muscle and serving as distributors of traction force. This force can reach substantial levels, which is why tendon repair sutures are counted among the strongest suture techniques that can be found in surgery. Ketchum et al. reported that the maximum amount of force that is transmitted through the extensor tendon during forceful isometric contraction is about 39N on the small finger tendons, while reaching 59N in index finger contraction (7).

At the level of the metacarpophalangeal joint another significant change occurs in tendon structure and path. This gradual shift from a classic tendon appearance to a multistranded system also is the reason, why in the literature the extensor system in the finger usually is referred to as the extensor hood or dorsal aponeurosis.

The tendon, upon reaching the metacarpal head gives off the sagittal bands, two fibrous bundles reaching around the bone into the transversal palmar plate, securing the extensor tendon in place (8). Going on, the tendon is then joined by the tendons of the intrinsic hand muscles, before splitting into three slips at the height of the proximal phalanx’ diaphysis.

Function of the metacarpophalangeal joint, or MCP joint, more specifically extension, is aided by the intrinsic hand muscles. Transverse fibres of the interosseus muscles, coming from the palmar aspect of the MCP joint, form a sling over the proximal phalanx. This way additional strength, stabilisation and some degree of compensative possibility is added (6).

The next joint is of special importance, as many interactions between the extensor aponeurosis and its surroundings, both bone and ligaments, take place right here. The extensor mechanism, after being joined by the intrinsic muscle tendons now splits itself up into three separate slips, crossing the proximal interphalangeal joint. Two of these only have an indirect effect on the joint, as they travel past it on either dorsolateral side, joining again over the distal third of the middle phalanx to then insert in the distal phalanx. Upon joining they share transversally running fibres forming the triangular ligament (5,9). The third strand runs medially to form the central slip, the main extending tendon in the PIP joint. To allow for active extension and passive flexion in both these interphalangeal joints with only one pulley system, a fine equilibrium of the tendon lengths is
necessary (10). To prevent dorsal bowstringing of the lateral slips during maximum extension of the PIP joint, there are oblique lateral ligaments first described by Landsmeer (LL). These bundles of fibre wrap themselves around the sides of the proximal interphalangeal joint, leading distally and connecting to the lateral strands around halfway past the middle phalanx. However, still it is possible for many people to overextend their PIP joint and, due to locking it in place like this, consecutively flex the DIP joint independently (10).

When now reaching the distal interphalangeal joint the dominant part of the collagenous tendon filaments of the dorsal aponeurosis' distal part inserts immediately distal to the articular surface. However, several minor strands provide additional stabilisation due to interaction with the surrounding tissue. Thus, some fibres lead into the articular capsule, or rather dorsal plate as described by Slattery, as well as up towards the skin. Another group leads on into the ligaments that hold the fingernail in place. The last strands lead on distally and interweave into the periosteum (9,11). This could also serve as an explanation for the currently not satisfactorily described cause of partially retained ability to extend the DIP joint after tendon injury. As quite often it is possible for a patient with complete Mallet fracture to still achieve some extension in the distal phalanx, some persisting adherence has to be suspected (11).

What could not be sufficiently shown by histologic examination, Slattery et al. were able to describe, using ultra-high field magnetic resonance imaging of cadaveric DIP joints. They could show the interaction of the extensor mechanism with both dorsal plate and dorsal septum. Also formerly described accessory collateral ligaments, while fibrous bundles being present in documented orientation, could not be seen as a distinct entity. Another structure that the research team was able to show in all the examined joints, was a ligament formation originally described by Cleland et al. They presented themselves as dense, cone-like, fibrous bundles arising from the lateral tubercules of the distal phalanx as well as the capsule and the lateral aspects of the middle phalanx towards their insertion point in the overlying skin. Yet also the extensor tendon itself was shown to have connective tissue bundles coursing to the skin in a randomly arranged pattern. However, they were not sufficiently organised or consistent to be labelled a discrete structure (9). Both of these might be a possible cause of the afore-mentioned retained dorsal extension in Mallet fractures, considering the close interaction of tendon and skin in this area.

Hoch et al. could show in plastination-histologic cuts of induced Mallet fractures in the distal phalanx, that there were tendon insertion points distally of the fracture line. This fact was then discussed as the reason, why a bone fracture does not directly correlate with the classic Mallet
injury with complete rupture of the tendon and how the mechanism of injury differs. In the author's opinion a fracture should not be seen as an equivalent of the Mallet, as it is not the whole of the dorsal aponeurosis that loses its insertion due to the injury (11).

This describes the course of the typical long finger tendons, which is very representative and usually almost interchangeable between the digits. One finger however, is not only structure-wise but also in its function different to the rest. Therefore the thumb deserves some separate attention.

Already in the forearm, the EPL tendon is probably the extensor tendon with the most critical anatomic gliding path as it has to take several steep angles including passing the Lister's tubercle. This point has an increased risk of causing tendon rupture after distal forearm fractures (12). Also after passing through the third extensor compartment, the tendon has to alter its direction for about 60° to 70° to reach the desired digit, where it finds an insertion point in the distal phalanx. There the EPL tendon is responsible for both extension in the IP joint as well as dorsal movement of the entire thumb, which can be tested by elevating the thumb of a flat surface.

Unlike other DIP joints, the distal phalanx of the thumb commonly hyperextends by a variable combination of the typically already hyperextended shape of the distal thumb segment itself and radiologically true hyperextension of the IP joint. This true hyperextension reaches up to -15° in a normal thumb and even up to -70° in the rather big group of people with lax, hyperextendable thumbs (1).

Due to their superficial position in the dorsum of the hand and the lack of subcutaneous fatty padding when compared to other structures the extensor tendons are prone to direct injury. Also the lack of a fascia or other separating connective tissue increases the likelihood of secondarily spreading infections throughout the hand (13). Also, due to the thin soft-tissue sheathing, perfusion is relatively low in the extensor tendons, which explains their slow healing properties (14–17). Also the exposed position allows for many of the typical injuries to extensor tendons, namely abrasions, avulsion fractures and skin loss, which typically cause difficulties due to the associated injuries (17). Due to these factors injuries in the dorsal hand can easily demand broad surgical skills to ensure adequate treatment.

While the general concept of finger mechanics and interactions between the different muscle groups has been very well understood in a static, anatomic sense, there are still evident gaps in grasping the
functional specifics of some elements. Due to this high level of connections, as well as the shift in function during activity due to changing angles and pulleys, the hand presents an incredibly intricate system that still poses questions. Newport et al. struggled with this problem in evaluating suture function, when during induced finger flexion by applying traction on the FDS tendon of a cadaveric hand, some fingers would show a consistent pattern of composite flexion, while others tended to completely flex one joint before flexing the other (18). This is usually not observed in conscious finger movement, suggesting a regulating element in antagonistic muscles.

Also this makes the effect of iatrogenous changes difficult to estimate. One example for this is the active shortening of the dorsal hood of the extensor mechanism in a cadaveric hand, which in succession leads to a distal rotation of the ligaments (18).

This is true in every field of surgery, but particularly so in hand surgery, as changes caused both by surgery as well as old injuries can significantly alter the intraoperative aspect of the hand. Therefore one has to expect changes in anatomy when operating on chronic cases. The hand leaves very little room for error and thus singular scar bundles can change both function and landmarks essential for surgical orientation and navigation. Cheema et al. reported of an EPL tendon, that after secondary rupture formed direct adhesion to its extensor compartment made up of scar tissue, which can lead to non-recognition of the injury, as well as force the surgeon, to extend his incision significantly (19). This means that in hands that have been operated on before, difficulties should be expected and discussed before engaging in the operation.

1.1.1.1 Vascular Supply
Healing processes of any sort require adequate perfusion to be able to close the formed gap, which is true none-the-less in tendon healing. Tendons, however, count among the bradytrophic tissues, with generally low degrees of perfusion. This also is particularly true in extensor tendon injuries.

In the forearm the tendons are usually still well supplied by vessels accompanying the muscle fascia or spreading in between the compartments before reaching the dorsal hand.

After direct supply of the overlying extensor tendons in the dorsum of the hand through the dorsal arterial arcs, the perfusion of the extensors becomes more difficult when reaching further distally. In the digits, vascular supplies of the dorsal extensor system essentially are extensions or branches of the flexor vascular supply, after these have been saturated (2).
As it has been seen in flexor tendon studies, that with rising age, the number of vinculae, which carry the main blood vessels for distal tendon perfusion, is reduced over time, thus impairing tendon supply and slowing down the tendon healing process (20). As the extensor tendon is also supplied by these vinculae, it is probably safe to assume, that a similar process, as has been observed in flexor tendons, may also happen in extensor tendons and their blood supply. Following this assumption younger patients should show ideal tendon healing properties due to optimal perfusion.

The blood supply of the finger becomes increasingly intricate the further distally we move. Up until the DIP joint the main vessels lie on the lateral aspects of the finger, as has been mentioned before, but in the distal phalanx this system spreads out into the last branches. Of these finest arteries, mainly two are of interest in extensor tendon surgery, running paracentrally on both the ulnar and radial side, feeding the proximal dorsal arterious arc and supplying both bone and germinal matrix of the fingernail. These vessels are at risk of disruption in both direct injury as well as in a dorsal surgical approach for Zone I reconstructions (11).

1.1.2 Surgical Specifics

The following section is intended to explain some of the surgical aspects of extensor tendon therapy, as well as the typical mechanisms of injury. Closer detail to the distinct areas of the tendon and their specific treatment will be paid in the next chapter.

To unify the different reports on tendon injuries, Kleinert and Verdan first suggested the classification still used today and known as the Zones of Verdan. This classification uses anatomic landmarks over the course of the tendons path along the forearm and hand, as can be seen in Figure No. 1 to distinguish eight separate areas in which injury of the tendon can occur (3). These eight were joined by a ninth when Doyle suggested that the muscle belly, whilst not of tendinous nature, should also be included in the classification, as presentation of lesion in this area can be very similar (21). The thumb, being somewhat unique in anatomy and functional aspects, is also included in this classification. However, due its differences, the digit itself is split up into three independent Zones named PI-III following the same principle as in the fingers, with uneven numbers addressing joint areas and even Zones describing phalangeal bodies. There is some controversy how far proximal this differentiation should reach. In this thesis, we will follow the original classification with Zone PIII going over into Zone VI.
Also the degree of injury can be very important, as partial ruptures are overseen on a regular basis, because they do not necessarily present with the loss in motion that would be expected in a tendon injury. However, the risk of secondary rupture and adhesion is drastically increased, as well as that of tendon lengthening with consecutive loss of function.

Figure 1: Verdan zones of the dorsal side of the hand used to classify injuries of the extensor tendons; Courtesy of Serah T. Seitz, BSc
Many typical mechanisms of injury, when it comes to impairing tendons, are closely related to age of the patient, as well as degree and type of physical activity. Apart from sporting injuries such as boxing, long-term overuse in gymnasts and climbing, extensor tendons are also prone to be affected in suicide attempts or operating of machines (2). However these numbers do vary with the population that is being assessed. This can be seen in injury distribution in the countryside, where a lot of sharp lacerations happen due to accidents with tools, such as sawblades, while a typical urban population will show a higher incidence of cuts with knives and glass fragments (22). Also depending on the local surroundings, such as the nature of employment, a different gender distribution can be seen in adult patients. Karabeg et al. were able to show this very nicely in the city of Sarajevo, with a vast majority of male patients presenting in the emergency room (17).

The areas afflicted, however, tend to show a stable pattern throughout various studies. So it is quite safe to say that about a third to half of all extensor tendon injuries afflict Zone I of Verdan, or the area of the distal interphalangeal joint. Among these patients the dominant group were closed injuries with about 75% of the cases (11). Other peaks appear in Zones III and V.

Due to the positioning of the lateral strands over the proximal interphalangeal joint in Zone III, central slip injury remains quite commonly unnoticed, due to the preserved extension of the digit (23). Because of this there have been quite a number of tests developed to improve early diagnosis of central slip injury, but most of them have failed. Amongst the most commonly used today count Carducci’s method as well as Boyes’. However, a simple test has been developed by Elson's with a much higher positive predictive value, which is as easy to perform. The patient places his finger on the corner of a table or other object with a downwards angled 90° edge, flexes the PIP joint over it, thus fully extending the central slip and forcing a slight passive flexion of the DIP joint of about 10-20°. The patient is then asked to extend his distal phalanx while the middle phalanx is held in place, only allowing movement in the DIP joint. Now if the central slip, is still intact, its full extension prohibits any further proximisation of the dorsal aponeurosis and thus leaves the distal phalanx flail. If it is not, the lateral strands can freely retract and extend the DIP joint. The test does not test for partial rupture and may be impeded by pain and or cooperation of the examined patient (10,23).

When setting the incision in this Zone, the high degree of PIP joint mobility has to be considered, which leads to an increased risk of both suture dehiscence and development of problematic scar tissue. Matev et al. faced a number of patients with considerable scarring after Zone III injuries.
(24). As mentioned above, a secondary intervention in tissue that has already been traumatised to this degree can be critical.

If there is a shortening of the tendon due to a tendon repair, flexion in the metacarpophalangeal joint will subsequently be decreased (7,25). This being the central joint in hand and finger function does not only affect the ability to clench a fist, but any more complex finger function. However, sutures in the more distal zones, such as I to IV, lead to little or no tendon shortening, as was shown by Newport et al. This appears to be due to the increasing number of surrounding restraining attachments that play an important role in extensor tendon function (18).

Over the last years it was also possible to show that many of the surgical and suture methods that have been proven helpful and effective over the metacarpals in Zone VI can be applied in the more distal Zones IV and III with apparent good results (18).

One specific matter concerning surgical treatment of thumb injuries again tackles the abovementioned issue of hyperextensibility in the DIP joint of the first finger. What can be seen after surgical repair is the almost universal complete, or at least extensive, loss of previously achievable hyperextension in the IP joint, after an EPL repair has taken place in any of the Zones PI-PIII. This also includes patients, who used to show considerable hyperextensive capabilities (1).

Another typical extensor tendon complication requiring medical attention of surgical nature, is post-traumatic injury to the tendon after a distal forearm fracture, in most cases a dorsally displaced radial fracture. Both sharp bone fragments and surgically inserted implants can lead to continuous damage of overlying structures. The tendon most afflicted by this is the extensor pollicis longus tendon, but also injuries of the extensor indicis proprius and extensor digitorum communis are not uncommon (26). In case of the EPL tendon rupture, it usually occurs 7 weeks after injury and tends to be more frequent in minimally or undisplaced fractures (12). Therefore, especially after distal forearm fractures, it is important to obtain proper radiographic images in order to ensure no bony fragments are overlooked. A dorsal flake, that is not seen due to a non strictly shot lateral view, can be enough to cause secondary tendon rupture, as has been described by Ghijselings and Demuynck in 2013 (12).
The mechanism of injury has been discussed repeatedly with new case reports questioning existing explanations. So far the common differentiation was set between mechanical and vascular causes, with mechanical shearing and direct contact obviously accounting for a major number of cases (19). A more elaborate differentiation has been offered by Wilhelm and Proksch, defining 4 independent groups that include acute and chronic causes. However, the classification is not widely known nor applied outside of German-speaking areas (27). Within the tendon's gliding path a sharp bone edge, the tip of a trans cortically positioned screw, as well as any structure, that forces the tendon to adjust its path, can lead to mechanical injury of the tendon. Kumar et al. reported the case of a 15-year old that suffered an EPL lesion after volar plate fixation, with screw tips puncturing into the third extensor tendon compartment (28). Once critical partial laceration has been reached a minor trauma or spontaneous movement can then lead to acute rupture of the tendon. However, not every rupture shows signs of direct mechanical affectation. As tendons count among the bradytrophic tissues, an adequate perfusion and blood supply is essential to ensure its stability under the high mechanical stresses it is exposed to. Therefore one widely accepted theory is that of the paratendinous haematoma, that can either lie subcutaneously or inside the extensor tendon sheath (intratendovaginal). The increase in the surrounding pressure reduces or ultimately stops blood perfusion inside the tendon and triggers diffuse immune reactions. The enzymes taking part in this reaction lead to both degradation of the clot and possible damage to the tendon via proteinolytic pathways. Another established theory proclaimed by Trevor in 1950 is that of an avascular necrosis due to a shearing injury of the nutrient vessels (26). The injury usually is only recognised after cast removal has taken place and the patient is once again able to freely move his fingers. Either then a lack of motion, due to tendon discontinuity, becomes apparent, or the tendon that has been intact up to this point, will now fray in active engagement (29).

Another possible complication of the distal forearm fracture, that has been seen only a few times, but affected children in most reported cases, is that of extensor entrapment within the fracture gap. The patients typically present with a history of Smith's radial fracture with loss of tendon function that had not been noticed before. Apart from the tenodesis effect, other clinical signs may include a dorsal wrist pain radiating along the anatomic path of the afflicted tendon (30). Intraoperatively the tendons usually show signs of significant damage, either because they have been frayed due to continued exposure, or because a release from the bone would not be possible without creating further defects (26). If there is a chance of intraosseous tenolysis, it should be attempted, but typically it will be necessary to do a subcutaneous tendon transfer, typically from the EIP to EPL tendon, or use a free tendon graft, either using the palmaris or plantaris longus tendon (30).
The mechanism of entrapment in the Smith's fracture is thought to occur during the initial trauma. As it is discussed to be the result of a combined move of over-pronation and flexion, the fracture gap would open up dorsally, with the bony fragment ends hooking into overlying tendon and dragging them into fracture gap, as partial reduction takes place. In this scenario the ulna acts as a pivot during pronation, the EPL tendon is displaced palmarly to be then trapped. Also the presence of tendon material in the fracture gap, quite commonly also leads to disturbances in bone healing, such as non-union or re-displacement of the fracture (31,30,26,32).

In rare cases it is possible, that ossification occurs without direct effect on tendon function, as has been reported by Kumar et al. The study group operated on a patient, who showed a slightly degenerated, yet fully functional EPL tendon within an osseus canal over Lister's tubercule. This is assumed to be the result of ossification of the pre-existing fibrous structure of the third compartment that has been triggered by screw placement (28).

However, as most reported cases were associated with the implantation of foreign material, the conclusion, as Kravel et al. suggested, lies near to reduce the number of injuries treated with open reduction and fixation. Instead cast immobilisation after closed reduction, as has been shown to be very effective in the paediatric patient should always be attempted unless there are absolute contraindications (29).

### 1.2 Specifics of the Paediatric Hand

Extensor tendon injuries of the paediatric hand, although not uncommon, do not count among the typical injuries. This fact makes it more difficult for inexperienced physicians to adequately examine and diagnose such an injury.

Due to the mechanism of injury sharp lesions of the flexor tendons are far more likely than extensor tendon injuries. This is especially true in young children, as grasping of or falling into sharp objects, with consecutive injuries on the palmar aspects of the hand counts among typical risk behaviour of a small child. However, as interaction with the child's surroundings increases and more tools and objects are used, the risk of direct damage to the extensor tendons drastically rises (4). The following section is intended to show the main differences of paediatric anatomy in contrast to adults, as well as specifics of primary assessment of the child and its injury.
1.2.1 Anatomy

There are vast differences between the anatomy of a grown adult and that of a child in all its different stages of development. The main differences, that I want to address here, are the ones that should make up for most of the changes in therapy that we see in children.

To start with bone development, there are several factors to be taken into consideration, when treating a child. With a locomotor system in the full growth process paediatric patients show a characteristic type of injury that is rather uncommon in healthy grown-ups. The growing bone, which as we know is more flexible than the adult counterpart, tends to give way easier than a tendon would rupture. This leads to a higher number of patients with osseus breakage at the tendon insertion point, with bone fragments attached to the tendon ends. This can also occur proximally with ruptures into the musculotendinous junction, through the muscular belly or at the origin points (2). This difference in bone density and mineralisation is the same that also causes greenstick fractures.

Also the physis plays an important role in both causation and therapy of extensor tendon injuries. This is particularly true in the DIP joint, as here a variety of fractures can occur that either mimic a Mallet finger or actually are equivalent to it. Thus we can have an Aitken I or II fracture as presented by Schmidt et al., both presenting themselves with loss of active extension of the distal phalanx (33). Also a full epiphysiolysis with consecutive dorsal displacement could occur, which again would present in the same way, while pathophysiologically being of a completely different nature with different complications to be expected.

The physis also plays an important in choosing the right therapeutic path, as some techniques that show good results in adults are not advisable in paediatric patients as the growth plate might be damaged in the process. This is why any temporary transarticular arthrodesis that naturally has to pierce and thus injure the physis should be very well considered and avoided if possible.

Another injury that is more typical in a child, although it can occur in adults as well, is a transverse fracture just above the physeal fissure. It is called a juxtaphyseal fracture or Seymour’s fracture and clinically presents itself very similar to the Mallet finger (34). However the injury, unlike the classic Mallet, typically is open and thus prone the infection, due to the large injured bone surface, with transverse lacerations of the germinal nail matrix being quite common. The mechanism usually involves either entrapment of the digit or heavy weight crush injury, which again would not be uncommon in Mallet fingers (35).
One fact that has been shown in several studies that included both adult and paediatric patients, is that children appear to have significantly better outcomes after tendon injuries. Suggested causes for this phenomenon have been a generally improved tendency of tendon healing, a higher degree of flexibility, lower extent of adhesion formation as well as better perfusion. Thus Friedel et al. were able to show that paediatric patients in their study of flexor tendon injuries showed the best results after tendon repair (20).

One reason for this is that the healing process in the paediatric hand is significantly more adaptive and can correct some degree of error due to it continued growth. However, the same effect can also lead to secondary problems, as is quite commonly known of long bone injuries, where an overgrowth can present as much of a problem as premature physeal closure. During the healing process of a tendon a single lengthening incident, such as in the postoperative immobilisation period, may contribute to lengthening of the tendon callus. This additional unintended tendon length, especially in the more distal Zones will most certainly lead to a lag in extension (4).

1.2.2 Examination
Examination of the paediatric patients presents with numerous difficulties, which is why the treating physician should not only be skilled and experienced in functional hand assessments, but also needs to make sure surroundings and assistance are adequate. Also some of the afore-mentioned anatomic differences necessitate different approaches in evaluating certain examination results, such radiographic findings or the degree of associated injuries.

Children, especially in pre-school age can be unable to communicate definite complaints, as well as cooperate in the physical examination of hand motor function (36). In addition to this, fear of the examining person, stress due to the unknown environment and of course a high probability of pain and expectation of pain, due to recent trauma or due to manipulation itself, make for a challenging task of performing a proper evaluation.

If any uncertainties remain after examination of the afflicted hand, the patient should be reviewed after a day or two and if possible consult a colleague, experienced in diagnostics and treatment of hand trauma in children, for definitive diagnosis and treatment (16).

Extensor tendon injuries often do not occur in isolation, due to the force necessary to cause tendon disruption. Therefore, significant damage to adjacent structures always has to be expected and a complete neurovascular examination should be performed (6). In support of this various modern imaging devices, especially sonography may be of particular benefit.
Considering radiographic evaluation of the paediatric hand one has to consider that the central physis of the distal phalanx starts to ossify at around 18 to 37 months for the fingers and about 12 to 19 months in the thumb. This means that in children of young age the occurrence of a rotational error, such as dorsal rotation, may not be recognised in radiographic examinations. However, if no prompt correction is initiated, growth deformity of the distal phalanx, disruption of the articular surface as well as derangement of the extensor mechanism may be devastating long-term results (35).

One possibility of increasing the diagnostic reliability has been presented by Soni et al., who were able to show that high-resolution sonography, when conducted by an experienced physician, was more accurate in detecting extensor tendon injuries than both physical examination and magnetic resonance imaging. This was particularly true in differentiating between partial and full rupture of the tendon, thus possibly preventing unnecessary surgical intervention, sparing both trauma and possible complications (37).

1.3 Specifics of the Extensor Tendon Zones

1.3.1 Finger

1.3.1.1 Zone I

When the topic of extensor tendon injuries and their representation in emergency departments is addressed very often the most common type of injury is failed to be mentioned. In its clinical appearance so typical and usually not associated with any wounds, the injury is well known but still seen as something different than classic tendon lesions. However, the Mallet finger, as seen in Figure 2, does count among tendon injuries and makes up a good percentage of these.

Hoch et al. reported about a third to half of all extensor tendon injuries to afflict Zone I of Verdan, or the area of the distal interphalangeal joint. Of these, the majority of 75% classified as subcutaneous lesions with no open wound to be seen (11). This number is stable among adult as well as paediatric patients and has been defined and treated the same for the last decades.
The mechanism of injury in rupture of the dorsal aponeurosis is understood to be active extension or isometric muscular activation, as in attempted extension, of the flexed distal phalanx against resistance. Due to this sudden stress on the already stretched out tendon, a rupture is likely to occur. All activities that create the possibility of such an incident to happen therefore increase the risk of causing a Mallet finger. The classical presentation, after which the injury was also named, is the maiden's injury. In this setting the bed sheets are pushed under the mattress with outstretched fingers, while the distal phalanx is often slightly flexed. If the cloth then gets caught, or the finger meets otherwise caused resistance, the sudden flexion and reflective extension can lead to rupture of the extensor tendon (11) (Figure 3).

This was quite commonly seen as cause of both soft-tissue rupture and Mallet fracture. Hoch et al., as well as Buck-Gramcko himself, however claim a different mechanism in bony injuries. According to their findings a fracture is more likely to occur, when there is an axial compression trauma to be found in the history, leading to an escaping motion of the distal phalanx. This is possible only, if one side of the joint base shears off, most probably being a dorsal flake or full fragment in the sense of a chisel fracture (11). The size of the fragment would then be due to position of the distal interphalangeal joint and the amount of axially active force. This way a fragment that includes up to 50% of the articular surface would appear to have been in hyperextension at the time of impact.
Irrespective of details in the mechanism, however, the separate entities still have a definitive presentation in radiographic examination. The well-known and clinically often used classification of Doyle has been expanded by Schmidt et al. to more specifically differentiate the physeal component as already included in Type IV A. Thus, Schmidt split up the subsection into A1 and A2 (Table 1), describing an epiphysiolysis with or without a metaphyseal wedge fragment equivalent to an Aitken I fracture -A1, opposed to a purely physeal wedge, fractured into the joint as we would see in an Aitken II -A2 (33).
Modified Doyle's Classification of Mallet Finger Injuries

<table>
<thead>
<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>I</td>
<td>Closed injury, with or without small dorsal avulsion fracture</td>
</tr>
<tr>
<td>II</td>
<td>Open injury (laceration)</td>
</tr>
<tr>
<td>III</td>
<td>Open injury (deep abrasion involving skin and tendon substance)</td>
</tr>
</tbody>
</table>
| IV A | Distal phalanx physeal injury (paediatric)  
 | A1: Aitken I  
 | A2: Aitken II  
 | B | Fracture fragment involving 20-50% of the articular surface  
 | C | Fracture fragment >50% of articular surface |

*Table 1: Modified Doyle’s Classification*

Standard therapy of Mallet finger injuries in adults usually consists of Stack splinting for 4-6 weeks with additional 2 weeks of night splinting, which is also feasible in paediatric patients and standard of care in many hospitals. Considering age and the common lack of compliance, however, Schmidt et al. promote a secure immobilisation by applying a single- or double-digit forearm cast for four weeks. The DIP is thus placed in hyper-extension with the hand in an intrinsic-plus position. The initial cast was then usually followed by another set of splinting with the Stack-splint for three to four weeks plus night splinting (33).

Outcome in conservative treatment studies usually is very good, although associated with a longer period of immobilisation and potential skin irritations due to the splint.

There are some study groups advocating surgical therapy in classic Mallet fingers as well as open lesions in Zone I. For example the study group around Nakamura was able to show very good results in a collective of patients that was primarily operated on, claiming that reduced splinting time and the exact repair method enabled the patients to return to work earlier. Also it was stated in the study, that patients, who had conservative treatment, apparently showed a lower level of satisfaction (38). Repair was performed with a wire thread that was left in situ.

As this is not a reasonable option in paediatric patients, in their surgical treatment group Schmidt had half of the patients treated with direct tendon suture and temporary trans-articular arthrodesis via K-wire (33). The other half was treated with either a variation of the two or with Lengemann sutures.
Valencia et al. described a possible complication in association with conservative therapy of type IV physeal fractures. If after closed reduction and immobilisation instability continues to persist or reduction itself proved to be incomplete in radiographic evaluation this could be caused by interposition of matrix. This then requires open reduction, freeing of the luxated germinal matrix as well as adequate internal fixation using K-wires, to prevent secondary displacement (36). With the idea of protecting undamaged strands, as well as attempting not to further compromise the perfusion of the extending system Hoch et al. suggested a different surgical approach, that is described in detail in chapter 1.5.1 (11).

In general, however, surgical treatment of Mallet fingers is viewed critically by many authors, as will be explained in chapter 1.5.3.5

As well-known as the anatomy is thought to be, there is still some degree of discussion about the insertion site of the extensor tendon on the distal phalanx. While the FDP tendon has a metaphyseal fixation, clinically the extensor hood has been assumed to only insert physeally, which has been proven wrong by both Hoch et al. and Slattery et al.. The study groups showed via histologic plastination and ultra-high field MR, that the terminal aspect of the extensor mechanism reaches all the way to the germinal matrix and thus further than the mere physis (9,11).

As described in 2005 by Ganayem et al. a juxtaphyseal fracture or epiphysiolysis with consecutive dorsal displacement of the fragment would not be classified as a Mallet finger as the tendon injury in an assumed physeal injury is not present and there is no injury of the articular surface (34). Just like the study group of Ganayem, Al-Quattan also stated this in his presentation of Seymour's fractures in 2001, where he extended it to all extra-articular transverse fractures at the base of the distal phalanx. This includes Salter Harris type 1 and 2 fractures as well as juxtaphyseal fractures. All three of these present with the exact same symptom complex as a Mallet finger, clinically mimicking the tendon injury (35). However, considering the afore-mentioned extended insertion site, one must view this statement critically. As the tendon insertion point reaches further than the physeal fissure, therefore, by definition, there also has to have occurred some sort of tendon injury. Whether this in itself is justifiable to officially call the fracture, atypical as it may be, a Mallet finger/fracture is a different discussion, which we shall not further pursue. Yet, as the therapy of these injuries does not significantly vary from the classic Mallet finger treatment, we have included our patients within this group for practical reasons.
As long as the fracture is not severely displaced simple splinting should suffice, while, if there is doubt about the patient's compliance a temporary arthrodesis via K-wire insertion may be appropriate. Also initial studies have shown that whilst some transverse fractures appeared stable during primary assessment, they developed instability after removal of the potentially lacerated fingernail. Therefore it is suggested to leave it in situ (35).

1.3.1.2 Zone II
Causes of injury in Zone II of Verdan most commonly are of sharp nature with laceration of the exposed tendon being the result. Another possible mechanism of injury, even though not as common, is that of crush incidents, as would be the case when outstretched fingers are caught within closing doors or similar objects (2).

Operative revision and suture of the tendon should always be attempted if the degree of laceration exceeds 50% of the tendon, as major deficits in function would follow (2). If the extent of the partial injury should be below this number, strict extension splinting can be attempted, with good results to be expected.

Surgical treatment of lacerations in this Zone will usually consist of adapting U-sutures, if there is not too much of a tendon deficit. If this is possible with limited strain, the outcome should be good. However, if a significant loss of tendon material is apparent usually a permanent arthrodesis of the DIP joint is advisable, as the loss in functionality is marginal and the patient should reach a stable and painless state (16). If otherwise wished by the patient, or a definite benefit can be expected, there is also the possibility to reconstruct the extensor system by using a free tendon graft. However, with the minimal gliding distances the risk of adhesions and subsequent unsuccessful results is relatively high.

1.3.1.3 Zone III
Zone III of Verdan is a rather critical one, both due to its exposed position in many activities, as well as its anatomic nature, as described above. Typical causes of injuries include sporting accidents and of course sharp laceration (23). The fine slips of the extensor aponeurosis have a high degree of interaction at this point, while at the same time, especially in the paediatric patient, being very fine, which increases both the difficulty of identifying a lesion and its surgical repair. In fact Nugent et al. could, in a small prospective analysis, show a delayed diagnosis in 80% of the cases, especially

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radiographic imaging and the common lack of a wound lead to false negative results (23).

Another problem with the area is the high risk of developing chronic impairments and structural changes such as the well known Boutonnière-deformity, which can be seen in Figure No. 4. This deformity typically develops gradually over a period of 10 to 14 days after initial trauma, “pulling up” the proximal interphalangeal joint and rendering it immobile if untreated, as active extension is continuously decreasing the further the lateral slips are moving palmarly (2).

The reason, why injuries in this Zone tend to cause chronic impairments so often, is the subtle balance reached by intrinsic and extrinsic muscular activities at this point. Thus, damage to one part of the system can lead to near complete loss of joint and finger function in the long term (39).

![Boutonnière Deformity](image)

*Figure 4: Boutonnière Deformity; Courtesy of Serah T. Seitz, BSc*

In a fresh injury, that has been diagnosed acutely and which does not show an open lesion, extension splinting of the PIP joint can be quite successfully attempted. The applied splint resembles the Stack splint and follows the same principle. Two half-tubes with a longitudinal offset of about 15 mm, are secured over the joint using medical tape, preventing any flexion in this joint (23). However, as mentioned above, said case is rather an exception.

While both lateral slips and central slip of the extensor hood can be damaged, laceration of the latter is the most common injury in this area. Repair of these structures would most likely be attempted by direct adaptive sutures, if there is no defect present. In that case simple Z-sutures or a U-suture
would suffice, as the amount of strain that is put on these strands is evenly spread onto all three slips. However, if the tendon injury, usually a central slip injury, remains unnoticed due to improper initial assessment or there is a primary defect, a functional reconstruction becomes necessary to allow for adequate use of the finger (40). Several techniques have been suggested and are still in active use, including reduction to a unilateral strand, whilst using the opposite one as a new central slip, or just plain suturing together of the lateral strands for part of their sliding distance above the proximal phalanx and thus preventing further lateralisation and improving extension (24,39). The benefit of this technique, is at the same time a disadvantage. Accessing the lateral strands necessitates a long surgical incision, and increases the risk of suture dehiscence in tendon and skin, but it does allow the correction of pathologically shortened lateral slips in long-standing injuries (24). Both of these techniques, however, show a rather high risk of recurrence in comparison to the following repairs as well as variable long-term outcomes (40).

More elegant and stable, but at the same time more invasive are a proximal turndown of the central slip in combination with suture of the lateral bands, a distally based flexor digitalis superficialis slip and the maximal therapy, which would be a free tendon graft transplant. The proximal tendon turndown is performed just as the name suggests by forming a new central slip, with a distal base, then flipping it over to readapt it with the torn off remains of the central slip. To ensure stability, the lateral strands are then sutured together to both reduce the risk of lateralisation and increase the strength of the newly formed central slip (39). With the distally based slip, difficulty increases to some degree, as the tendon's original direction of force is reversed. To achieve this, part of one of the lateral strands of the flexor superficialis tendon, typically the ulnar one, is tenotomised, leaving only its distal insertion point intact. Next a hole is drilled through the base of the middle phalanx, through which the slip is pulled to be then woven into the extensor system using the Pulvertaft technique. This serves as a strong and reliable reconstruction, that anatomically mimics the central extensor slip, with the benefit of only needing a midlateral entry point as well as a small incision in the palmar crease (40).

The free tendon graft, usually harvested from the palmaris longus tendon, is woven into the extensor hood and then pulled through a drilled hole in the middle phalanx, where it is secured by knots. Li et al. were not able to find a significant difference in the outcome of the above mentioned two techniques and also did not see any secondary Boutonnière formation (39).
1.3.1.4 Zone IV

Zone IV injuries have a high probability of presenting with partial lacerations, as the extensor mechanism at this stage is very broad. However, even if this should be fully severed, still the lateral extensor strands, partly reaching in from intrinsic muscles, partly already splitting up to pass the PIP joint, are able to achieve a certain degree of active extension. These structural elements should also keep the extensor tendon stumps from retracting (2).

The successful diagnosis of injuries to the extensor hood in Zone IV can be quite tricky, as even full thickness lacerations might only present themselves as weakness in extension. Also partial lacerations can lead to secondary adhesions and thus corrupt functionality. Therefore, a diligent examination is essential to proper treatment of Zone IV injuries. The therapy in both cases, that is full and incomplete laceration, is adaption most commonly using U- and Z-sutures, with focus on preventing any stray fibres to freely grow. Post-operatively Windolf et al. suggest a 5-weeks course of immobilisation (16).

1.3.2 Dorsum of the Hand

1.3.2.1 Zone V

Zone V of Verdan is a very common site for injuries to the extensor tendon to happen. This is due to its exposed position on the hand, as the prominent metacarpal heads prop the tendons up to be the most dorsal structure in only the slightest of the flexed MCP positions. Typical injuries include direct laceration, abrasion injuries and blunt crush traumata, with different effects on the tendon and its neighbouring structures.

If transection of the tendon occurs, usually there will be a loss of MCP extension, with partially retained DIP and PIP extension. This is due to interconnecting strands. Firstly, as the lesion occurs distal of the juncturae tendiuneum or connexus intertendinei they can no longer compensate for the deficit (5). However, the insertion point of the intrinsic hand muscles is to be found in Zone IV, which means their extending force will still be active.

The advisable suture technique at this level has also been a matter of discussion, as it depends on the skill and adaptability of the surgeon. In theory at this stage the tendon is still broad enough to anchor a proper core strand technique, which would also be advisable due to strong forces acting on this pulley point. However, the tendon also has a relatively flat profile, which makes placing of these sutures a difficult task. Also the positioning of the knots has to be well thought through, as
chronic irritation of neighbouring structures can easily occur due to the rather long gliding distance. All these reasons make a horizontal mattress suture a feasible option (7).

A classic injury in Zone V, that is frequently seen in emergency departments, is called “fight bite”. The name is derived from its usual cause, an indirect bite injury during a fistfight. The open laceration is created, when one combatant hits his opponent's mouth with a closed fist, thus bringing his exposed knuckles into direct contact with the incisors. A “bite” occurs, that typically, due to the force put into the hit, does not only severely damage the extensor tendons, but also carries a high risk of opening up the joint capsule, which can then lead to serious infection (6). This unique bite injury is well known for being associated with probably the worst bite-related infections (13). Some authors, amongst them Armstrong and Adeogun, go as far as to advocate that every open Zone V injury should be treated as a bite injury until proven otherwise, to make sure, that adequate therapy would not be needlessly delayed. In case of delayed initial management such as thorough washout and antibiotic therapy, varying degrees of cellulitis and local inflammation can be the result. Especially in children, where opening of the capsule can both happen and be overseen easily and where an infection of such an essential joint can lead to disastrous complications and long-term deficits, this standard procedure could be advisable (2).

Due to the unusual microbial contamination that is often found in the human oral flora a vast variety of bacteria have to be expected, including plant, water and soil specific entities. Although very unlikely, a rather uncommon transmission of viruses may also take place, especially so after human bites. Infections with hepatitis B and C, HIV, syphilis, HSV and HTLV-1 have been documented (13).

At the level of Zone 5, lateral fibre bundles of the just forming aponeurosis, named sagittal bands, reach around the MCP joint radially and ulnarily attaching to the volar plate, securing the extensor tendon in place and centering it (6,16).

After blunt trauma to the MCP joint, rupture of the sagittal bands can occur, subsequently leading to subluxation of the extensor tendon over the head of the metacarpal. Diagnosis is made by observation as in clinical examination patients usually have difficulty achieving full MCP extension while the interphalangeal joints are fully functional. Also the tendon typically shows deviation towards the ulnar aspect of the joint (6).
Tendon displacements over the metacarpal head have been classified into three types by Rayan and Murray. Type I injuries involve a contusion without tear, while Type II is associated with subluxation of the extensor tendon. Subluxation is defined as extending of the tendon border past the midline, while still maintaining contact with the metacarpal head condyle. A full displacement of the tendon to one side of the adjacent metacarpal heads will then be referred to as type III (6).

This full displacement of the extensor tendon is an uncommon injury and often a secondary complication of severe crush incidents to the knuckle. It is very rare in patients that do not also suffer from rheumatoid arthritis, but can and does happen on occasion, especially in children with thus far undiagnosed lax soft-tissue (8). Apart from a direct blow to the knuckle, another mechanism of injury has also been reported to be due to an indirect force, such as the patient powerfully grasping with the hand. Once the instability has been caused it can be diagnosed clinically, as it is usually accompanied by discomfort and snapping over the MCP joint during active extension of the digit (8). This is true in both type II and type III injuries because of the lateral tendon movement during flexion and extension (6).

In single tendon digits the displacements will typically occur in the ulnar direction, whereas in double-tendon digits, such as the index and small finger, a bilateral displacement may occur. In the fifth finger radial displacement of both tendons may also occur. In traumatic genesis usually what occurs is a rupture of the sagittal bands, which, as mentioned above is essential for directing the tendon over the metacarpal head. Interestingly, in contrast to the spontaneous displacements, the full sagittal band will rupture if relevant trauma occurs. Intraoperative findings have shown that patients with spontaneous displacements usually only had disrupted superficial aspects, while the deep layers stayed intact (8).

In acute displacements a good response to non-surgical treatment, usually flexion block splinting of the afflicted digit, could be shown. For this the MCP joint is put in neutral or minimally flexed position for the next six weeks, which may suffice for the tendon to heal itself. Inoue et al. therefore suggest conservative treatment in patient that present within two weeks after the initial trauma has occurred. In patients with a longer history there is little benefit to be expected (6,8).

Surgical repair of a Zone V displacement either implies direct suture of the sagittal bands, if it should still be possible, or reefing the defect using tendon material of the juncturae tendineum, or if
the material should prove to be insufficient, with graft material from the fascia lata. If both of these options are not feasible, an elegant reconstructive technique can be attempted, where a distally based tendon slip is formed and then anchored in the contralateral side of the MCP joint capsule. Typically this would be the radial side (8).

1.3.2.2 Zone VI

Injuries in Zone VI are quite common and tend to affect several tendons at the same time, as all extensor tendons of the long fingers are set in one plane on the dorsum of the hand. Sharp lacerations are the dominant cause of injury and usually are treated with direct suture, as circumstances support this procedure. Depending on the height of the injury, the risk of tendon retraction will differ, as the intertendinous connections do or do not prevent this from happening (5,15). However, this can also lead to a lower detection rate of an afflicted lesion, as partial or even full extension in the fingers may be achievable. Also if one tendon of a double stranded digit is singularly affected, then it is possible, that not even a difference in extension force might be detected. This can be the case in the second finger with either the extensor indicis proprius or the EDC being injured, as well as in the fifth finger, where the extensor digiti minimi may compensate or be compensated after laceration.

Therefore, diligent examination of hand function by an experienced surgeon is essential. If any doubt of the integrity of a structure is given, that cannot be answered by sonographic aid, then operative examination should take place.

If direct suture is attempted, some authors advocate simple techniques, such as U-sutures (16), while others support the use of mattress sutures due to the flat aspect of the tendon in this zone (7). Others again support the use of classic tendon suture techniques from this level onward, to ensure a stable repair with strong core elements (1).

However, when direct repair is not an option due to unbridgeable tendon defects, there are a variety of local techniques to choose from. Firstly, a coupling of extensor tendons can be performed, with the distal stump of the tendon being sutured onto an intact neighbouring tendon, thus allowing for extension function, whilst giving up individual controllability. Another possibility is the transfer of one of the two additional extensors that we usually find in the hand, being the extensor indicis and the extensor digiti minimi tendon. When performed correctly the patient should only suffer minor
extension loss in the donor finger, while gaining proper extending function in the receiving digit. The ultimate solution, as mentioned several times before offers a free tendon interposition, commonly using either the palmaris longus or plantaris longus tendon as graft donors (16).

A positive aspect of this Zone is its wound healing properties. In relation to other Zones injuries show a relatively low risk of developing adhesions, which may be due to their isolated path. Unlike other areas, the tendons do not cross any joints which would imply some degree of interaction with the fibrous capsule (16). This is also the reason why lacerations in this Zone show a low number of secondary problems. A typical, complicating factor, which is injury of joints, is rarely associated with these events, as lacerations of the fifth Zone tend to be single-Zone injuries.

1.3.3 Forearm

1.3.3.1 Zone VII

Due to its anatomic properties Zone VII is amongst the areas in the forearm with the lowest risk of extensor tendon injuries. Both the overlying retinaculum and their proximity to the bones offer some degree of protection against direct cuts or abrasion injuries. Still possible damage can occur in penetrating trauma, as well as secondarily due to fractures. To exclude this possibility, diligent physical and surgical examination of the injured Zone should always be performed if there is any cause to suspect injury in this Zone. Clinically the injury should present itself as complete loss of extension in the MCP joint of the longfinger, or as loss of motion in the distal interphalangeal thumb joint (16).

During surgical evaluation, the extensor retinaculum needs to be opened via Z-incision to allow for proper vision of the potentially afflicted structures. If there are any tendon lacerations to be seen, the same techniques, used in flexor tendon repairs, can be attempted here, as tendon cross-sections should show a near-circle.

Whatever technique may be chosen to repair the tendon, a careful closure of the entry incisions is very important. Therefore the retinaculum should always be sutured with adapting running or interrupted stitches. To avoid the undesirable effect of tendon bowstringing, a dorsal stabilisation should always be given (16).

Any injuries at or in the vicinity of the extensor retinaculum pose a high risk of developing adhesions over the course of tendon healing. This mechanism has been demonstrated in a cadaveric study by Chinchalkar et al. in 2010 and is due to several reasons. Firstly, formation of direct strands
of adhesion to the retinaculum can occur after injuries to both tendon and tendon sheath, potentially affecting any other tendon gliding through the same extensor compartment. Secondly, there is the possibility of direct tendon adhesion to another, most commonly affecting the independent strands of the extensor communis digitorum tendon. If such an adhesion forms just before or after entering and leaving the extensor retinaculum and their respective compartment, the conjoined tendons fail to pass through. In serious cases this can not only lead to loss of individual finger control, but even diminish wrist flexion or extension as a whole (21). This is especially true in chronic injuries and tears, where scarring of the tendon stump to other soft- or bone tissue can occur, thus losing functionality (6).

1.3.3.2 Zone VIII & IX
When an injury in Zone VIII occurs, usually there is extensive soft tissue damage to be expected. The tendons can reach quite deep, which means that along with subcutaneous tissue there also will be some degree of vascular injury, making initial examination more difficult and necessitating surgical exploration in almost all cases (16). Considering tendon repair however, the tendons both show a strong and even profile at this height, which makes the placing of supportive core strand sutures a relatively easy task. Also due to the mechanism of injury, usually no major loss in tendon length is to be expected.

The tendons in this Zone cover gliding distances of over 40 mm, which leads to a very low number of scar adhesion complications, due to reduced contact time. Wildly growing fibrous tissue will be sheared off before taking any effect on tendon function. Also perfusion values is better in this proximal area, which does not only improve and speed up tendon healing, but also ensures adaptation of the surrounding tissue to oedema etc (16).

Due to its special nature of musculotendineous passages, setting stable sutures can be at times very challenging. If rupture of the tendon goes on into the muscle, the surgeon has to make sure, that he places the suture bites into the centre of the muscle, where a stronger fibrous structure is found. Matzon et al. suggest in their study to perform multiple figure-of-eight stitches, to ensure that enough soft-tissue is being grabbed and the thread will not rip out immediately. They also advocate the use of a slowly resorbing suture material (6).

The ninth Zone of Verdan, as added by Doyle, is the driving muscle belly. This distinctly sets it apart from injuries in the other Zones, as neither causes, presentation nor therapy correlate with
these (2). Luckily injuries in Zone IX do not occur very often and if they do, either careful readaptation of the muscle can be performed with uncertain outcome, or muscle function will have to be replaced by others.

1.3.4 Thumb

As already explained in chapter 1.1.2 the thumb can also be classified in Zones of Verdan, just as the rest of the hand is. The zones are named PI to PIII and then go over into the “classic” zones VI and onwards. There has been some discussion on whether or not also to differentiate zones PVI and PVII, but there is no relevant change in therapy, that would necessitate such action.

1.3.4.1 Zone PI

Zone PI of Verdan also describes the area distal and immediately adjacent to the IP joint, with the mechanics in action being very similar to those in the long fingers. Changes that are of some relevance to both likelihood and type of injury as well as to therapy and healing processes, are mainly the change in axis and a different tendon structure.

With the EPL tendon entering the dorsum of the hand in the third extensor compartment, it not only has to travel at strong angles in zone VI, but also offer a rather strong extension for the distal phalanx. The tendon therefore presents itself with a much rounder transverse section that only during the very last millimetres changes to a more elliptical shape.

Differentiations that must be considered especially in the thumb, due to its unique anatomy, are the names of “Mallet” and “dropped” finger. While the clinical presentation may appear to be the same, the zone of injury in the Mallet finger will by definition always be the first of Verdan’s (I, PI). The dropped finger presents with history of injury in a more proximal zone, typically up to the metacarpophalangeal joint (V, PIII). This way it is easy to see, that both therapy and outcome of the non-Mallet reach into a different treatment plan that will be discussed separately. Therefore it is important for the initial evaluation to take into consideration the history of the injury. A dropped thumb may also develop “trick extension” after a few days. This is caused by intact expansions running from the abductor pollicis brevis and adductor pollicis to the extensor hood (41). Amongst many authors there is still some degree of discussion on how the injury should be classified and
whether or not there is an equivalent status to the classic Mallet finger, due to the afore mentioned
differences in tendon size and structure (1). Overall incidence of Mallet finger injuries in the thumb
is by far lower than in the long fingers (42).

Back in 1983 Din et al. suggested surgical treatment of all Mallet thumbs due to three reasons: the
lack of reported successfully conservatively treated injuries at that time, the stronger and thus easier
to suture tendon and the in contrast to the long fingers higher chance of tendon retraction due to the
lack of the connexus intertendinei, as well as fewer direct connections to anatomic structures of the
dorsal thumb (41). Patel et al., however, recommended an approach completely contrary to that of
Din, not only advocating the conservative therapy of subcutaneous rupture, but even treating two
patients with sharp laceration of the EPL tendon with simple extension splinting, one of which was
a 15-year old boy with per secundam healing. Also, he stated that tendon retraction is not as critical
as so far assumed, due to a relatively stable insertion of the aponeuroses of both APB and adductor
pollicis over the entire tendon length (42).

Elliot et al. described an increased effect of an EPL lesion on the interphalangeal joint movement,
the further the injury moved distally, which means that at the height of PI one should be able to see
a maximal effect in IP movement reduction due to EPL lesion (1).

Overall, one can say, that the Mallet thumb does in many ways resemble the Mallet finger in both
clinical presentation and therapy. However, lower incidence and less therapeutic experience may
lead to higher numbers of surgical interventions, than the injuries would benefit from.

1.3.4.2 Zone PII
As mentioned above Zone II of Verdan has a relatively high incidence of sharp injuries due to its
exposed situation. Even more so in Zone PII, as the thumb of the non-dominant hand plays an
important role in grabbing and holding of objects. Therefore, most of the injuries in this zone are
lacerations that demand some sort of surgical attendance.

Very typical injuries of Zone PII are sawblade lacerations, either due to saw slippage in hand held
saws, or because of reaching into a stationary machine. Especially in the paediatric hand a single
bounce off the dorsum of the extended thumb can be enough to cause partial to full tendon
transection. Depending on intensity of impact, type of saw and breadth of the blade, there is a
relatively high chance of creating a tendon defect, which can be very difficult if not impossible to
reconstruct in this zone. Usually there would be need of a tendon interposition graft or whole
tendon transposition, as the EPL tendon does not offer good properties for using proximal turndown slip techniques.

A positive aspect of this Zone, however, is that usually still no tendon retraction will occur, as the insertion of the APB and AP muscles hold both ends in place (5). Therefore, if no relevant defect is found, adaptive sutures using Z- or U-sutures should suffice to achieve adequate tendon positioning.

Not presenting a common, but still very typical injury, trauma of Zone PII therefore should be treated with a focus on reaching a good functional outcome as it significantly attributes to the function of the most important finger.

1.3.4.3 Zone PIII

The third Zone of Verdan in the thumb is unique in the aspect, that, unlike Zones PI and PII, there are no interconnections to other tendons any more. Therefore an injury at this height allows for free retraction of the proximal tendon stump. A vast majority of injuries in this region are caused by direct trauma with sharp objects and laceration in result, mostly by knives or glass, whilst only a very small number is caused by blunt crush trauma (1).

In correction of injuries to this region, typically it is necessary to set a wide initial incision for successful detection of tendon ends. When placing this S-shaped cut, the surgeon has to consider the sharp angle the EPL tendon has to take and therefore aim for a point just distal of the third extensor compartment. Tendon repair usually is possible using one of the more adapt techniques, due to the good profile of the EPL tendon. If there is too much gapping, or too many adhesions in old injuries the most commonly used reconstructive technique would be forming an extensor indicis transposition. For this the extensor indicis tendon, after making sure its EDC companion is strong enough, is dissected just proximal to the MCP joint, tunnelled over to the thumb and there reconnected or -inserted (27).

An important aspect that has to be considered is that, when doing an extensor indicis transfer, the surgeon must be very careful in choosing the load or initial level of tension, that is put on the new tendon. A lax structure, with too little stress to hold the joint in place, will be useless and non-functional. Then again, if the initial tension is set too high, the transfer may hinder the thumb from reaching full flexion, a complication, which is not only highly restricting in everyday activities, but also will not be recognized too soon, as initial immobilisation makes it impossible to diagnose the degree of maximum flexibility (16).
A relevant problem in this Zone, as in many others, is that of tendon adhesion, as there are still relevant distances to travel and several surrounding structures can serve as adhesion points.

As described above the tendons of the abductor and adductor muscles share insertions with the extensor mechanism. According to Elliot et al., this also appears to be the reason why in proximal EPL tendon injuries, leading to secondary scarring, there seems to be less interference with interphalangeal joint movement (1).

Elliot et al. were also able to show a fascinating effect in thumb function that they, whilst describing it, were not able to fully explain. Patients with EPL rupture or otherwise caused loss of function, exhibit a phenomenon of change in relative movement of the two distal thumb joints. Thus, a reduced range of motion in the IP joint quite commonly is associated with an increased range of MCP movement, as well as the other way round. This “adaption” to loss of a single joint by utilising space in the other joint may simply reflect the versatility of this special finger (1).

1.4 Conservative Therapy

In paediatric surgery, conservative therapy holds a very unique position, due to the incredible ability of children to spontaneously correct a whole variety of injuries due to normal growth. This can also be partially true in tendon injuries, as some defects, that ended in overlength or shortening of a tendon, may no longer show a noticeable loss in function after few months or years. However, any full lesion will need medical attention, either with surgical therapy or conservative measures.

1.4.1 Immobilisation

Immobilisation of an injured extremity in neutral positioning can, if applied correctly, allow for the tendon ends to reconnect and regain functionality. The following points should explain some of the most common ways of reaching sufficient immobilisation of the limb. However, upon using these there are a couple of limitations that have to be considered.

The critical age for any sort of immobilisation is in children five years old or younger. Fitoussi et al. could show a higher percentage of extension lag in patients within this age group, when compared to other children with analogue injuries. This is partly due to the extreme difficulty of adequate fixation, which the treating physician or nurse faces when applying either cast or splint, as well as caused by the low level of cooperation, that can be expected (4).

Loos et al. specifically focused on the importance of proper immobilisation in context of suture
dehiscence in EPL reconstructions, as significantly increased numbers of this complication could be found in patient group without immobilisation of the affected extremity (27). This has been repeatedly seen and reported in many different injuries and affected regions, which is why adequate immobilisation is always suggested.

### 1.4.1.1 Stack Splint

The Stack splint is a very simple and yet effective immobilisation device for the distal interphalangeal joint invented and tested by Stack. Its form mimics half a finger, into which the injured digit is inserted. The distal part is open on the dorsal side, allowing for a direct view onto fingernail and surrounding tissue as well as improving ventilation. The proximal end is open to the palmar aspect of the finger, where fixation can be applied either in form of a velcro band or more typically using a strip of tape.

In classic Mallet finger injuries Windolf et al. suggest 8 weeks of continuous splinting, with another 4 weeks of night-splinting to follow. This should ensure a stable tendon situation not in need of further physiotherapy, as long as the patient applies sensible levels of exertion. This simple technique can also be attempted in old ruptures with quite some success (16).

The main problems that do occur when using this splint, are skin irritation due to inadequate ventilation of the digit in combination with bad hygienic measures. Another difficulty is that of taking off the splint. While it is advised to do so, in order to clean finger and splint, it is essential that no flexion occurs during these off-splint times. A single flexion event can undo weeks of healing. Also due to their standard measures, fitting them to children may not be possible in some cases.

An alternative to the established Stack-splint was suggested by Dr. Abouna in 1965, introducing a wire based DIP splint that allows for better fitting and improved ventilation, therefore theoretically eliminating the main complication that is skin maceration. However, the splint did not prove to be practical and could not show improved outcomes (43). Another splint, introduced in 1993, also followed the principle of an improved fit by making it a malleable padded aluminium alloy system, thus reaching a higher applicability and less skin complications. In a randomised trial, the antero-posterior DIY splint showed comparable functional outcomes associated with a lower number of both macerations and ulcers, making it a feasible alternative to the Stack splint (44).
Richards et al. presented a model for the conservative management of the Mallet finger using custom-fitted thermoplastic splints. The greatest benefit of this technique lies in avoiding the two most common complaints of the Stack splint, improper fit and skin irritations (45).

1.4.1.2 Single-/Double Finger Splint Cast
This is an immobilisation device that is commonly used in our hospital, as it allows for general immobilisation of the forearm, thus reducing the risk of unintended slippage of the splint, as well as making it harder for the paediatric patient to willingly take off the splint.

This system has a pliable finger splint as basis, which will then be fixed to the hand using plaster of paris or synthetic plaster substitutes. Depending on the age of the treated child only the afflicted finger or, following the buddy-tape idea, the neighbouring as well, will then be fixed onto the splint using medical tape. To allow approximation of the detached extensor tendon it is necessary to relax the lateral ligaments. To achieve this a splint should ideally be able to hold the PIP joint in a flexed position while the DIP joint is extended. (46). Moulding the splint, a mild hyperextension of the DIP joint should be achieved, to ensure proper contact of the tendon or bone ends. In addition a small block of foam could be placed under the distal phalanx to support hyperextension while ensuring there is not too much pressure applied to the joint.

Possible complications include those that will be found in any cast therapy, which are rashes, compression spots and breaking of the cast. However, in general it is a very reliable system, that allows for little to no manipulation of the afflicted digit.

1.4.1.3 Full Cast Immobilisation
Putting the full forearm into a cast will become necessary in any tendon lesion, where movement of the tendon is to be prevented. This includes nearly every tendon repair, which is not treated with early active motion therapy. Every other lesion should be put in a cast that inhibits any voluntary and involuntary activation of the hand, as is especially necessary in the waking phase after surgery, where due to inadequate vigilance and lack of pain significant overstress of fresh sutures is possible and has quite often led to rupture of repairs.

The cast should, if possible, be applied in a manner that allows for vision of the surgical site and skin sutures, so as to make monitoring possible. In extensor tendons this is usually possible when wrapping the plaster around the wrist and forearm in a spiral. Thus, coming from the palmar side of
the hand, Zones V to VII should be fully visible. This is then kept in place by using gauze and elastic bandages. Instead, there is also the option of a plain palmar plaster splint, which should also give good initial stability.

In specific tendon injuries special techniques may be of use, as can be seen in EPL tendon injuries. After EPL reconstruction it is advised to immobilise the patient using a hitchhiker's cast. In this special cast, the forearm is put in plaster, with the thumb protruding at a near 90° degree angle. It should be kept in place for about 4-5 weeks after injury (27).

1.4.1.4 Early Controlled Motion Rehabilitation

The topic of early partial mobilisation and passive mobilisation after tendon repairs has become increasingly important over the last decade, as several large scale studies were able to show significant benefits in avoiding secondary complications such as adhesion, joint contractures and muscle loss (47).

However, as these techniques are always very closely connected to the accompanying therapy, it will be discussed in more detail in point 1.6.2 Occupational Therapy.

One splint technique that finds its use in early controlled motion techniques, is a flexion block yoke. It is used as an adjunct to a palmar wrist arthrodesic splint, described by Howell et al. It allows the treating physicians to reduce the angle at which the wrist is set, as flexion of the injured finger can never exceed that of his neighbouring digits -10° (48). If all digits are moved at the same time however, no stress can be applied to the suture site, as passive movement of the afflicted tendon is achieved over the intact juncturae intertendineum, thus allowing for adequate tendon gliding and preventing the formation of adhesions.

1.5 Surgical Therapy

In sharp lacerations of extensor tendons, primary suture or generally speaking, primary repair should almost always be attempted, unless factors such as severe contamination, infection and complex hand defects forbid such procedure. Interestingly flexor tendon lacerations show a significantly higher degree of contamination due to the different soft-tissue structure, where detritus is caught much easier. In comparison the extensor systems tend to be cleaned rather easily unless there are joints involved (22). Steinberg et al. even classify the lack of a handsurgically trained team
as a relative contraindication for primary suture of flexor tendons (20). Due to secondary oedema and tendon retraction delayed repair can present with severe difficulties and cause further complications.

The specifics of surgical therapy may vary between surgeons and departments, but general consensus in paediatric surgery usually includes a proper surgical environment, that allows for diligent examination of the afflicted area and careful repair or reconstruction of the injury. This means the operation should ideally be conducted under ischaemic conditions or at least with partial blood flow arrest, as well as using a loupe (16). In children this also means, that the operation usually cannot take place in the alert patient, as cooperation and compliance are not to be expected below school age. Therefore usually a total intravenous anaesthesia, or deep gas narcosis is the method of choice. Also Elliot et al. presented a higher incidence of complications in patients, where tendon suture was performed under local anaesthesia (1). If already in adults such a difference can be shown, it is most likely safe to assume, that in paediatric patients with lack of understanding the process and the implications of movement, combined with general anxiety, even with patient sedation, local techniques will not be beneficial in outcome.

1.5.1 Specific Surgical Techniques

In the following chapter a couple of techniques that are commonly in use when doing surgical repairs or could be of interest in further development of the surgical finesse will be described. It does not give a full representation of techniques available, nor are all of them to be suggested in paediatric patients.
1.5.1.1 Incision Techniques

The decision where to place the surgical incision in the hand does not only affect long-term scar formation, but can also effect blood supply of the region operated on, as well as directly influence the outcome due to accessibility of the desired structures. Several studies were able to show the influence of scar structure on both diagnostic accuracy and functionality (24).

In paediatric patients (Figure 6) most of the above named factors apply in an even further increased importance, as due to growth some scar structures may also expand to increased prominence and visibility. The may as well, however, develop in the opposite direction, with the repair tissue being rigid and restricting normal expansion and development of healthy tissue. This way secondary contractures of joints may be created, as well as normal hand movement be changed in a way that does not allow the child to develop natural function.

Figure 6: Incision Techniques; Courtesy of Serah T. Seitz, BSc
Many scars that are due to accidental lacerations can not be influenced, but wherever surgical incisions are set, heed should be paid to their consequences.

Transverse incisions over joints, as well as extensive longitudinal incisions should, if possible, be avoided, as increased tensile stress can occur during finger flexion that could then lead to scar dehiscence (16). The same is true for any incisions on, or closely parallel to the interdigital webs, especially between the first and second finger, as well as circumferential and spiral incisions in the fingers.

The skin should also be considered when setting incisions, as the dorsal skin is significantly thinner and has a poorer blood supply than its palmar counterpart. Also while usually forming zig-zag lines in the palm, lazy S-shaped incisions might be preferred on the back of the hand (5,16).

If there are any pre-existing wounds, that can be integrated in the incision, this should only ever happen at the wound ends, to avoid forming of mini-flaps and star-shaped, stellate scars. Generally speaking no wound edge should have an angle of less than 90° if that is possible.

1.5.1.2 Temporary Arthrodesis

In some cases it can be necessary to put an artificial limitation to joint mobility if it serves the cause of tendon healing. Most typically this will be the case in Zone I injuries to the distal end of the extensor mechanism, but it may as well be applied in other Zones within the phalanges and possibly metacarpals. Any Zone more proximal would not only offer unideal locations for transfixation but also be at a much higher risk of wire fracture, as strength and leverage increases.

While a proper arthrodesis would imply significant surgical manipulation of the joint, the idea of a temporary arthrodesis is that of bridging the joint with a stable object that usually will be fixated internally. Most commonly this is done using normal Kirschner-wires that are placed through the joint with an electric drill and then cut off just above skin level to allow easy removal.

In case of a DIP joint immobilisation there are several options to choose from, each offering different risks and benefits. First off, a single wire can be sent straight through the whole distal into the middle phalanx, with an insertion point just below the nail bed. This usually is relatively simple to place and should therefore only demand a single drilling canal (33). While being placed in a strong axis and thus holding the joint very well, it also does not offer any rotational support.
Theoretically, in an epiphyseolysis thus a rotational error could occur without noticing or treating it adequately. Another option would be to place the K-wire diagonally through the DIP joint, anchoring it within the corticalis of the middle phalanx. This indeed is an elegant method, if performed correctly. Risks are higher, that it is not properly anchored in one of the bones, as well as drift off in a second axis, which is why this must always happen with radiologic realtime evaluation.

As in both PIP and MCP joint an axial transfixation is not really an option, usually these two joints will be blocked with a diagonally running wire.

1.5.1.3 **Ishiguro Extension Block Technique**

The team around Ishiguro found a surgically assisted blocking technique of the distal interphalangeal joint in Mallet fractures, primarily Doyle's IV B and C, not only to be effective, but also to show lower complication rates as compared to open revision. To achieve a proper fragment alignment, the distal phalanx is distracted and while in flexion blocked dorsally by drilling a Kirschner wire through the distal extensor tendon into the middle phalanx, thus preventing any retraction of both tendon and the attached fragment. After the first K-wire is safely placed, the distal phalanx is extended dorsally, pressing it onto the fragment and ensuring proper contact. A second Kirschner wire is then inserted through both phalanges for temporary arthrodesis at an angle of 30-40° flexion, which is also supported by applying a splint (Figure 7). The wires are meant to stay in place for about four to six weeks and to be removed once radiological evidence of bony healing can be seen (49).

Pegoli et al. could also show astoundingly positive results in a collective of 76 patients of which 11 were lost to follow-up. Of all these patients only one developed a pin tract infection and nail deformities, which were not persistent, were seen in two patients, making up a 5% complication rate. The results showed 13 fair and one poor outcome, assessed with the Crawford’s evaluation criteria. Also the research suggested a percutaneous curettage in chronic cases with the initial trauma lying back more than 5 weeks ago. This is performed with an 18g needle, to puncture the fracture gap with a dorsal approach and then freshen up the opposing bone surfaces (50).
As good as this technique may appear for the adult patient it does present several difficulties in paediatric application. Most importantly one must consider the effects of the compression onto the growth plate and the possible impact on physeal healing. Another problem is the amount of radiation that is necessary to be applied to successfully place the wires and to verify the stable bone structure upon removal of the metal. Also any use of K-wires must be put into relation to possible infections and secondary bone loss. As the same injury usually does heal without major complication in the child, setting the indication for a therapy with this degree of invasiveness should always be judged critically. Still, the Ishiguro extension block technique is a valid therapy with reduced tissue trauma and should, in our opinion, be considered as an option.
1.5.1.4 Functional reconstruction in Zone I

Due to the risk of potentially damaging still intact parts of the tendon in Mallet fracture repairs, Hoch et al. suggested a surgical approach entering from the side of the DIP joint. This would protect any dorsal strands that still support the fragment. The transarticular entry into the fracture gap allows for a more diligent alignment of the fragments and fixation with K-Wires, via retrograde drilling (11). However, especially in the growing patient, the heavy manipulation, that is necessary to successfully set the fixation can lead to injury of the physis and physeal fissure. Therefore it might not be recommended to pursue this technique in paediatric patients. One benefit of the approach however, that could be of particular use also in paediatric patients is that small fragments, that have a higher chance of fracturing, when directly pierced by a Kirschner wire, tend to stay intact when drilled into from the direction of the fracture (11).

Gu et al. presented a new technique of functional reconstruction in Zone I and Zone II lesions of the extensor aponeurosis, which did show promising results in a collective of adult patients being operated by microsurgically highly experienced surgeons (51). Their patients consisted of chronic as well as acute cases of injury to the distal extensor tendon without fracture or any sort of osseus involvement. The study group then went on to harvest a palmaris longus tendon slip of about 30-40 mm length which they knotted up on one side to increase tendon width. In the next step a hole was drilled through the base of the distal phalanx leaving enough space so as neither to harm the joint cartilage nor the germinal matrix. Through this hole the palmaris longus slip was then threaded coming from palmarly until the knot blocked further insertion. To complete the procedure a pulvertaft weave of the slip into the sound extensor tendon was performed.

While results of the technique were exceptionally good, to our reckoning it is neither a feasible option with small fingers and inadequate microsurgical training to perform such a task, nor is it necessary in nearly all paediatric cases of Zone I injuries.

1.5.2 Suture Techniques

Generally speaking of tendon sutures and especially in the case of extensor tendon sutures there are several aspects that have to be considered. Many of these are closely related to the specific characteristics of the tendon as a total and its changes along the course, as described under point 1.1.1.
From a practical point of view, especially in the paediatric patient, basic aspects, such as time to perform the suture, necessary equipment or advanced microsurgical training and feasibility of the techniques in very small tendons, become relevant. At the same time scientifically measurable properties of a suture offer a certain degree of comparability amongst different types and options. These are typically assessed by material testing devices, derived from industrial purposes, such as described by the study groups of Newport and Lee (7,25). Variables in these tests usually are load to failure, load to gap formation, tendon shortening, suture/tendon stiffness but also time to perform the technique. Also one factor that very inconsistent and thus not easy to anticipate is the degree of adhesion that will follow the injury. Although probably not the main factor, there is still a definite influence of the suture technique onto adhesion formation.

Limitations of the studies often tend to be of methodological nature. As vital tendons outside of an animal model do not offer the option of proper testing, most often research teams opt for either anatomically preserved tendons or fresh frozen tendons to perform sutures and tests. Even though these offer the possibility of a horizontal comparison between the different techniques only very limited conclusions can be drawn regarding a vital tendon. Apart from altered consistency of the tendon material and following changes in the likelihood of tendon rupture or a tear of the thread canals, also the strain in the material is different in the living or rather moving organism. While material testing devices apply a constant linear pull, there is the same level of strain throughout the tendon. Due to changes in hand position there are changes in strain on the different parts of the extending structures (7). Also most core suture studies usually use round tendons as can be found in flexor tendons, while few ever attempt to show the effects on the flat tendons of the dorsal hand. Also specific suture techniques aimed at extensor hood injuries tend to be very few, as both incidence of these injuries is not as high and the anatomy of the structures often only allows for adaptive interrupted sutures.

As mentioned above, side effects of suture, such as loss of tendon length due to the adaptation technique can bring about new difficulties. Not only is both knot and tendon more likely to give way under the increased pull, even if the splint is set up to alleviate the problem by increased extension, it also has a direct effect on the mechanical properties of the system. Even in the developing child deficits in tendon length may not be fully compensated. Looking at the effect on functional parameters of the finger Newport et al. reported that a tendon shortening of only 8 mm
during suture resulted in a 23° loss of flexion (25). In contrast to these findings, the study group was able to show surprisingly low shortening effects, when they repeated the exact same suture techniques in Verdan zone IV. Also there was no significant loss in flexion to be seen in both MCP and PIP joints. Newport interpreted these findings as due to the strong interaction of the extensor hood with both bones and connective tissue at this level. So these structures do not only prevent retraction, but also reduce side effects of surgical treatment (18).

There is one very interesting fact about extensor tendon repairs, which shows how much of a difference there can be between seemingly similar structures, as well as prove, that extensor repairs just as any tendon repairs belong in the hand of an experienced surgeon. Functional testing of extensor tendon sutures have shown that with any given suture technique the repairs are only approximately 50% as strong as flexor tendon repairs with the exact same technique (7).

1.5.2.1 Kirchmayr-Kessler

The Kirchmayr-Kessler suture is probably the most common suture technique in hand surgery (Figure 8), being a strong and reliable system that is relatively easy to learn and can be modified into other, even stronger techniques. Also, while it was originally used in flexor tendon repair, it does also serve very well in proximal extensor tendon injuries in Zones VI-VIII. This technique also is the primary suture in our house.

Being a two-stranded core suture, the suture is started off by introducing the needle into the tissue at the rupture site and pulling the thread through to a distance of about 5-6 mm into the vital tendon. At this height the needle is sent through the tendon transversally, creating the first of four loops. After the passage of the needle through the tissue the third bite leads the thread back into the rupture site, from which on, the exact same procedure can be repeated on the opposing tendon end. The surgeon should end up with four minor loops on the lateral sides of the tendon ends that tighten with placing of the knot within the rupture site. To reduce the risk of adhesion by singular strands growing off-direction and to further improve the stability of the technique, a circular continuous or interrupted suture of the epitendineum is also performed with a thinner thread.

The classic Kirchmayr-Kessler's suture when performed with a single-strand core element has been reported to show a mean load to gapping of about 13-16 N in flexor tendons, as compared to other multistranded tendon repair techniques that have shown ultimate tensile strengths of over 30 N (52).
However, the report by Nietosvaara has to be viewed with the limitation that, while the comparative aspect is true for extensors as well, the load to failure cannot be seen as equal.

Typically core suture material of 4-0 to 5-0 is used in paediatric patients, while the epitendineum is sutured with a 6-0 thread.

![Figure 8: Kirchmayr-Kessler Suture; Courtesy of Serah T. Seitz, BSc](image)

### 1.5.2.2 Modified Bunnell

The Bunnell suture technique, also known as Lee's, and its most commonly used modification are quite closely related to the Kirchmayr-Kessler suture. It follows the same principle of placing the knot with the two core strands into the rupture site and attempting a stabilisation by adding transversally running lines of thread. Also the tendon zones where it can be used effectively correlate with the afore-mentioned technique.

The needle is again inserted in the lacerated tendon face, but contrary to the Kirchmayr-Kessler suture already crossed over now and passed through the contralateral side of the tendon. In the
classical Bunnell technique the surgeon would now either sling around the tendon or set a transversally running bite, while the modified Bunnell sets another cross suture distal to the rupture site, as shown in Figure No 9. The needle is then worked back mirroring the opposite side and creating the double cross this way. Once the thread has reached the rupture site, the same is repeated on the other end of the tendon. Again, the knot is buried in the rupture site to prevent irritations, while the epitendineum is closed as described in the Kirchmayr-Kessler technique.

Lee et al. were able to show the mechanical properties of this technique or rather a further adaptation with a four strand core element in their attempt to prove the superiority of the Horizontal Mattress Technique. Their devices showed them a tendon stiffness of about 6.719 N/m, which is quite comparable to Becker's technique. They did, however, also show a tendon shortening of about 6.3 mm, due to the cross-stitches, that create some degree of longitudinal compression. The ultimate load to failure, whilst not statistically significant, was shown to be the lowest of the tree sutures compared with about 48 N (7).

In a comparison of zone IV tendon repairs, the modified Bunnell's technique could be shown to have a significantly stronger mode of failure, with a low number of suture pullout (18).

Figure 9: Modified Bunnell's Suture; Courtesy of Serah T. Seitz, BSc
1.5.2.3 Augmented Becker

The augmented Becker's suture is a multiple core strand technique, depending on the number of sutures, that the surgeon wants or is able to apply to the tendon. It is a further development of the original Bunnell suture and follows the same principle, with both the knot being buried within the tendon and the stabilisation being drawn from cross-stitches. Unlike the Bunnell's however, the criss-cross-stitches do not only go through the tendon, but also across the surface and far more close to each other.

The knot is started off the same way, by introducing the needle into the tendon at the rupture site, but pulling it through to the surface after 2-3 mm already and performing the first cross-stitch, before doing an intratendinous cross with the second bite, which is again followed by a superficial cross. After a straight transversal bite, the next steps mirror the procedure so far, completing the crosses as can be seen in Figure no. 10 and 11. The procedure is repeated in the opposite tendon end, with care not to twist the tendon while doing so, as two to three of these sutures are set into the tendon. Any change in tendon rotation can affect its gliding properties, especially in the extensor tendon that underlies strong changes in tendon structure.

![Figure 10: Becker's Suture; Courtesy of Serah T. Seitz, BSc](imagedata)

![Figure 11: Modified Becker's Suture; Courtesy of Serah T. Seitz, BSc](imagedata)
This suture was also evaluated in a comparative study published by Lee at al. In this study a double augmented Becker's suture was assessed, which means that the system had a four-strand core suture element. A tendon stiffness of 5.971 N/m could be shown, as well as a tendon shortening of about 6.2 mm due to the traction. The ultimate load to failure was found to be the highest amongst the compared with a destructive force of about 53 N being necessary for the suture to give way (7).

### 1.5.2.4 Running-Interlocking Horizontal Mattress Suture

The Running-Interlocking Horizontal Mattress Suture is a relatively young technique when compared to the traditional suture systems, that have been in use for over 60 years. However, due to several studies conducted over the last decade it has started to gain an increasingly good reputation and has become standard of care in many hospitals.

In contrast to the afore-mentioned suture techniques, this one starts off with a classic running epitendinous suture leading away from the surgeon as seen in Figure No. 12. The idea of this basic primary adaption is stabilise the tendon for the second suturing line. At this point the tendon cannot be seen as stable and there should be a careful focus on not putting any tension on this construct. However, it must be made sure, that there is enough tension on the thread throughout this first step, as this technique is one continuous suture.

Once this first line of bites has been set, the suture continues using the same tendon returning in direction of the surgeon, but switching from the simple running type to the wider spread mattress stitch (Figure 13). In addition to the broader set in between the bites the entry points are chosen to allow an interlocking of the thread, while still leaving an appropriate distance between the puncture holes to prevent rupture of the superficial tendon. This way a good distribution of the acting forces can be achieved and the risk of pullout minimised. Also the strong connective character in its horizontal orientation makes it possible, to set the bites rather close to the rupture, which then again leads to a lower shortening (7). Due to their system both the modified Bunnell as well as the augmented Becker techniques necessitate suture placement farther away from the rupture site than this technique (7).
It is important to notice, that this technique follows a completely different system than the others and could thus be better suited for extensor tendons, than other systems. The surgeon appears to ignore the three-dimensional aspect of the tendon and, instead of superficially anchoring strong core strands, he appears to only apply a two-dimensional flat suture. However, exactly this in combination with its strong testing values makes it a great technique in extensor tendons and their rather flat aspect.

1.5.2.5 Pulvertaft Weaving Suture

The Pulvertaft suture as it is usually used today differs from the original publication, as it was not well defined in said paper. Over the following years and decades the technique has been repeatedly varied applied in different ways and circumstances (53). The technique described in this thesis, which is also depicted in Figure No. 14, is to our knowledge the most common technique at this time, and is also the same as is usually used in our house.
Unlike the simple side-to-side suture technique which implies a single weave through the distal tendon end and fixation of the tendon, the Pulvertaft suture is a multiple weave technique, which allows for a greater contact zone between the tendons and more stabilising cross-stitches.

Several incisions are made on both sides of the distal tendon stump, through which consequently the proximal tendon is then pulled most typically using a mosquito clamp or other sharp clamp. Thus weaving one tendon into the other, the end of the proximal stump is then sutured to the epitendineum of the distal tendon (Figure 14). On every entry and exit point of the tendons further cross-stitches are set to reduce the risk of a secondary tendon gap and dehiscence.

Brown et al. compared the side-to-side tendon repair to the Pulvertaft technique and managed to find significantly lower values for tendon stiffness and maximum load to failure for the Pulvertaft repair (53). However, the team did not compare it to the cross-stitch secured weave, but rather to a variation, were the Pulvertaft suture is only stabilised with a mattress suture, resulting in tendon slippage, once the knot gave way.

Overall, one can say that the Pulvertaft weaving suture is a very reliable and strong technique to successfully reconstruct tendon defects. However, to be able to achieve proper suture strength an overlap of at least 10 mm is necessary, which usually is not an option in common extensor tendon injuries. In reconstructive surgery, especially when it comes to EPL tendon reconstruction and Zone VI to VIII defects, the Pulvertaft weave is an effective and advisable technique to connect tendon interpositions.

Figure 14: Pulvertaft Weaving Suture; Courtesy of Serah T. Seitz, BSc
1.5.3 Complications

Whether it may be due to surgical intervention or because of the original trauma, handling the long-term consequences of unwished side-effects can be challenging and treatment may not always be possible. As stated by the American hand surgeon Wyndell H. Merritt, “The greatest challenge in treating the hand is to preserve the function in all of the structures not directly injured.”, one can see, that the hand being a fascinating and complex system needs continuous stimulation and activation to preserve its function. Once these stimuli and tasks are taken away from it, due to injury or immobilisation, there is a high risk of creating additional problems.

As in many different fields of paediatrics, both of surgical and medical nature, children once again show astonishingly low numbers of complications after therapy. The growing body is not only able to compensate for a wide variety of lost functions, but also quite commonly actually heals without signs of the original impairment.

However, the hand is still a region that has to be handled with care, as quite a variety of potential problems can occur. These are of varying origin, as the extensor mechanics are an intricate system affecting and interacting with bones, skin and blood vessels in every Zone one way or the other. Therefore classical “tendon” complications such as adhesion, contractures, secondary rupture and callus lengthening must be considered just as well as osteomyelitis, epiphysiolysis, wound dehiscence and both tendon and skin necrosis.

According to the findings of Fitoussi et al. the main complications after extensor tendon repairs in children unlike in adults are tendon rupture and callus lengthening (4).

Also in hand surgery one can quite commonly observe a trend of rising incidence of poor or failed end results with increasing number of surgical interventions that have taken place. This has been shown by Friedel et al. in a flexor tendon collective, but clinical experience suggests similar numbers in extensor tendon injuries. This is also true for the extensiveness of a single procedure (20).

1.5.3.1 Adhesion

A major problem in tendon repairs, that puzzled early hand surgeons and was the primary drive in developing new tendon sutures, is that of adhesions, bundles and strands of fibrous tissue coursing from the tendon to tendon sheath, skin, bone and other tendons. They can significantly limit tendon movement and lead to complete immobility as the tendon gets fused with the surrounding structures.
Several reasons for this significant phenomenon in hand surgery have been discussed over the last fifty years, with Bunnell already stating that the main problem most probably was due to tendon tethering, which has been proven conclusive by several following studies, as well as by individual clinical practice and experience (1). This also leads to modification of tendon sutures to reduce the presence of free tendon strands being exposed to surrounding tissues, as can be seen in chapter 1.5.2.

Adhesion formation is usually reduced by the fact, that during undisturbed tendon healing, there is an increase in synovial fluid, which diffuses around the lacerated tendon allowing for intrinsic tendon healing, without direct contact to surrounding structures. If this is not possible, or overlying structures are injured as well, extrinsic tendon healing processes start to be at work, with proliferation of fibroblasts originating from the peripheral epitendinous layers. This increased activity is predominantly mediated by an influx of fibroblasts and inflammatory cells from the tendon sheath (2).

Following this rationale a diligent epitendinous suture which prevents free tendon strands to provoke partial extrinsic healing should significantly contribute to successful prevention of tendon adhesions.

Elliot et al. described an increased degree of scar adherence of finger extensor tendons in injuries within the digit itself. This is due to several reasons, including the reduced gliding distance of the tendon, as well as the reduced space for the post-traumatic expansion of the extensor compartment. This makes the accommodation of oedema inbetween skin and bone more difficult, increasing pressure, reducing joint movement and thus increasing the risk of adherence (1).

In accordance to this, it has been described in several cadaveric studies that to successfully prevent tendon adhesion, a gliding distance of at least 5 mm in Zones V to VII. To achieve this extent of tendon mobility, a metacarpophalangeal motion of at least 30° would be necessary (21). This again would support the use of early active motion therapy.

Also extensor tendons have been shown to be more prone to developing adhesions than flexor tendons due to their different shape. The characteristically flat tendon body allows for a greater surface area between tendon and most typically, bone (17). Secondary adherence to the underlying bone or the overlying skin by scar tissue formation, largely explains restrictions in finger movement. As the extensor system shares strong interactions with dorsal capsules of the joints, thickening of the scar tissue serves as another relevant factor to the loss of motion (1).
Facing all these factors, that can influence successful tendon healing, Newport et al. go as far as to say that iatrogenic surgical factors may not even play a significant role in poor and fair results after extensor tendon repair in Zone IV, but rather adhesion formation most likely being the main cause of therapeutic failure (18).

Tenolysis being the surgeon's option of tackling this problem, should only be attempted after a minimum of three months wait after the initial surgical procedure. That is, with free passive joint mobility being given and a patient, that is cooperative enough to suggest success at such a tricky intervention (16). Logic as it may seem from a mechanical point of view, removing the adhesion and constricting factors, obviously opens up a multitude of tiny lacerations on the tendon surface. This in combination with a patient, that already appears to be prone to developing this complication, the risk of returning adhesions obviously is quite high.

1.5.3.2 Tendon Rupture
Secondary tendon rupture after successful initial repair is probably the most dreaded early complication of extensor tendon surgery. Although with new suture techniques and a higher degree of specialisation of surgeons the numbers of tendon ruptures go down, there are still many possibilities for it to happen.

As mentioned above the most common incident would be directly after surgery, with a patient regaining partial control over his body while still not being fully vigilant. Any forceful contraction can lead to rupture of the fresh sutures, especially as the patient cannot yet be warned by pain due to analgetics. One option to prevent this from happening is to apply local plexus anaesthesia, paralysing the arm until cognitive protection of the wound can set in.

Also one has to take into consideration, that compared to flexor tendons extensor tendons due to a lower number of crossing fibres offer less grip to sutures and generally present with a higher rate of thread slippage.

The most critical time of tendon rupture, however, only starts after 2-3 weeks. This is not due to suture technique or involuntary action, but rather because of patient compliance. At this point, the skin should be healed, any residual pain should have vanished and the hand will feel as if it is able to function again. However due its slow physiology, at this point the tendon is still far from being fully functional. Thus any slight active force can lead to distraction and any actual contraction can be enough to set an end to a beginning healing process.
1.5.3.3 **Callus Lengthening**

As mentioned above, Fitoussi et al. were able to show that amongst the primary complications in pediatric patients is that of callus lengthening (4). Just as in bone healing, there is also a callus formation to be found in tendon healing. This callus forms around the third to fourth week, offering a first connection and bridging of collagenous fibres across the gap. Any slow traction that is now applied to this structure will lead to a tendon, that is relatively longer than intended. Again this mechanism is very similar to bone healing, where the same system is actively used to increase bone length.

This traction can be any chronic process that forces the tendon to follow, as could be witnessed in improperly fitting immobilisation devices that instead of achieving proper extension or hyperextension allow for a small degree of flexion. A tendon chronically set in this position will memorise the maximum degree of extension and set this as a new standard.

One benefit however, is that in children, there is a relatively high chance, that a certain amount of overlength may be corrected during further growth. Therefore when callus lengthening does occur, a period of watchful waiting and monitoring the child during its maturation is advisable.

1.5.3.4 **Infection**

Soft-tissue infections of the hand are a dreaded complication in hand surgery, as progression may be rapid and many essential structures can be afflicted within days or even hours. This is due to the combination of many continuous organs and elements offering pathways for bacteria to spread, as well as very little soft-tissue that would form some sort of natural barrier against invading bacteria.

This differs slightly when viewing the dorsal and palmar aspects of the hand. While offering less fatty tissue and fibrous elements to reduce the risk of infection, cleaning of the area usually is easier and more effective than in palmar areas, where deep contamination can take place (22). Therefore, in comparison the extensor systems tend to show lower rates of infection unless there are joints involved.

Apart from all the typical injuries to the hand, that bring with them all sorts of bacteria, such as sawblades, knifes and other machinery, there is one particularly dangerous source of infection, which is the human bite. More virulent than most animal bites, this is not an uncommon sight in emergency departments.

Typical germs that are to be expected in human bite wounds include Staphylococcus aureus,
Streptococci family, as well as Haemophilus, Bacteroides and Eikenella corrodens. Antibiotic prophylaxis, typically using penicillin based antibiotics such as Flucloxacillin, is required in all bite injuries that reach deeper than the epidermis, especially over joints and cartilaginous areas, as well as all presentations with a delay of over nine hours (13).

In case of animal bites, the hand is typically the most prone area to sustain a wound, as petting, grabbing of an animal or in defensive action when shielding the face put in the first line of attack. This is also true for children, which due to their natural curiosity and naivety are often put at risk of suffering bites. The second most bitten area, very common in toddlers, would be the head as it typically is in range. When comparing different animal bites however, it is noteworthy that, in comparison to dog bites, cat bites are more likely to lead to infection of the bitten hand (13).

Also in cutting injuries with a knife, there should be a diligent history taken. Especially after being in contact with raw meat, the risk of developing an infection is very high.

1.5.3.5 Zone I Troubles

The topic of surgical treatment in Zone I injuries repeatedly appears in literature with study groups presenting excellent results in their own collective of operative Mallet finger repairs (38). However, several studies conducted on a larger scale managed to show a higher morbidity in operative treatment as opposed to conservative therapy (33,46,54). Therefore it may be safely suggested, that unless there is an open injury to the DIP joint or an irreducible fracture-displacement, conservative splinting should always be attempted.

Kang et al. were able to show a complication rate of 41% in surgical treatment of Mallet fracture patients. Complications included marginal skin necrosis, which made up the dominant part of 14 cases, but also recurrent flexion deformity in 8 cases and pin tract infection in 4 cases. All the patients were treated with the classical approach of open reduction of the fragment and consecutive transarticular fixation with a Kirschner wire. For skin incision two different cutting techniques were used, the lazy S-shaped and the T-shaped incision, which is also in discussion of disrupting proper blood flow to the insertion site. 10 of the 14 cases of marginal skin necrosis were seen in patients were the lazy S-shaped incision was used. However the skin complications tended to resolve within an average of two weeks (54).

As seen in this study, skin complications usually show a high potential of healing without further intervention being necessary. The fingers being one of the most distal organs have a high risk of
reaching a dangerously low perfusion pressure and especially when the injury or the operative access leaves narrow skin flaps or edges an adequate nutrition of the areas cannot be ensured. Secondary wound healing however covers defects quite well. If the necrotic gap is too wide, a full-thickness skin graft should be considered.

The dreaded complication of osteomyelitis following pin tract infection, rare as it may be, still causes problems on a regular basis. Early signs for an infection, diagnosed by localized swelling and pus discharge at the pin site and following the pin track, should be immediately answered with oral antibiotics. The question, whether or not to remove the Kirschner wire is still very much in debate, although leaving them in-situ appears to be safe under close monitoring, regular check-ups and continuous medication (54). If there are any radiological signs of beginning osteomyelitis along the pin track, as can be seen by a loss of density in the bony structure, there is an absolute indication to remove any foreign bodies, to both reduce the existing bacterial count as well as improve circulation as it is.

In recurrent flexion deformity it can be attempted to achieve correction by conservative splinting. If this fails to show the desired effect, the options are rather limited. Either another attempt in surgical treatment is made, although at this stage, usually the inevitable loss of tissue and material forces the surgeon to apply reconstructive measures, which tend to show less beneficial results the further distal the defect presents itself. Especially in Zone I even a persisting extension deficit might be favoured over the risk of another surgical intervention at such a site.

Another common complication in Zone I are temporary or permanent nail deformities, most commonly caused by postoperative haematoma over the nail bed or direct injury of said structure. The pressure onto the germinal matrix of the nail can cause irritations and the consecutive lack of stimulation, local overgrowth or, upon direct injury, partial displacement and growth in the wrong direction. This might be prevented by avoiding placing the skin incision too close to the nail bed, as well as diligent haemostasis. However, while the incidence of postoperative nail deformities could be predicted by the presence of a subungual haematoma, the severity of the haematoma could so far not be seen in correlation to the severity of the following nail deformity (54).
1.6 Complementary Therapy

The key to any success in surgical treatment, as has been stated by Friedel et al., is the diligently conducted post-operative care. This is incredibly important in all hand injuries, but in extensor tendon injuries with all the possible complications that have just been named, this becomes even truer (20). The following aspects of hand therapy should give a small glimpse into the wide therapeutic possibilities that can and should be accessed in paediatric hand patient care.

1.6.1 Hand Therapy

A major field of occupational therapists and physiotherapists in hand therapy is the continued supervision and therapy of patients with complex immobilisation systems, such as the various different types of early active motion systems. In treatment of these patients it is essential to ensure sufficient communication between treating physician and therapist if a good functional result is wished for. Also the therapist should be familiar and confident with the system in use, just like the physician prescribing it. However, if these circumstances do apply, active systems of immobilisation can bring significant benefit to a large number of patients (55).

The option of early controlled motion rehabilitation becomes increasingly relevant the further proximal a laceration occurs, as hand and wrist function in general have a higher risk of suffering from prolonged immobilisation. This may lead to joint contractures, tendon and band shortening as well as adhesion formation (47). Friedel et al., for example, promote immediate mobilisation not only after tendon suture, but also after nerve suture, which usually is considered at even more risk to develop dehiscence, starting on the first postoperative day (20).

During the early phase of these exercises, however, the treating medical staff should monitor both the local aspect at repair site, to keep oedema under control, as well as the vigour of exercise so as not to incite an unnecessary inflammatory response (48).

In a large scale systematic review of studies using static splinting versus studies advocating dynamic splinting and early controlled motion, Sameem et al. could show “excellent” and “good” results of 61%-100% of the cases treated by static splinting, depending on both Zone and study group, where the tendon repair was performed. The assessed Zones reached from V to VIII. The
studies using a dynamic splinting regime however, could show final evaluations of “excellent” and “good” cases of 81% to 100% with a greater overall total active motion (TAM) in postoperative examination. Early active motion studies also have shown very similar results to dynamic splinting, but with less comparability, as stated by the authors. Very few comparative studies have been undertaken evaluating these protocols directly, which makes it very difficult to draw conclusions regarding the superiority of one over the other. However, the benefit of dynamic splinting systems over a static regime in extensor tendon repairs of the Zones V to VIII was apparent (47). Even though these numbers appear to speak in favour of a dynamic system in all patients, this systematic review only assessed studies conducted in adult patients. Therefore it is difficult to draw definitive conclusions in the paediatric patient.

As mentioned above, in extensor tendon injuries close to the extensor retinaculum there is a high risk of tendon adhesion to both retinaculum and neighbouring tendons. To prevent this, a specific dynamic mobilisation protocol has been suggested by Chinchalkar et al. The wrist should therefore be put in a tenodesis splint with individual finger loops preventing active extension. In this splint differential tendon gliding exercises have to be practised, ensuring sufficient flexion in the MCP joints, as mentioned above (21).

However, there can also be limitations to this technique, as immediate mobilisation has been reported by Elliot et al. to frequently cause pain and discomfort to the patient, which can then lead to these being reluctant to exercise. So, apart from paediatric patients usually tolerating a longer period of immobility without secondary limitations in function, early or immediate mobilisation should only be attempted under adequate analgetic therapy (1).

One aspect that also tends to be easily forgotten by doctors and seen by therapists is that of general functionality. Because essential as continued training may be to transplanted or sutured tendons, there also has be taken care of structures that will be affected in consequence. Therefore in EPL tendon reconstruction using the extensor indicis muscle and tendon as functional transplant, apart from the obvious therapeutic necessity of the altered thumb extension, it is also important to train index finger extension. Again, this is even more so in paediatric patients, as a choice in profession usually has not yet taken place and, so as not to create possible limitations, the treating physicist and therapist should always aim to ensure a forceful extension of the index finger (27).
Another domain of hand therapists is that of fabricating special splints, addressing the individual needs of patients which can be of benefit in many different Zones and repairs. Richards et al. for example presented good outcomes in treatment of Mallet finger patients, when using custom-made thermoplastic splints. These offer the benefit of always providing a proper fit as well as showing a significantly reduced number of patients with skin irritations. This may be due both to the proper fit preventing sliding of the splint while also needing less medical tape to ensure it will stay in position, while allowing for adequate ventilation within the splint. A good hand therapy department should therefore be able to supply these crafted splints (45).
2 Material and Methods

2.1 Study Population
The Department of Paediatric and Adolescent Surgery in Graz, Austria is the biggest centre offering tertiary care in the south-eastern part of Austria. It serves a population of about 1 million with primary care of rural areas usually being provided by general surgeons and trauma surgery departments, that will refer the patient if the extent of injury is too great or complications arise.

The study design being a descriptive retrospective analysis of the epidemiology in extensor tendon injuries was intended to show an overview of causes and therapy of these traumata. Originally it was intended to expand the study to include functional follow-up examinations for all patients, which was abandoned due to time issues. Therefore, a pure statistical evaluation of the existing data was performed.

After approval from the local ethics committee of the Medical University Graz we went on to search the medical records of all patients treated between 2003 and 2012 for patients who had been treated at our department for injury of an extensor tendon of the hand, filtering databases with a variation of the terms “extensor”, “extensor tendon” and “tendon laceration”. The retrieved files were then evaluated for whether or not they met the inclusion criteria.

This pool of patients was then analysed for a variety of influencing factors such as age, type of injury, accompanying injuries, mode of therapy and complications.

2.2 Inclusion Criteria
Criteria for inclusion of patients in our study were injury to an extensor tendon of the hand with complete or at least essential treatment at the Department of Paediatric and Adolescent Surgery Graz, including aftercare and early follow-up. The patients' age was defined to be 0-18 years, as all patients within this age group are treated in the department.

Treatment of these injuries was allowed to include both surgical and conservative therapies.
2.3 Exclusion Criteria
Exclusion criteria were loss to follow-up in case of several patients that injured themselves during their holidays and where secondary care was provided at home, as well as patients from peripheral areas that preferred further medical attendance close to their home town.

Furthermore, any patients with complete amputation of the limb in question were excluded from the study, as a whole variety of influencing factors make the objective assessment of the tendon injury near impossible.

2.4 Research Methods
Acquisition of relevant literature was performed with the help of databases such as PubMed, Ovid, and Google Scholar, which were searched using a variation of the terms “paediatric extensor tendon injury” in differing compositions. This led to a surprisingly low output of about three studies and reviews specifically addressing the subject of extensor tendon injuries in children. Therefore, the limitations to included studies were loosened to include studies which allowed for extrapolation of relevant information, such as extensor tendon injuries in adults or flexor tendon injuries in children. Also several studies with mixed populations, including both paediatric and adult patients were scanned for information on performance of young patients in these study models.

Progressing in research, defined topics concerning specific sub-themes were searched for. This included clinical and mechanic studies on suture techniques and clinical feasibility, infection risks, possibilities of immobilisation as well as topical anatomical findings. This also included specifically searching for relevant studies cited in other documents.

Defined as relevant to this thesis were clinical studies, as well as reviews and case reports offering theoretical background on functional, anatomical and clinical aspect of extensor tendons. This also included repair and splinting techniques that currently find application in paediatric patients.

2.5 Statistical Analysis
Analysis of the retrieved data was primarily done in LibreOffice Calc, using descriptive tools to assess the individual patient groups.

The registry was searched for patient contact data in case of secondary assessment, while in a separate sheet all relevant factors concerning accident and therapy were listed.
The assessment was split into the segments of “mechanism of injury”, “primary assessment”, “therapy” and “outcome/complications”. Also in all cases where operative care had been provided another group of “surgical therapy” was added. Within these segments various parameters and findings were noted.

The section “mechanism of injury” included date of accident, age at injury, cause/activity and associated injuries. “Primary assessment” included the factors of whether or not primary care had taken place in another hospital and if so, where that was and what measures were taken by the staff. Also side, Zone of Verdan, tendon and in multiple lacerations, the number of afflicted tendons, as well as type of injury and functional presentation was assessed.

In “therapy” evaluated data included time to first contact and treatment of choice, including wound care, immobilisation device or devices and relative duration of immobilisation. In case of surgical management the parameters included time to surgery, surgical date, surgical technique, suture technique, suture material, multiple surgeries, and duration of inpatient stay.

The evaluation of “outcome and complications” included the number of times a patient was seen again, final evaluation of function when existing, as well as temporary and permanent complications. These unfavourable outcomes were split up into functional deficit, fragment displacement, pain, infection, loss of sensation, failure of immobilisation device, cutaneous problems, nail deformities as well as rare issues, such as hypertrophic scar development and granuloma formation.

The evaluated functional parameters were then retrospectively classified using Miller's evaluation (56) of extensor tendon repairs.

Each of these parameters was then assessed for relative numbers and percentages in the full collective and then repeated separately for all patients with injuries to Zone I of Verdan, as it presents a unique entity and major group of extensor tendon injuries.
3 Results
The following results have been extracted from the recorded data. As no standardised procedure has been followed at the time of assessment and documentation, repeatedly unsatisfactory information was found, which, however, should not significantly alter the data presented here.

3.1 Epidemiological Aspects
After exclusion of all patients with incomplete sets of data and inadequate follow-up examinations, the total number of patients included in our study was n=143.

The injuries included in our study reached from a single case at the end of 2003 to 2012 with a minimum of one in the first included year. As this may be due to filtering more realistic minimum numbers are presented in 2004, 2005 and 2012. The maximum number of patients was treated in 2011, where 28 cases of extensor tendon injuries presented themselves. A mean of 14 patients were treated per year as can be seen in Figure 15.

![Figure 15: Cases per Year](image)
Also, as was to be expected, distribution of the incidence of extensor tendon injuries over the course of a year showed a preference towards spring and summer months. As many accidents are associated with sports and other outdoor activities, this trend proves to be the same as in most paediatric trauma cases.

Thus, we could find a 19 patient peak in extensor tendon injuries in the month of June accounting for 13.29% of recorded cases. The months with the lowest incidence were February and December with 6 patients each being registered over a course of 10 years. During the meteorological seasons of spring and summer about twice the number of patients was injured, making up 90 patients or 64.94% of the collective (Figure 16).

In our patient population we could see a gender distribution of three to one, as 106 patients were male and only 37 patients were found to be female, making up about 26% of the group. This appeared relatively stable when viewing patients with Zone I injuries independently, where 32% of all injured children that we included in our study were female. In a collective of 77 cases this made up 25 girls and 52 boys.

*Figure 16: Yearly Distribution*
Furthermore we took a look at the age of the patients and whether any definite and characteristic patterns were obvious regarding this parameter. While the number of injuries showed a stable increase reaching from 1 year of age in four cases to one 18-year-old patient, a very clear peak could be shown among 14-year-old’s. With 21 cases and making up 14.69% of all patients, they exhibited the highest probability of extensor tendon injuries in our group.

The average age of the patients was 10.8 years with a median age of 12 years. Viewing different age groups, one could see a steady increase of injuries over the years. While in 0-5 year-old infants and toddlers the number of injuries was 24, making up 16.78%, it rose to 35.66% among school children (6-12 yo) and was 47.55% of the group with 68 injured adolescents (13-18 yo).

This trend was also visible when assessing Zone I injuries independently. The trend of increasing risk with rising age even appeared to be stronger in this single Zone, as the age groups started at 11.59% (n=8) in infants and toddlers, to reach 57.97% (n=40) in adolescents (Figure 17). Median and mean age, however, were only slightly higher than in the whole group, with the mean age lying at 12.0 years and a median at 13 years of age.

![Figure 17: Age Distribution](image-url)
The injury did not show any significant preference in side. This was found to be true in both full group and Zone I patients. By trend in the full group the left hand was afflicted bit more often, with 75 injured patients (58.04%), while the right hand was injured in 67 patients, accounting for 46.85% of the collective. Viewing Zone I injuries independently, this slightly higher count of left hand injuries was further diminished to 52.17% with 36 patients versus 47.83% or 33 patients with injuries to the right hand.

A total of 60 patients (41.96%) were seen and/or treated in other hospitals before coming to our hospital for definite treatment. These hospitals included 13 Austrian hospitals within a radius of about 75 km, as well as 2 foreign hospitals. Also 3 patients were primarily treated by general practitioners.

### 3.2 Injury

The injury itself occurred due to a variety of reasons. With 56 cases of the full collective cut injuries reached the highest percentage of 39.16%, closely followed by injuries caused by ball sports/play. These cases made up 29.37% and counted 42 (Figure 18). Other relevant causes, although set at a significantly lower number, were contused lacerated wounds (CLW) in 11 cases, crush injuries in 9 cases as well as fight injuries, both blunt and sharp, in 6 cases. When combining bike and road accidents with their different specific causes of injury, traffic associated injuries made up 8 cases.

Of the cut injuries many were contracted during household activities, such as using a bread knife or while carving pumpkins, counting up to 6 documented cases, as well as during crafting. These injuries occurred while whittling, or using Stanley's cutting knives, and reached a number of 15 cases. In case of ball play and ball sport injuries, in close to half of the cases a specific sport was not documented, which could be both due to undefined play or lack of documentation. However, in all patients were a notice could be found, football made up 19.05% of all ball associated injuries, counting 8 injuries. In addition, Volleyball was found to be the cause in 5, and Handball in 4 cases.
When viewing Zone I and PI as an independent group, cut injuries drastically lose in relevance, while still being the second most common cause of injuries to this Zone at 10.14% (n=7). The highest rate, however, has ball play. At 57.97% (n=4) it is highly relevant to consider in unknown causes.

In 27.27% of the cases (n=39) accompanying injuries were documented, which counted up to 51 injuries in total. Most common were fractures in 22 cases (43.14%) and CLW's in 13 cases (25.49%). This number also went down to 20.29% (n=14) in Zone I injuries.

The Zones most commonly affected were Zone I with 56.10% of the cases (n=69), as well as Zone II and V with 9.76% (n=12) and 10.57% (n=13). This pattern slightly changed when including the Zones of multiple Zone injuries. While also gaining in numbers (n=79), the dominance of Zone I lesions was slightly lessened going down to 47.31% of the cases, while especially Zone II and III rose to 11.38% (n=19) and 7.78% (n=13). Solitary Zone injuries were documented in 123 cases, while 20 patients exhibited lesions in multiple Zones.
When evaluating which tendons were primarily injured, the extensor digitorum communis tendons of the second and third digit showed the highest risk of injury with 28.00% (n=35) and 28.80% (n=34) amongst the solitary tendon injuries. Still in multiple tendon injuries the same pattern can be seen, with Zone II and III coming down slightly to 27.95% (n=45) and 27.33% (n=44). In our full collective solitary tendon injuries were seen in 125 cases which is 87.41%, while multiple tendon injuries accounted for 12.59% (n=18)

Considering the number of tendons in multiple tendon injuries, in 13 cases two tendons were affected, 4 cases with triple tendon lacerations were seen, as well as a single case, where transection of 4 tendons occurred.

Among the patients with Zone I and PI injuries a 3:1 ratio of open versus closed tendon lesions could be shown. Sharp laceration of the tendon occurred in 20 of 77 patients, making up 25.97%, while all closed injuries combined, including subcutaneous ruptures and avulsion fractures, reached a total of 81.16% (n=56). In Zone I alone sharp lacerations made up 18.84% of all injuries (n=13).

Among the group of closed injuries, subcutaneous ruptures made up 23.21% of all Zone I injuries (n=13). Of these 2 ruptures were found to be old injuries, with delayed presentation to primary assessment. The injuries were classified as old when the surgeon examining during initial presentation documented it as such. This usually was the case in patients were the time of accident lay back more than 7 days and no adequate primary care was performed during this period. In case of avulsion fractures this number was at 5, with 3 patients having old displaced bony fragments.

Avulsion fractures in general were separated into two groups, those who did show displacement of the fragment and those who did not. The total number reached 48.05% (n=37) of all Zone I and PI injuries while 37.84% (n=14) of these showed osseus displacement and 62.16% (n=23) did not.

Additionally 2 patients (2.6%) presented with an epiphysiolysis of the distal phalangeal base and consecutive partial dorsal displacement.

The most common tendon or digit affected by Zone I injuries was the extensor digitorum communis digiti III tendon, which finds its insertion point in the middle fingers distal phalanx. It was afflicted in 39.13% of all Zone I injuries (n=27), while the other tendons were set at 23.19% (n=16) in ED dig II and 18.84% (n=13) in ED dig IV and V.
When splitting this up even further into closed and open lesions, then an interesting trend can be seen. While closed injuries, as in Mallet finger injuries, show roughly the same tendon distribution, with the ED dig III coming first with 44.23% (n=23) and the other tendons being set at 23.08% (ED dig IV, n=12), 17.31% (ED dig V, n=9) and 15.38% (ED dig II, n=8), open injuries prefer different fingers. In these patients 47.06% of the cases (n=8) afflicted ED dig II, showing a definite preference towards the index finger when compared to 23.53% in ED dig III and V (n=4).

3.3 Therapeutic Measures

Time to treatment varied ranging from less than 2 hours up to a maximum of 48 days, with the majority of 105 patients, which is 73.43% of the full collective, being treated within a day of the accident. Within the time frame of 4 to 7 days post-trauma, 10.49% (n=15) of the patients were treated, while during the second week after injury only 5 patients were treated. However, 14 more patients or 9.79% of all cases were treated 15 days after accident or even later. Treatment of these figures included both conservative and surgical measures.

3.3.1 Conservative Treatment

A variety of different cast and splinting techniques were used in our patients, including some that found exclusive application, while others were used in conjunction with differing methods. The splints included the traditional Stack splint, thermoplastic custom-made splints, as well as dynamic splint systems. Casts that were used included forearm or full arm casts, especially in young patients, while there were also specific techniques such as the “Hitchhiker’s” thumb cast or a palmar plaster backslab.

In addition other, more invasive techniques of immobilisation found application in some patients of our study. These obviously cannot count among conservative measures, however as support of these a Kirschner wire may be placed for transfixation and immobilisation of the joint of interest.

The most common immobilisation device found in this study was the plaster backslab with single or double digit extension with usage in 75.52% of the patients (n=108). The second splint that found broad use was the Stack splint in 47.55% (n=68), while dynamic splinting and simple dressing were the most uncommon in 1.40% (n=2) and 2.80% (n=4) of the cases.

Duration of splinting varied amongst different techniques, Zones and tendons. However, the average duration backslab finger casts were applied evened out to 4.17 weeks, surpassed only by Kirschner wires, which stayed in situ for about 4.42 weeks. The Stack splint, which was typically
used secondary to backslab treatment, showed a reduced usage time of only 3.14 weeks. Custom-made thermoplastic splints stayed on the injured limb for 3.5 weeks.

In Zone I immobilisation presented similarly to the full collective with increased prominence of classic immobilisation methods, as was to be expected. Thus 71.01% of all patients with injury to this Zone (n=49) were immobilised using a single- or double-digit plaster backslab and another 68.12% (n=47) then followed or primarily treated, with Stack splints. Also custom-formed thermoplastic splints were not uncommon, as they found application in 20.29% (n=14). Duration of immobilisation in a backslab plaster in Zone I injuries averaged on 4.04 weeks, while Stack splints usually were kept on for 3.5 weeks.

3.3.2 Surgical Treatment

Of the total number of 143 patients 68.53% (n=98) required some sort of surgical intervention to successfully treat the injury, while in 31.47% (n=45) conservative treatment sufficed. The number of patients operated on includes all cases and thus primary interventions as well as secondary surgical measures due to an unsuccessful conservative attempt.

Time to surgery ranged from same-day intervention in 61.86% of all surgical patients (n=60) to a maximum delay to accident of 49 days. On average delay was 3.01 days with the median of 0 days. 15.46% (n=15) were operated on the following day, 4.12% (n=4) on the second and third day and 7.22% (n=7) within the fourth to seventh day. 11 patients (11.34%) were operated on old injuries, defined as a delay of over 7 days. Of these, 5 patients showed an old avulsion fracture in Zone I while one patient presented with an old subcutaneous tendon rupture in the same Zone. The remaining 5 patients developed secondary difficulties after initial wound management had been performed inadequately. Two of these had suffered a contused lacerated wound and three showed old cutting injuries.

Multiple surgeries were necessary in 11 patients, which makes up 7.69% of the full collective.

When assessing which Zones were predominantly operated on and how many patients in each group needed surgical intervention as opposed to a conservative approach, interestingly it turned out, that apart from Zones I and PI every other Zone showed a 100% rate of surgical revisions. Among
patients in Zone I only 36.23%, that is 25 of 69, were treated surgically, while in Zone PI 87.50% of all patients were operated on, which are 7 out of 8. A total of 63.11% of all single tendon injuries needed surgical intervention.

The suture techniques most commonly used in tendon reconstruction, as are extracted from all definite mentions of the suture technique in the surgical protocol, are U-sutures followed by Kirchmayr's core sutures and the classic interrupted suture. Not every protocol did include the suture technique, as well as some did include a combination of several techniques, or several mentions for several independent structures, that were readapted. Therefore, the following numbers cannot be put into direct relation to complications or outcome and should rather be seen as a rough representation of techniques used in our hospital.

U-sutures, being the most common technique, were applied 40 times, which amounts to 49.38% of the 81 mentioned sutures, while the Pulvertaft weave technique was only mentioned in a single case. The Kirchmayr suture was the most common core-suture and reached a number of 19 (23.46%), when combining original form and modified versions. And even though it would not be expected in tendon injuries, 12 mentions of interrupted sutures made up for 14.81% of all sutures. This number is most likely due to its preference in distal strand lacerations.

When viewing the Zone repairs independently a steady decrease in advanced suture techniques could be seen upon moving distally in the hand. While the only solitary laceration in Zone 7, as well as 3 of 4 injuries in Zone 6, were treated with a Kirchmayr-Kessler suture, in Zone 3 and 4 no core suture technique was used in any of the lacerations. Instead U-sutures were used more often, which was shown in Zone 3, where 3 of 4 repairs were done with these stitches.

In contrast to this, Zones PI-PIII showed a different suture preference. Thus 3 out of 7 PI repairs were performed using the Kirchmayr-Kessler technique.

In injuries with multiple tendons affected, there also was a higher number of complex suture repairs to be found, even though no injury to Zones 7 and 8 and only 1 laceration in Zone 6 was reported. Even the higher number of EPL lesions can only partially explain the high number of Kirchmayr-Kessler sutures of 6 in 20 lacerated tendons.

Surgical therapy in Zone I of Verdan presented with interesting results. While in some types of injuries no invasive therapy took place others presented with surgery performed in 100%. Thus, all of the 11 fresh subcutaneous ruptures, 19 undisplaced avulsion fractures and physeal detachment
patients were treated conservatively. Sharp lesions, however, were operated on in all 13 cases without exception. The remaining injuries, showed surgical intervention in about 50%, without clear indicators why the treating surgeon decided for or against surgical therapy.

Upon dividing Zone I into closed and open lesions it was also possible to see a much higher surgical rate amongst all open injuries. In all 17 patients were some sort of disruption of the skin had taken place, invasive therapy was deemed necessary, while only 8 out of 52 patients with closed lesions were operated on. This is as little as 15.38% of a group that makes up two thirds of all Zone I patients.

3.3.3 Follow-up Treatment

All patients treated in our hospital were seen on a regular basis post-operatively. These check-ups usually took place in specific hand clinic hours, with an experienced surgeon assessing the progress of wound healing and regaining of functional properties.

In six patients or 4.20% of the collective these exams took place in a different hospital, with limited information on functional evaluations. In another 5 patients only one examination had taken place, before referring the case to a local hospital or the patient did not present again. In 10 patients (6.99%) there were 8 or more follow-up examinations, exceeding the usual number. In all of these patients complicating factors such as non-adherence to therapy, repeated fragment displacement and necessity of re-splinting were to be found.

Thus the minimum number of follow-up examinations was at 0, whilst the patient with the most visits to our clinic reached 13. The mean number of check-ups, however, was found at 4.2 with the median lying at 4 examinations.

In 31.47% of all cases (n=45) therapy of the extensor tendon injury was possible as a day-clinic procedure, without the patient needing to stay in the hospital and all following treatment taking place in the out-patient department. However, 68.53% (n=98) of all patients were kept in hospital for the initial post-operative phase. The typical duration of in-hospital treatment was two days with a total of 41 patients, which makes up 28.67% of the total population or 41.81% of all patients receiving stationary care. This care was set in a time frame of one to four days in 89.80% (n=88) of all in-patients, while 4.08% (n=4) of the cases stayed up to seven days and 2.04% (n=2) underwent an in-patient period of over a week.

Another 4.08% (n=4) patients had multiple stays recorded due to repeated surgical interventions.
3.4 Outcome

3.4.1 Complications

In 39.16% (n=56) of our patients some sort of complicating factor was found during therapy. Loosely defined, these included all problems or difficulties patients presented with, such as undefined pain or subjective worsening of the situation, as well as objective clinical findings.

Most common complications included splint and cast associated problems in 28.57% of patients exhibiting difficulties or 11.19% of the total population (n=16), as well as secondary fragment displacement in 7 patients, which lead to surgical intervention in one. They made up 12.50% of all patients with complication and 4.90% of the collective. All remaining types of complications ranged in between 2 and 4 cases (3.57%-7.14%) (Figure 19).

The persisting deficit was the most dreaded, yet also most common complication with appearing in 37.50% of all complicated cases as well as in 14.69% of the total number of patients (n=21). This includes all cases, where any sort of functional impairment was documented at the last examination. Any further improvement would be to expected, but could not be shown. In 3 patients, outcome and thus functional parameters remain unknown due to change of centre providing after-care.

In 13.99% (n=20) of the patients secondary treatment, that is after a primary delay of over 7 days, had taken place. Of these 8 patients were treated with conservative measures, while 12 had surgical therapy performed on them. This significant delay in adequate therapy led to a relatively high number of persisting deficits in these cases. Among the conservative patients 25.00% (n=2) showed a persisting deficit, while the surgical group did even worse with 33.33% (n=4) of the cases presenting with unfavourable results.
When the rate of complications in Zone I injuries is assessed independently, there is an almost 50% chance of from one or another complicating factor. In 50.71% (n=35) of the cases complications were noted, while only 44.39% (n=31) reported no complaints. Three cases (4.35%) were not followed up in our house and are therefore not represented.

Complications primarily included skin and splint issues, either due to maceration of the adjacent cutaneous areas, pressure marks or displacement of the splint/cast. This was the case in 44.44% (n=12) of all complications or 17.39% of all Zone I injuries. The second most common complication was displacement of the bony fragment in avulsion fractures, which occurred in 22.22% or 8.70% (n=6) of the cases. Interestingly no patient described an effect on sensation in the finger, neither in the laceration group, nor in blunt injuries.

However, contrary to general complications persisting deficits were relatively low in Zone I injuries and at the same time comparable to persisting deficits in the whole collective. In 13.04% (n=9) percent of all cases in this Zone a measurable degree of functional deficit could be found, while in 82.61% of patients no relevant limitations could be found.
3.4.2 Final Assessment

In all patients that were not lost to follow-up some sort of final assessment took place, stating clinical aspect and functionality of the afflicted tendon. While descriptions of these, due to lack of a specific protocol, were varying in detail, still enough functional information could be drawn to classify outcome using Miller's rating system.

Therefore a total 108 patients (75.52%) of all cases having received primary care could be found with excellent outcomes, as well 13 patients (9.09% / 65.00%) in the secondary treatment group. 5.59% of all patients (n=8) were found to have good results after primary treatment, while it was 3 in the others.

In total excellent and good results made up 92.31% (n=132) of all cases, while unfavourable results were found in 5.59% (n=8) of the patients. 3 cases were not included in this rating due to lack of sufficient information. In the group of primary treatment excellent and good results made up 94.32% (n=116) of the cases as opposed to 80.00% (n=16) in patients with therapeutic measures taking place over 8 days after the incident occurred.

During final assessment of all patients presenting with injuries to Zone I of Verdan 82.61% (n=57) showed an excellent result using Miller's rating system. In 8.70% (n=6) of patients a good result was to be found, which makes a total of 63 patients (91.30%) with excellent or good therapy outcomes. Fair or poor results were seen in 4.35% (n=3) of all patients with 2.90% (n=2) being rated as fair and 1.45% (n=1) as poor.

Also there was no relevant difference to be seen when comparing outcomes of patients undergoing primary treatment, as opposed to patients with initial delay in therapy. The groups showed 91.30% (<8d, n=51) and 92.31% (>8d, n=12) of excellent and good results.
4 Discussion

4.1 Main Findings

The main findings in this study primarily centred around initial presentation of the patient, genesis of injury, as well as finding preferences in conservative and surgical therapy. Secondarily typical complications, their rates and general outcome of injuries to the extensor tendon system in the paediatric hand were found.

In the study population a significant dominance of the male gender can be seen. With 74.13% of the collective this number even exceeds generally elevated levels of male representation in trauma. This may very well be due to the typical mechanisms of injury, which we found to be ball sports or cut injuries. These two causes together made up over two thirds of the full collective, as 39.16% were afflicted by cuts and 29.37% injured themselves while playing ball, summing up to 68.53% combined. The patients age showed a steadily increasing trend towards higher incidences in juveniles and teenagers as can be seen by 14.69% of all patients being 14 at time of the accident. Also the age group that presented with most patients included 47.55% of the population and all 13 to 18 year-olds.

Interestingly, when viewing the injury itself, unlike it has been described in literature, we were not able to find a significant difference in which hand was affected. Both sides appear to be equally prone to injury (52.45% vs. 46.85%), with a slightly higher percentage in left hand cases. What causes may be the reason for this will be discussed later on. When viewing the Zones affected most often, obviously Zone I returned as the most common with 56.10% of all single tendon injuries, followed by Zones II and V. Of all tendons typically either ED II or III were injured, reaching a combined 56.80% of all cases. In 87.41% of the patients only a single tendon was injured, making multiple tendon injuries rather an exception.

Viewing the surgical aspect of extensor tendon injuries we could see, that in our house any tendon injury that was not in either Zone I or Zone PI was managed operatively. Suture techniques most commonly used for this were U-sutures in 49.38%, as well as Kirchmayr-Kessler sutures.

All in all, this study had a relatively high rate of patients developing complicating factors. These almost 40% usually either suffered from temporary cast/splint effects, being the case in 11.19% of all patients, or showed lasting deficits to digital function. This factor alone however is, with 14.69% significantly less than in other studies, which is also supported by our outcomes using the Miller's rating system showing excellent or good end results in 92.31% of our patients.
4.2 Comparison to literature

Relevant literature concerning extensor tendons injuries in the paediatric patient is at most sparsely to be found. Therefore certain limitations are set to directly compare our data to pre-existing studies. However, a variety of propositions can be taken from studies in adults and interpreted in context of a younger age group.

4.2.1 Study Population

4.2.1.1 Patients

In accordance to most studies (16,22), the male gender was afflicted significantly more often in our study, showing a 3:1 ratio when compared to their female counterpart.

When viewing the age of our patients, as stated above a strong increase in incidence is noted with higher age. Most studies on paediatric trauma, however, tend to include only patients up to onset of puberty, due to local treatment regimes. These often find incidence peaks between one and two years of age as well as around the age of 10 to 11. This was shown in the case of distal phalanx fractures, which are commonly associated with extensor tendon injury, by Valencia et al. (36).

When assessing patients up to the age of 12 independently from the full collective, a much more stable distribution could be seen, with most years ranging in between 6-8 cases. However, upon repeating this in Zone I patients, two peaks could be seen, one of which was quite dominantly set at 12 years, while 2 and 4 year-olds also showed a much higher Mallet finger rate of over 50% than other patients from 0 to 10 years old.

As opposed to several studies stating differences in which hand was primarily affected, in our full group no difference between the likelihood of right or left hand injuries could be found.

In an adult cohort of distal phalanx injuries Werber et al. found 74% of the cases to afflict the dominant hand, as well as 90% of the patients injuring one of their three ulnar fingers (14). These findings do not at all correlate to our group of paediatric patients, which showed a very even distribution of right to left hand injuries of 48 to 52%. A limitation to these numbers is that in our patients the dominant hand was not assessed in most cases. However, assuming that a majority of the patients would be found to be right hand dominant, this would only further decrease the validity of Werber's statement in paediatric patients.
Concerning cutting injuries there was a minor tendency to be seen in our patients. By trend in the full group the left hand was afflicted bit more often, showing 75 injured patients and 52.45% of the group. This number went down in Zone I injuries, where the importance of cuts is less as well as the mechanism of a cut injury typically slightly different to the rest of the hand. Therefore upon assessing cut injuries independently a dominance of the left hand with 59% of the cases was to be seen. One explanation for this phenomenon is the role of the left hand in holding and fixing the object being cut and the consecutively exposed position it is found in.

4.2.1.2 Injury

In a collective of 87 predominantly male adult patients Karabeg et al. found the most frequent types of injury that lead to severing of the extensor tendons to either be Vulnus lacerocontusum or CLW in 61% of the patients and Vulnus sectum, being almost three times less likely at a percentage of 24% (17).

Examining paediatric patients, Fitoussi et al. found 74% of their extensor tendon injuries to result from a cut with a sharp object (4), which we could not find to be true in our study. While being the dominant group of injury types, cuts only made up 39% of our patients. Even when all sharp lacerations are combined and set against blunt traumata, still the 84 cases only add up to 59% of the collective. Concerning CLW injuries, as stated by Karabeg et al., we could only find a combined number of 22 cases among our patients, which would make 15% of all injuries.

Upon viewing the different Zones of Verdan, Hoch et al. found about a third to half of all extensor tendon injuries to afflict Zone I of Verdan, or the area of the distal interphalangeal joint (11). Among these patients the dominant group were closed injuries with about 75% of the cases. As Zone I injuries made up 56% of our single Zone injuries the first statement is most definitely true in both adults and paediatric patients. The number of closed injuries in this Zone, however, is even a little higher in our group, reaching a total of 56 patients or 81%.

While Windolf et al. claim that subcutaneous lesions of Zone I are quite rare in paediatric patients, when compared to adult results, we could only find this partly to be true in our collective. With 26% of our patients with Mallet finger injuries suffering a subcutaneous tendon rupture, it reaches a percentage that is lower but still comparable to adult study collectives (16). However, our study does include a considerable number of patients in the age group of 14 to 18 years, amongst which the predicament of bone fracture before tendon rupture tends not to be as relevant any more.
Werber et al. also described the three ulnar digits to be affected more often in distal phalanx injuries and stated a share of 90% in his study (14), which could not be found to be true in our patients. Even upon ignoring injuries to the first Zone of Verdan in the thumb, still only 77% of the injuries affected ED dig III to V plus EDM. When including Zone PI as equivalent to the other Mallet finger injuries, then a further decrease to 69% can be seen.

Concerning multiple tendon injuries a different pattern of Zone distribution can be seen. While also gaining in numbers (n=89), the dominance of Zone I lesions is slightly lessened going down to 54.09% of the cases, while especially Zone II and III rise to 13.21% (n=21) and 10.65 (n=16). Therefore it can be said that in our collective multiple Zone injuries primarily affected Zones II, III and V.

### 4.2.2 Therapy

#### 4.2.2.1 Treatment

Windolf et al. claimed that simple extension splinting also does show quite successful results in old tendon ruptures (16), a proposition which could only be backed by our data. In our study no relevant difference was seen when comparing outcomes of patients undergoing primary treatment, as opposed to patients with initial delay in therapy. The groups showed 91.30% (<8d, n=51) and 92.31% (>8d, n=12) of excellent and good results.

However, chronic extensor tendon injuries, or rather the arising deficits still can cause significant difficulties in treatment once a functional defect was allowed to consolidate. Even more so, when it comes to zone I, where a chronic defect in adults most commonly either remains untreated or an arthrodesis will be performed. Gu et al. however were able to show surprisingly good results in a functional reconstruction of the DIP extensor function in adult patients (51). Especially considering the long-time benefits a child would gain from such an operation makes further research into this technique very interesting.

#### 4.2.2.2 Immobilisation

On average our patients with Zone I injuries had immobilisation times of 4 weeks of plaster backslab splinting plus another 3.5 weeks of Stack splinting. This goes in concordance with
Armstrong et al.’s suggested duration of immobilisation which included 6 weeks of strict extension splinting followed by further 2 weeks of night splinting, to prevent accidental overflexion (2).

When discussing the relevance of early mobilisation programs in paediatric patients, Fitoussi et al. supported the notion that the risk of adhesion formation and development of contractures is very rare in paediatric patients (4), which can only be supported by our results. Therefore, with a focus on preventing the common complications of tendon rupture and callus lengthening and relying on the child's strong capacity of recovering a strict immobilisation regime is advisable. This, however, must be relativised in teenagers and adolescents as their rehabilitation should follow adult treatment plans.

4.2.3 Outcome

The Miller's Score for rating the outcome of an extensor tendon repair, which we also used to assess our patients, does not offer ideal conditions for doing so in paediatric patients. While being widely used in adults, it was set up for standard functional parameters as can be found in fully grown hands. It therefore does not consider any degree of hyperextension which can be found quite frequently in children up to puberty (4). When evaluating the outcome of a functional repair it would then be sensible to include a comparative element to the opposite side, which in most cases displays the current developmental stage in the most practical and accurate way.

In our retrospective analysis typically there was no mention of the healthy counterpart apart from a few exceptions. Any elective clinical follow-up however, should take bilateral evaluation into consideration.

Factors that cannot be influenced by the treating physician include the age of the patient and their level of compliance, both of which have been shown repeatedly to improve the long-term outcome of tendon repairs (20). Age of the patient in our study definitely showed improved results, when compared to an adult patient group with matching injuries. Compliance as such is a very difficult parameter, especially in paediatric patients. But one could see that children whose parents showed a higher compliance regarding follow-up visits, also tended to develop less complications associated with splinting.

4.2.3.1 Complications

Interestingly in comparison with the full collective patients with Zone I injuries showed a higher chance of developing complications. They had a 50% chance of suffering from one or another
complicating factor as opposed to 39% in all patients. This partially goes in accordance with the findings of Fitoussi et al. who noted a higher percentage of extension lag as well as the highest percentage of fair to poor results in Zones I to III when compared to Zones IV to VII (4). However, upon comparing the number of persisting extension deficits there was no significant difference to be found in our study (14.69% of 143 vs 13.04% of 69) and neither could the notion on worsened outcomes using the Miller's Classification be confirmed.

4.3 Limitations to this study

There are several limitations to our study, which certainly alter the results to some extent and may be reflected in some of the figures.

Firstly, as the retrospective assessment used general case documents, as well as surgical protocols as source of information, all information lacking in these will affect this study. There is no universal standard of treatment on extensor tendons in our hospital and also no strictly standardised documentation. Therefore especially initial assessment, which was often performed by younger physicians, may be deficient in functional specifics.

Another factor, which may bear some relevance, is that of patient presentation at a higher age. Many local hospitals, as well as one other hospital in Graz, will offer basic trauma management for patients over 14 years of age. Thus, as long as a non-critical hand injury occurs, in our house there will be a certain selection and reduction of cases within the age group of 14 to 18 years.

Also due to structure and extent of this study all results presented in this thesis must be seen within these confines. A major review with higher numbers of patients as well as definite assessment plan will be necessary.
5 Conclusion
There are a number of conclusions that can be drawn from this study.

First of all, judging from the lack of adequate studies found on the topic of extensor tendon injuries in children it is essential that further studies need to be conducted addressing this topic. Also definitive evaluations of treatment regimes that are currently in use should be performed. This means that there need to be prospective, comparative studies on specific splinting and suture techniques to establish scientifically approved standards of therapy.

Currently there are still major variabilities in treatment due to various differences amongst countries, hospitals and surgeons. Tradition still strongly dictates the choice of method and to this point no definitive scientific suggestions in therapy can be found.

5.1 Risk groups
Looking at our data, the critical group of contracting an extensor tendon injury are male boys and teenagers around the age of 12 to 14, with blunt ball sport trauma and cutting injuries being the major causes. In Zone I injuries the same factors are true, yet with a significantly higher emphasis on ball sport injuries and other axial compression traumata.

5.2 Pre-emptive Measures
As has been proven quite successfully, accident prophylaxis and pre-emptive intervention has played a significant part in reducing the incidence of many injuries in the paediatric patient. This preventive effort has not only saved lives and limb function, but also reduces treatment cost.

However, not all risk factors can be effectively handled in advance. For example, there will always be an increased risk behaviour in adolescent males, as well as a strong affinity towards ball sports and ball play.

Then again, risky use of knives is a topic that could be addressed and may consecutively lead to a reduction of sharp tendon lacerations. Most of the cut injuries occurred in context of either kitchen work, as in pumpkin carving and cutting of bread or meat, or whittling of sticks and other use of pocket knives. Although not easily prevented, parents could be taught to control or supervise the use of such tools in their children.
Also, although only one patient was included in our study, potential reasons for secondary tendon ruptures should be diligently avoided. Any sharp ends of cortical screws, ESIN nails and plate borders should either be retracted or carefully filed off.

### 5.3 Ideas for New Studies

As originally intended, follow-up examinations and long-term results would be of considerable interest not only in these patients, but in paediatric extensor tendon injuries in general. Changes in functional outcome with continued growth are very likely occur, as it may both lead to improved function via compensatory mechanisms, as well as worsen an existing substance defect or contracted element when additional strain and tension is put on it.

Also, as suggested by some authors a further increase of conservative approaches may be interesting to prove scientifically. Several cases of open injuries/lacerations in Zones I and II have been reported to heal with good functional outcome after simple splinting and skin suture. This is most likely due to the low level of tendon retraction in distal extensor tendons. Therefore a comparative study of conservatively and surgically treated wounds in these Zones would be of great interest.

Furthermore, as suggested above, a rating system to evaluate the outcome in tendon repairs and more specifically extensor tendon repairs in the paediatric patient would be needed to appropriately classify these injuries. Therefore, studies setting up and comparing both adaptations of existing systems as well as working on new ones would be of considerable interest.


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