

General

Zone II Flexor Tendon Repair – Number of Strands, Technique, and Postoperative Rehabilitation: A Narrative Review

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Zone II flexor tendon injuries remain among the most technically demanding challenges in hand surgery. The confined anatomy, dual-tendon configuration, and complex pulley system render this region particularly vulnerable to adhesion formation, repair gapping, and stiffness. Over the past decades, advances in multistrand core suture techniques, epitendinous augmentation, and early controlled mobilization protocols have markedly improved repair strength and postoperative function.

This narrative review synthesizes current evidence on surgical techniques and rehabilitation strategies in Zone II tendon repair, emphasizing the interplay between biomechanical stability and functional mobility. It explores the anatomical and biomechanical considerations unique to Zone II, evaluates the evolution from traditional two-strand to modern four- and six-strand repairs, and discusses the critical contribution of epitendinous sutures to tensile strength and tendon glide. Additionally, it reviews the rationale and safety of pulley venting, delineating when partial A2 or A4 release may be beneficial. Finally, the review examines postoperative rehabilitation protocols, from immobilization to early passive and active motion; and their relative effects on rupture risk, adhesion formation, and range of motion. Despite technological progress, optimal management still requires individualized decision-making that balances repair robustness with safe mobilization to achieve the best possible functional outcome.

INTRODUCTION

Zone II flexor tendon injuries represent one of the most enduring challenges in hand surgery. First described by Bunell as “no-man’s land,” this anatomical region became synonymous with poor prognoses due to high complication rates and consistently disappointing functional outcomes in the early to mid-20th century.¹ Verdan later formalized the classification of flexor tendon zones, cementing Zone II as the most complex area to repair due to its unique anatomical and biomechanical features.²

Modern advances in microsurgical techniques, multi-strand core suture configurations, epitendinous augmentation, and structured rehabilitation protocols have significantly improved the strength of tendon repairs and the predictability of clinical outcomes.^{3,4} However, despite these advances, the delicate balance between achieving biomechanical integrity and preserving gliding function continues to pose unresolved challenges. While robust multi-strand constructs enable early mobilization and decrease rupture risk, they simultaneously increase repair site bulk, predisposing to adhesion formation.^{5,6} Rehabilitation remains another critical variable; systematic reviews demonstrate that early active mobilization protocols im-

prove tendon excursion and functional outcomes, but they also heighten the risk of catastrophic rupture if improperly executed.^{7,8}

Given the enduring complexities of Zone II repair, it is imperative to revisit its anatomical and biomechanical underpinnings while integrating contemporary surgical strategies and evidence-based rehabilitation principles. This review synthesizes historical context and modern literature, highlights ongoing controversies, and provides insights for optimizing functional recovery following Zone II flexor tendon injuries.

ANATOMY AND BIOMECHANICS OF ZONE II

The flexor tendon system of the fingers is an intricate construct designed to maximize digital strength, precision, and motion. Each finger is supplied by the flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS), which traverse the fibro-osseous digital sheath before inserting on the distal and middle phalanges, respectively.¹ Within Zone II — extending from the distal palmar crease to the insertion of the FDS — the FDP and FDS tendons course together in a narrow synovial sheath, accompanied by a complex pulley system.

The annular pulleys, particularly A2 and A4, are biomechanically indispensable. They act as fulcrums that maintain tendon proximity to the phalanges, preventing bowstringing and ensuring efficient finger flexion.² The cruciate pulleys provide flexibility, preventing sheath collapse during motion. The tendons are further supported by the vincular system, a delicate network that supplies vascular perfusion. These structures are critical for tendon nutrition but highly susceptible to iatrogenic damage during repair, which can compromise healing.⁵

Biomechanically, the tendons of Zone II endure significant forces during grasp and pinch activities. During resisted finger flexion, tensile forces may exceed several times body weight, placing extreme demands on suture strength.³ This necessitates multi-strand repair techniques that can resist gapping under cyclic loading. However, the confined anatomy magnifies the consequences of increased tendon bulk; even small increases in cross-sectional area at the repair site can impair gliding within the sheath, leading to adhesions, stiffness, and functional limitation.^{4,6}

Furthermore, the biomechanical paradox of Zone II repair lies in reconciling two opposing requirements: a repair must be strong enough to withstand early mobilization forces while simultaneously being fine enough to preserve tendon excursion. The unique presence of two tendons (FDS and FDP) in the same confined sheath compounds this difficulty, as scarring may tether them together or to the sheath, profoundly restricting motion.¹ Unlike repairs in Zones I or III–V, where space is less restrictive, Zone II repairs carry the additional risk of pulley compromise, which can alter tendon biomechanics irreversibly.

This delicate interplay between anatomy and biomechanics explains why Zone II remains the most challenging site for tendon repair, despite decades of progress. The region's intricate pulley system, dual tendon configuration, and high biomechanical loads collectively render surgical repair a balance of competing priorities — strength, gliding, and preservation of digital motion — making outcomes more variable than in any other tendon zone.^{2,5}

EVOLUTION OF REPAIR TECHNIQUES

The management of flexor tendon injuries, particularly in Zone II of the hand, historically was thought to be impossible to repair due to the fact that the tendon had to glide within the sheath of the pulleys.⁹ However, recently, due to advances in surgical technique and new low profile suturing materials a paradigm shift was seen, notably the Kessler and Bunnell techniques, which laid the foundation for modern tendon surgery. These methods emphasized the importance of achieving secure tendon apposition to facilitate healing.¹⁰

Enhancing repair strength and minimizing postoperative problems have become the main priorities in recent decades. It is now common practice to use low-profile, multi-strand core suture procedures.¹¹ These methods increase the biomechanical strength of the repair and lower the chance of suture failure through the utilization of multiple suture strands to more evenly distribute the repair stress.

Furthermore, it has been demonstrated that the use of epitendinous sutures improves tendon gliding by lowering friction and avoiding adhesions.¹² To enhance tendon excursion and avoid stiffness, early mobilization methods have also been established that promote active tendon movement after surgery. Compared to conventional immobilization techniques, studies have shown that early active motion procedures can result in better range of motion (ROM) and functional outcomes.⁷ However, the optimal rehabilitation strategy remains a topic of ongoing research, with various approaches being evaluated to determine the most effective regimen for enhancing tendon healing and function.

NUMBER OF CORE STRANDS

The number of core strands used in tendon repair historically was 2-strand repairs. Recently through biomechanical studies surgeons are starting to shift to 4 or even 6 strand sutures due to their increase in biomechanical stability and mitigation of gap formation under tension.^{10,13} These advantages are particularly significant in Zone II injuries, where the tendon is confined within a narrow fibro-osseous sheath, and the risk of gap formation is heightened. For instance, a randomized controlled trial (RCT) comparing four-strand and six-strand techniques in Zone II flexor tendon repairs found favorable outcomes with both methods, though the six-strand technique demonstrated enhanced biomechanical properties.¹⁴ Despite these findings, the clinical significance of the additional strands remains a subject of debate, with some studies suggesting that the benefits may not translate into substantial functional improvements.

A balance between biomechanical strength, surgical complexity, and potential complications must be struck when selecting a core suture technique. In order to decrease gliding resistance and improve healing strength, epitendinous sutures have been used. In an effort to maximize the functional results of the repair, methods such as cross-stitch, intraligamentary, and running-locking epitendinous sutures have been reported to be successful in increasing tendon strength and reducing gliding resistance.¹⁵ The extra suture material, however, can result in a more prominent repair and impair biologic healing of the tendon. The ideal amount of core strands should therefore be chosen depending on the specific patient's characteristics, such as the type of tendon injury, the surgeon's level of experience, and the intended ratio of tendon mobility to strength.¹⁵

ROLE OF EPITENDINOUS SUTURES

A. CONTRIBUTION TO STRENGTH AND TENDON GLIDE

The epitendinous suture has evolved from a supplementary step to a crucial element of flexor tendon repair. Although the core suture establishes the baseline tensile strength, the epitendinous layer greatly improves both the mechanical stability and the functional gliding of the tendon.

Savage first showed that incorporating a circumferential running suture enhanced tensile strength by almost 50% in comparison to core repair by itself, effectively delaying gap formation and improving the repair's capacity to endure load.¹⁶ Further research refined this concept. For example, both Moriya et al. and Kanchanathepsak et al. demonstrated that adding an epitendinous layer increases the force necessary to create a 2 mm gap at the repair site, which is a clinically important benchmark, as gaps larger than 2–3 mm are closely linked to repair failure and impaired tendon healing.^{15,17} This load-sharing mechanism is accomplished by more uniformly distributing tensile forces throughout the repair area and strengthening the alignment of the tendon ends.

In addition to mechanical reinforcement, the epitendinous suture plays a critical role in optimizing tendon glide. Gelberman et al. showed through various experimental and animal studies that less friction and preservation of tendon excursion are directly associated with improved functional recovery, especially in Zone II, where the tendon needs to slide beneath the intact A2 and A4 pulleys.^{18,19} Cadaveric and in-vitro studies comparing epitendinous repair methods demonstrates a compromise between strength and surface smoothness: some interrupted or heavy mattress suture patterns enhance repair strength but can lead to a more irregular tendon surface and increased gliding resistance, while optimized continuous or cross-stitch patterns achieve a more favorable equilibrium of strength and reduced friction.¹⁵

Consequently, the epitendinous element plays a role not only in enhancing repair strength but also in creating a biomechanical setting that restricts adhesion formation and supports early controlled mobilization.

B. DIFFERENT TECHNIQUES AND THEIR IMPLICATIONS

Different epitendinous techniques have been examined, varying in depth, locking configuration, and circumferential coverage. These variations directly influence both the mechanical properties of the repair and the functional outcome in terms of tendon glide and resistance to gapping.

The simple running epitendinous suture remains the most commonly utilized peripheral technique for repairing flexor tendons. A recent global survey of hand surgeons indicated that more than half (51%) preferred this approach, making it the leading option in clinical practice.²⁰ Its widespread use can be linked to its comparative technical simplicity, capacity to offer circumferential support, and the production of a smoother tendon surface that facilitates tendon glide. Biomechanical evidence supports that the simple running configuration provides moderate reinforcement. Wieskötter B et al. showed in a porcine model that the technique greatly enhances tensile strength in comparison to core repair alone, although it is still consistently outperformed by more complex configurations such as cross-stitch or mattress sutures under high load conditions.²¹ Similarly, Moriya et al. showed that while simple running repairs exhibit greater susceptibility to gap formation and reduced ultimate failure loads during cyclic testing, they nonetheless contribute to smoother tendon contours spe-

cially when knots are positioned internally instead of externally, thereby reducing gliding resistance within the sheath.¹⁵

The locked running epitendinous suture was created to address the mechanical limitations associated with the simple running technique. By integrating locking loops into the peripheral suture, this design offers a more robust mechanical interlock with the tendon surface, leading to enhanced gap resistance and ultimate tensile strength. Numerous biomechanical studies support this conclusion. Moriya et al. discovered that running-locking, cross-stitch, and interlocking horizontal-mattress (IHM) epitendinous patterns exhibited greater failure loads following cyclic testing compared to simple running finishes.¹⁵ Xie and colleagues demonstrated that enlarging the locking area enhanced both the gap force at 2 mm and the ultimate strength in strand-locking repairs.²² Furthermore, Kanchanathepsak et al. reported that a complete (360°) circumferential epitendinous suture, using the running locked technique, provided significantly greater force to a 2-mm gap compared to partial peripheral repairs.¹⁷ Thus, partial circumferential epitendinous sutures offered significantly less resistance to gap formation and lower ultimate tensile strength.¹⁷

PULLEY VENTING

A. ANATOMY AND BIOMECHANICAL ROLE OF A2 AND A4

The digital flexor sheath-pulley system, comprising the A1–A5 annular and C1–C3 cruciate components, is a complex structure that facilitates the normal and efficient functioning of flexor tendons. This sheath-pulley system consists of a deep synovial component and a superficial retinacular or pulley component. The pulleys are made up of fibrous tissue that nearly encircle the flexor tendons, creating a fibro-osseous channel that keeps the tendons close to the phalanges.²³ This arrangement allows the translational force produced by the muscle-tendon unit to be converted into a rotational force on the phalanges, reducing bowstringing and maintaining effective flexion.^{23,24} Among these pulleys, A2 (located at the proximal phalanx) and A4 (at the middle phalanx) serve as the primary restraints; their integrity has the most significant impact on tendon movement, moment arms, and the work involved in flexion.²⁴

B. EVIDENCE FOR LIMITED VS. COMPLETE VENTING

Due to the increased tendon bulk and friction associated with repairs in Zone II, surgeons may sometimes consider relieving constriction through pulley venting, which aims to restore smooth gliding while still providing sufficient restraint to prevent bowstringing. Surgeons might partially release the A2 pulley for various reasons, such as visualizing the injured tendon, retrieving the ends that have retracted proximally, accommodating core suture placement and allowing smooth gliding of a repaired and edematous

tendon.²⁵ Although venting may be practically necessary, there is no agreement in the literature regarding the safe amount of pulley that can be released. Most authors suggest a “judicious” or limited approach to venting, yet they do not specify a definitive threshold.

Clinical and biomechanical research indicates that careful partial venting is beneficial when tendon passage is obstructed. In a significant consecutive cohort study (n = 126), Ben & Elliot found that 64% of Zone II repairs necessitated some form of venting—usually between 10–100% of A4, and less frequently, a 4–10 mm slit in the distal A2 to allow for atraumatic passage and smooth gliding.²⁶ From a biomechanical perspective, a partial A2 release of up to 50% results in only minor alterations in gliding resistance, indicating that limited venting is safe when required.²⁷ More recent biomechanical studies measuring the effects of A2 venting reveal that there are gradual increases in bowstringing and tendon slack with the progression of venting; although minor amounts may be acceptable in a clinical setting, this suggests caution against performing routine or extensive A2 releases.²⁵ Significant alterations in metacarpophalangeal flexion were observed solely following the full release of the A2 pulley, and this impact was restricted to the index finger, with no changes noted in proximal interphalangeal movement. Consequently, when clinically indicated, the functional advantages of A2 pulley venting are likely to outweigh the potential risk of motion or strength loss.²⁵

Regarding A4, quantitative assessments involving repaired flexor digitorum profundus tendons demonstrate that both partial and even full A4 release can maintain acceptable mechanical properties under controlled conditions.²⁸ For instance, following an FDP laceration and repair in the region of the A4 pulley, work of flexion did not increase by more than 3% from control conditions after partial or complete A4 pulley release, and work of flexion was significantly less than that achieved by performing a repair and leaving the A4 pulley intact.²⁹ When an injury occurs on the middle phalanx while the A3 remains intact, Tang states that complete venting of the A4 can be beneficial to support the repair and enhance gliding without compromising function, as long as the other primary pulleys are intact.²⁹

Therefore, although there is some supporting evidence for partial venting, particularly concerning A4, the threshold for A2 and the extent for A4 still demand case-by-case assessment.

C. CONTROVERSIES AND CLINICAL JUDGMENT IN PRACTICE

Most surgeons prefer to vent A4 prior to A2, given A2's greater contribution to anti-bowstringing, Ben & Elliot's clinical series reflects this tendency.²⁶ Several studies demonstrated that it is safe to vent A4 as long as the primary pulleys remain intact, particularly to facilitate atraumatic passage of the tendon in multistrand repairs and early mobilization strategies.^{25,28,29} In narrow tunnels, bulky multistrand repairs often impinge at A2–A4, making venting a useful strategy to support early active movement

and minimize adhesions.³⁰ In situations where extensive releases are necessary, tools such as thermoplastic “external pulley” rings can help prevent bowstringing and preserve motion as the tendon heals and glides.³¹ Surgical reconstruction options (such as V-Y plasty of A2/A4) are generally reserved for specific cases that require structural restoration following release.³⁰

REHABILITATION STRATEGIES

There is currently no clear guideline regarding postoperative management and rehabilitation of flexor tendon repair. Rehabilitation is essential for adhesion prevention and to restore function of the tendon as early on as possible.³² Rehabilitation strategies can range from complete immobilization to early mobilization.

A. TRADITIONAL IMMOBILIZATION

Following a zone 2 flexor tendon repair, traditional immobilization for 3 to 4 weeks is thought to prevent stretching of the repaired tendon, thereby preventing adhesions and allowing proper healing.¹ A dorsal blocking splint places the wrist in 10–30 degrees of flexion and the metacarpophalangeal (MCP) joints at 45–70 degrees of flexion with the slab extending past the finger tips, keeping the interphalangeal joints in a comfortable 15 degrees of flexion.³³ This technique was found to have low rupture rates; however, was associated with higher rates of adhesion formation contrary to original belief.³⁴ Immobilization is typically reserved for younger and more non-compliant patients.³⁵

B. EARLY PASSIVE MOBILIZATION (DURAN, KLEINERT PROTOCOLS)

In the 1970s, studies focused on the impact of early passive motion after flexor tendon repair and its relationship with tendon healing. It was thought that early mobilization allowed early tendon gliding and, therefore, prevented adhesion formation.³⁶ In the mid-1970s, the Duran and Kleinert protocols were developed whereby early controlled tendon mobilization prevented adhesions.³⁴

The Duran protocol uses passive flexion and flexion-extension exercises with a dorsal blocking splint and is divided into three stages.³⁷ The initial 4 weeks work to establish a 3 to 5 mm tendon glide. At week 5, the splint is replaced with a rubber band and active extension exercises are initiated. Following this stage, at 8 weeks, the patient starts resisted flexion exercises.¹¹

The Kleinert protocol involves passive flexion with rubber bands and active extension. This technique also utilizes a dorsal blocking splint with the wrist in 45 degrees and the MCP joints in 10–20 degrees of flexion.³⁸ Here, the initial 3 weeks use a rubber band traction from the wrist to the fingernails with 10 minutes of active extension of the fingers every hour. The next 2 weeks promote active movements of the fingers with minimal active flexion initiation at week 5. Starting week 6, the splint is modified to extend only to the PIP joints, the wrist in 30 to 45 degrees of palmar flexion

and the MCP joints at 50 to 70 degrees of flexion. This in turn ensures maximum passive flexion.¹¹

C. PLACE-AND-HOLD PROTOCOLS

The place and hold protocols are applied 3 to 5 days after flexor tendon repairs to allow improved finger motion when compared to passive techniques. This technique allows gentle loading of the tendon, thereby allowing mobility and healing with minimal stress on the tendon.³⁹ This approach presented favorable outcomes for grip strength and total active motion of the flexor.³⁷

Patients are placed in a dorsal blocking cast with the wrist at 0 degrees extension, MCP joints in 60 degrees flexion and the thumb interphalangeal joint in extension. With the cast in place, the patient undergoes passive DIP and PIP flexion and extension exercises with the cast in place starting 3 days post operatively until 4 weeks. The following 2 weeks allow cast removal during the day with active IP flexion and MCP extension added. The following 2 weeks allow complete cast removal with added flexor gliding and blocking exercises.⁴⁰

D. EARLY ACTIVE MOBILIZATION

The concept of early active mobilization of a repaired tendon was introduced to promote tendon healing, increase tensile strength and, like other techniques, decrease the risk of adhesion formation. This in turn aims to improve gliding of the tendon and optimize tendon repair prognosis.¹ Active mobilization of the tendon depends on the strength of the repair. Stronger, multi-strand core suture repairs typically allow earlier mobilization with lower risk of re-rupture of the tendon. However, this protocol should be applied in a specialized center to minimize risk of rupture.³³

E. COMPARATIVE OUTCOMES AND CLINICAL APPLICABILITY

In literature, the different rehabilitation techniques affect recovery and complication rates. A systematic review by Starr et al. (2013) found higher rupture rates in patients who underwent early active mobilization when compared to passive. Both protocols also showed higher rupture rates compared to immobilization.³⁴

A meta-analysis conducted by Mortada et al. (2024) compared the early active and passive mobilization techniques. The study found improved ROM with the active mobilization compared to passive mobilization. There were comparable rupture rates and grip strengths between active and passive mobilization protocols.⁷

COMPLICATIONS AND OUTCOMES

Rupture rates vary depending on the rehabilitation technique applied. Repaired tendon re-rupture is typically seen at the weakest period while healing, during the first 2 weeks.³³ Immobilization protocols provide the highest level of protection to the tendon and thus, the lowest risk of ten-

don rupture. Rupture rates were also found to be lowest among mobilization protocols in multi-strand repairs of the tendons.¹

While rehabilitation procedures aim to minimize adhesion formation over the tendon, and, in turn, minimize the need for tenolysis, inflammation is a natural part of the healing process. Accordingly, some adhesion formation is to be expected. Patients who had traditional immobilization compared to mobilization protocols were at higher risk of adhesion development.³³ Adhesion formation was also found to be higher in patients who underwent passive mobilization when compared to active.⁴¹

Assessment of functional recovery of the repaired tendon and operated finger is by the total active motion (TAM) score. The higher the TAM score, the more functional the finger is post-operatively. Early passive ROM protocols had a statistically significantly decreased risk for tendon rupture but an increased risk for postoperative decreased ROM compared to early active motion protocols.³³

Reoperation rates vary greatly depending on many factors including the type of injury to occur and the type of rehabilitation that occurs post-operatively. Re-ruptures of the tendon and adhesion tenolysis are the most common causes of reoperation.¹

CLINICAL DECISION-MAKING: BALANCING TECHNIQUE AND REHABILITATION

To date, there are no clear recommendations and no specific protocol for treatment and rehabilitation of Zone II flexor tendon injuries. Management decisions should entail patient factors (compliance, access to therapy) and surgeon expertise; and should balance the repair technique with the proper postoperative rehabilitation.

Xu et al. conducted a meta-analysis comparing early active motion (EAM) and early passive motion (EPM) – active flexion/extension and place-and-hold vs. Kleinert, Duran, or modifications, respectively. They found no significant difference in rupture risk between place-and-hold and EPM protocol, but a higher risk with active flexion/extension specifically when 2-strand repair techniques are utilized. The EAM group had better functional outcomes with improved motion recovery compared to the EPM group.⁴²

Multiple studies support the finding that there is no significant difference between EAM and EPM in regards to both re-rupture rates and long-term functional results (ROM, strength, patient reported outcome measures [PROMs]), provided that a multistrand repair technique is adopted.⁴³⁻⁴⁶

CONCLUSION

Zone II flexor tendon repair has evolved from a historically poor-prognosis injury to one with consistently improving outcomes due to advancements in surgical and rehabilitative science. The transition from two-strand to multi-strand (four- or six-strand) repairs, reinforced with epitenodinous sutures, has provided the mechanical strength

necessary to support early active motion without increasing rupture risk. At the same time, a refined understanding of the A2 and A4 pulley system has led to judicious venting techniques that enhance tendon glide while maintaining functional biomechanics.

When paired with structured, evidence-based rehabilitation, these developments allow for earlier mobilization and reduced adhesion formation, translating into improved ROM and patient satisfaction. However, the choice of repair construct and rehabilitation protocol must remain patient-specific, accounting for injury complexity, surgeon expertise, and compliance potential.

While current evidence supports early active mobilization after robust multistrand repairs, further RCTs are needed to clarify optimal strand configurations, epitendinous patterns, and the thresholds for safe pulley venting. The ongoing challenge in Zone II tendon repair lies not only in surgical technique but in integrating biomechanics, biology, and rehabilitation into a unified, individualized approach to restore natural hand function.

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AUTHOR CONTRIBUTIONS

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