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HAND

SURGERY AND REHABILITATION FOLLOWING FLEXOR TENDON ZONE II INJURY OF THE HAND: A LITERATURE REVIEW

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ABSTRACT

Background : Flexor tendon injury of the hand is common and it used to end up with poor outcomes. It gives negative effects to patient's daily life. Successful treatment for these cases is a challenge for surgeons. Before 1967, Injury in Zone II was called as "No Man's Land". Flexor tendon repair and rehabilitation have been substantially improved through advances in repair and rehabilitation.

Method : We reviewed literatures from PubMed, MEDLINE, Cochrane and Google Scholar. It was researched using the terms *flexor tendon zone II injury*, *flexor tendon zone II repair* and *flexor tendon zone II rehabilitation.* Topics covered included anatomy, suture repair and material, and rehabilitation.

Result : There is no significant difference of rupture rates and functional outcomes in the number of core suture. Braided polyester suture is the choice for core suture and monofilament for peripheral suture. There is no significant difference in rehabilitation using early passive motion or early active motion. The preference for post operative treatment is by using short splint without immobilization of the wrist.

Discussion : Repair sutures techniques and suture materials have been improved as well as active mobilization rehabilitation protocols including a change of wrist position by modification of splints. Improvement in putting splint from a traditional dorsal blocking splint into splint that not immobilize the wrist. Despite all of these modifications, tendon ruptures have not been eliminated. The definitive answer remains elusive.

Keywords: *flexor tendon zone II injury, flexor tendon zone II repair, flexor tendon zone II rehabilitation*

Latar Belakang: : Cedera tendon fleksor pada tangan sering terjadi dan mengakibatkan hasil klinis yang buruk. Hal ini dapat mengganggu kehidupan sehari - hari pasien. Keberhasilan penatalaksanaan cedera tendon fleksor merupakan suatu tantangan bagi dokter bedah. Sebelum tahun 1967, cedera pada Zona II di sebut "No Man's Land". Penatalaksanaan pada cedera tendon fleksor semakin membaik seiring dengan berkembangnya teknik operasi dan rehabilitasi.

Metodologi: Kami mengulas literatur yang berasal dari *PubMed*, *MEDLINE*, *Cochrane* dan *Google Scholar*. Pencarian dengan menggunakan istilah *flexor tendon zone II injury*, *flexor tendon zone II repair* and *flexor tendon zone II rehabilitation.* Topik yang termasuk adalah fungsi anatomi, teknik dan material penjahitan, serta rehabilitasi.

Hasil: Tidak ada perbedaan signifikan dalam angka kejadian ruptur maupun hasil secara fungsional berdasarkan jumlah *core suture*. Benang *braided polyester* merupakan pilihan dalam *core suture* dan monofilamen untuk *peripheral suture*. Tidak ada perbedaan signifikan dalam rehabilitasi menggunakan pergerakan secara aktif maupun pasif. Penatalaksanaan paska operasi dengan menggunakan *splint* pendek yang tidak mengimobilisasi pergelangan tangan merupakan pilihan.

Diskusi: Teknik dan material penjahitan baru telah dikembangkan, begitu pula dengan protokol rehabilitasi dengan mobilisasi aktif. Perkembangan terbaru dalam rehabilitasi adalah dengan merubah posisi pergelangan tangan dengan modifikasi *splints* serta perubahan dari dorsal *blocking* tradisional menjadi *splints* yang tidak mengimobilisasi pergelangan tangan. Terlepas dari semua modifikasi ini, tatalaksana ruptur tendon masih sulit untuk mendapatkan hasil yang sempurna

Kata Kunci : *flexor tendon zone II injury, flexor tendon zone II repair, flexor tendon zone II rehabilitation*

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INTRODUCTION

Tendons are essential for complex hand function including pinch, grip and motor dexterity. When flexor tendons get injured, preoperative, intraoperative, and postoperative factors may affect functional outcome. Intraoperative and postoperative factors can be influenced by the surgeon. The surgeon may influence outcome intraoperative by meticulous atraumatic tissue handling when trying to provide the right and best repair. Postoperatively, a surgeon influences the result by choosing right rehabilitation and right time to do so.

The surgical treatment of flexor tendon injuries has always been controversy.[1,2,3]

Bunnell in 1960 stated surgeons had to avoid primary repair of flexor tendons in zone II. It referred to as "no man's land".[4] This principle was challenged by Verdan and Kleinert. They presented their clinical results after primary tenorrhaphy. It had been transforming from "no man's land" to "some man's land.".[5]

Base on biologic aspect, functional problems of injured tendon systems are related to the response of tendon in repairing.[6] Restrictive scar formation remains as one of the most unpredictable factors contributing to postoperative morbidity.[7] Others complications of repairing injured flexor tendons are gap formation, repair site elongation or rupture which continue to be an issue especially with intrasynovial tendon repair. [8,9,10,11,12] Management of injured tendon consist of two most important steps. They are surgery step and rehabilitation step. The goal of tendon surgery is to get back the optimal function of flexor tendon. The goal of rehabilitation is to optimize tendon gliding and functional range of motion (ROM).[13]

Anatomy of Flexor Tendon

Flexor tendon of the hand consist of 11 flexor tendons. They consist of four flexor digitorumsuperficialis (FDS), four flexor digitorumprofundus (FDP), flexor pollicis longus (FPL), flexor carpi ulnaris (FCU), and flexor carpi radialis (FCR). [14]

The FDS and FDP tendons are encased by the digital flexor sheaths. Flexor sheath has two distinct layers: the visceral layer (epitenon) and the outer layer. Epitenon adherent to the tendon itselfand the outer parietal layer selectively is reinforced by a fibrous thickening of tissue (flexo pulleys). [15]

There are three distinct types of pulleys. Doyleidentified them as annular pulleys (A1–5) and cruciate pulleys (C1–3). A2 and A4 are the largest pulleys.[16]

After entering the A1 pulley, the FDS tendon bifurcates, with its slips rotating laterally and dorsally relative to the FDP tendon. The two bifurcated FDS reunite dorsal to the FDP at the Camper chiasm. Camper chiasm overlies the distal aspect of the proximal phalanx and proximal interphalangeal (PIP) joint. The FDS tendon divide again before attaching separately onto the volar aspect of the middle phalanx. The insertion at the finger's middle phalanx allowing it to function as a strong wrist flexor and flexor of themetacarpophalangeal (MCP) and the proximal interphalangeal (PIP) joints of the fingers [14] .Because FDP is the only flexor tendon that inserts into the distal phalanges of the fingers, it is solely responsible for distal interphalangeal joint (DIP) flexion. But it can also flex the MCPs and the wrist. [14]

By knowing the anatomy of the hand and its surface markings allows us to classify flexor tendon injuries into zones. It will influence subsequent management and the prognosis. Zone II offlexor tendon, which we concern to, starts from the proximal aspect of the A1 pulley and ends at the insertion of the FDS tendons at the middle phalanx.[5] This Zone is the most commonly affected zone of flexor tendon injury.[17]Injuries in it are almost exclusively laceration injuries because the FDS splits into two slips exactly at the base of zone II and the reunite at the inferior side of FDP. FDP is usually involved in injury to this zone. Assessment of zone II injury can be made by examining the function of DIP and PIP. By that too we can identify which flexor tendon involved in the injury, whether is FDP, FDS, or both.[18]Because of its anatomy, zone II become the most difficult zone to successfully perform flexor tenorrhaphy. The Challenge is to restore tendon gliding of the injured flexortendon within a tightfibroosseous. The formation of adhesions between tendons and sheath is a frequent complication, causing Bunnell named it as "no man's land".[19]

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Healing and Adhesion

Tendon healing has three phases. It begins with an inflammatory phase. In this phase, tissue trauma triggers a coagulation cascade that leads to formation of a clot around the injured area, release growth factor by platelets and cells in the clots, invasion of extrinsic cells such as neutrophils and macrophage that clean up nocrotic debris and produce more growth factors to iniatiate proliverative phase. [20] Fibroblasts from within the tendon and the surrounding sheath arrive at the repair site. And during the first week following tendon injury, macrophages and fibroblasts work together to remodel the extracellular matrix. The second phase followed in weeks 1 to 3. It's characterized by fibroblast proliferation and migration with production of immature collagen and other extracellular matrix proteins, and neovascularization.[8] Fibroblastic phase makes fibroblast from the epitenon and endotenon synthesize and resorb collagen. There're increased production of type III collagen anddecreased production of type I collagen initially. The relative increase of type III / I collagen ratio during early healing period is considered to be normal healing process. In association with pathological dense adhesion formation, the relative amount of type III collagen remains lower. [21] The final phase of tendon healing is dominated by remodeling of the collagen fibers. Cellular activity at the repair site decreases and maturation and longitudinal alignment of collagen take places. [22] It happens in weeks 3 to 8. [18, 23]

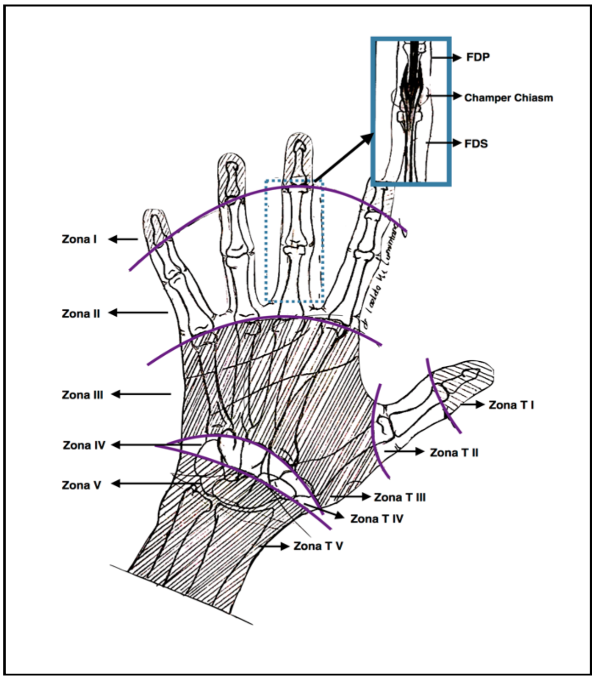

Figure 1. Flexor Zones of Hand

The tendon healing process needs unobstructed sources of nutrition. The nutritions for tendons come from intrinsic and extrinsic. The intrinsic nutrition come from vascular perfusion and the extrinsic supply come from synovial fluid, thatispredominat. [24,25,26] Synovial fluid diffuses into the digital flexor sheath passively . It is delivered to the tendon through imbibition, with the fluid pumped into the interstices of the tendon during joint motion.Blood supply for flexor tendons are provided by intrinsic longitudinal vessels from the palm. It receives segmental blood supply from the vincular branches of digital arteries at the osseous insertions of the tendons, from the flexor sheath, and from the FDS tendon. These segmental arteries enter dorsally, leaving the volar aspect of the tendons relatively avascular. [27] Tendon healing occurs through the proliferation of cells from the surrounding flexor sheath (the extrinsic mechanism) and from tenocyte response within the epitenon and endotenon (the intrinsic mechanism). [28,29]
By immobilizing the repaired tendon, collagen at the repair site becomes disorganized and adhesion formation between the tendon and the surrounding sheath can be created.Reversely the early mobilization of repaired tendons shifts the mode of healing. Intrinsic mechanism become the dominant mode, which results in collagen orientation that more closely replicates the native tendon and results in less adhesion formation. [30]

INTRODUCTION

PubMed, MEDLINE, Cochrane, and Google Scholar were searched using the terms *flexor tendon injury, flexor tendon zone II injury, flexor tendon zone II repair* and *flexor tendon zone II rehabilitation*. Topics covered included anatomy, suture repairand material, and rehabilitation. Papers not in English were excluded. One reviewer manually screened appropriate articles by review of titles and abstracts. Futher review of ful ltext was conducted by the first author and seventy-seven articles were selected for inclusion based on their relevance and recent publication date.

RESULT

Flexor Tendon Repair

In 1995 Strickland described the characteristics of an ideal primary flexor tendon repair. They are easily placed in tendon, secure knots, smooth junctions, minimal gapping, minimal interference with tendon vascularity, sufficient strength throughout healing to permit application of early motion stress.[31]

There have been many different techniques described for the repair of digital flexor tendon injuries, including the Kessler repair,[32] which was modified in 1979, [33] Strickland repair, [34] and Savage repair.[35] Many studies have showed that the strength of the repair is roughly proportional to the number of suture strands crossing the site of the repair.[36,37,38] But more strands will be bulkier [39] and increase work of flexion.[40] Tang JB in 2007 recommended repairing with 2, 4, and 6 strands. The greater the number of strands, the greater the tensile strength of the repair.

The significant improvement in the strength of the repair site is not seen until after thirdweek, so the initially suture must be strong enough to withstand the forces applied during early mobilization.[42]

In 2014 published another review,[46] which showed a similar result. There is no difference in functional outcomes between 2-strand and multistrand core suture flexor tendon repairs (Strickland Criteria group vs ASSH criteria group). There is no significant difference in either the outcomes or the rupture rate in comparing the repair technique zone 2 in the 2-strand repair group with modified Kessler versus other techniques.

A series of flexor tendon repairs between 2011 - 2013 which is using a six strand repair and early active flexion protocol with flexion of the wrist in 30° for 4 weeks demonstrated a surprisingly high rupture rate of 10%. This rupture rate is in contrast to another published series of flexor tendon repairs which had been treated with the same way. It recorded a rupture rate of 2%. [47,48]

There is some evidence that suture material has a deleterious effect on tenocyte activity and, hence, a possibility that increasing amounts of suture material increase this effect.[49] So even if some studies in the last 10 years have showed that rupture rates have slightly decreased, there remains great variation in results between different units.

Mechanical testing of different repair techniques shows that the number of core suture strands and the purchase of the peripheral suture are the two most influential factors affecting potential elongation.[50] The peripheral suture (the epitendinous suture) serves the dual purpose of preventing gapping and minimizing the bulk of the repair

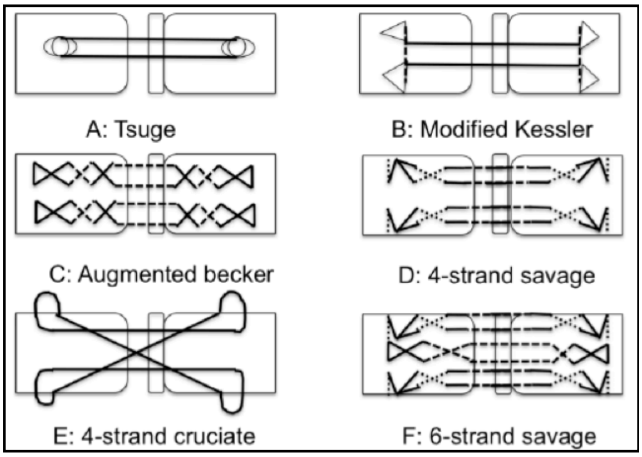

Figure 2. Flexor tendon repair techniques [32]

Suture Material

The ideal suture material should be biologically inert, has a high ultimate tensile strength and a high modulus of elasticity, handles and ties easily and holds well when knotted.[51] Stainless steel fulfils the first 3 of these criteria,[52] but now it has fallen out of favour because of its poor handling characteristics, problems with kinking, and bulky knot formation. Despite them, it has been shown to be stiffer and have a higher tensile strength than others material. [53,54]

The suture material can be monofilament or multifilament. Monofilaments run through tissues smoothly with no sequestered spaces for bacteria. But it handle less well when compared to multifilament sutures.[55] The most commonly used materials are synthetic polyester for the core suture, usually 3-0caliber. [56,57,58]

Ethibond is one of suture material that has become increasingly popular now. This synthetic material is next stiffest polyester, non-absorbable and multifilament.[59,60] In addition Ethibond is also stiffer than Nylon. [61]

Alavanja et al evaluated braided polyester suture for zone II flexor tendon repair and found no differrence between 3-0 and 4-0 caliber suture. And by using a 2-0 core suture, significantly increases the maximum tensile strength of the repair when compared with 3-0 or 4-0 sutures but also increases the resistance to gliding of the tendon.[62]

For peripheral suture, some literatures show same usual use of a monofilament which is 6-0 caliber for peripheral suture.[63,64.65] It is placed 2 mm from the repair site at a depth of 2 mm (as opposed to purely within the epitenon) to maximize the strength of the repair.[66]

POST-OPERATIVE REHABILITATION

Post-operative management has a significant effect on the result of flexor tendon injuries repair. The rehabilitation must balance between protection of the repair from excessive forces and prevention of adhesions. Historically, tendon repairs were immobilized for at least three weeks to protect the repair from rupture. Now this has been abandoned because early motion of the repair leads to improved tendon excursion, fewer adhesions andimproved tensile properties. [67,68,69,70,71]

Even it has been widely accepted that the tendon should be moved soon after the repair to prevent adhesions. There is more discussion over the right time to start the movement, the excursion of the movement required and the loads placed on the tendon.

A systematic review from Sameem M et al in 2011 reported that static splinting is likely only to yield 60% of the total active range of motion (ROM) when compared to dynamic splinting protocols.[72] Trumble TE et al in 2010 reported same result, better range of movement, smaller flexion contractures and greater patient satisfaction.[73]

ROM exercises are not initiated until at least 4 days (but no later than 7 days) after surgery because in the first 3 days the edema will make the work of flexionincrease. But it should begin before 7 days postoperatively. It based on an animal studies that showed waiting longer has resulted in an increased risk of adhesion.[74]

Flexor tendon repairs are now immobilized by most surgeons in a dorsal blocking splint as an additional safeguard against tendon rupture. But there are some papers presented in 2014 to the American Society for Surgery of the Hand (ASSH)compared the results of similar flexor tendon repairs, treated after surgery with splints that either did or did not immobilize the wrist. The short-splint group had significantly ($p< 0.05$) better interphalangeal joint motion. Rupture rates were similar in the two groups.[75,76]

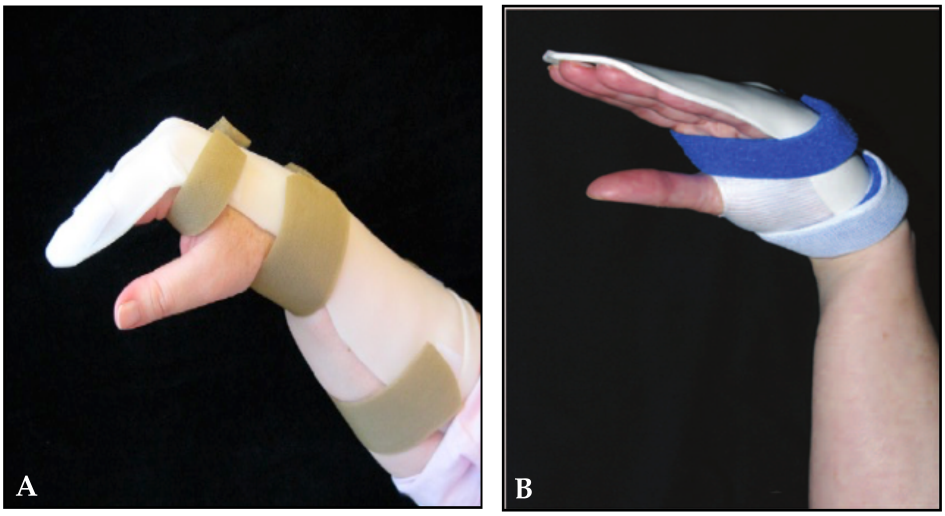

Figure 3. Dorsal blocking splint **(a)**; short splint **(b)** [75,76]

DISCUSSION

Over the last 15 years, repair strength (2, 4-and 6-strand repair) and latest suture materials (polyester/ethibond) have been improved as well as active mobilization rehabilitation protocols including a change of wrist position by modification of splints. And the improvement in putting splint from a traditional dorsal blocking splint into splint that not immobilize the wrist. Despite all of these modifications, tendon ruptures have not been eliminated. And the near future show whether a change of wrist position and avoiding place and hold positions in the controlled active motion protocols will improve the results, or whether application of lubricant.[77] will help to avoid gapping and rupturing. But finally there is still no 'best' repair suture technique and no 'best' rehabilitation, the choice of each in anyone unit, country or area of the world is more often determined by opinion, historical precedence and availability of particular materials than by science. Rather than thinking which is the best protocol for getting freer ROM, we have to set sufficient therapists. Because all of them is depending on therapists. Rehabilitation protocol must be matched with the patient's anticipated ability to adhere to the program's restrictions.

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