Review Article

Zone 2 flexor tendon injuries: Venturing into the no man's land

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Abstract

Flexor tendon injuries are seen commonly yet the management protocols are still widely debated. The advances in suture techniques, better understanding of the tendon morphology and its biomechanics have resulted in better outcomes. There has been a trend toward the active mobilization protocols with development of multistrand core suture techniques. Zone 2 injuries remain an enigma for the hand surgeons even today but the outcome results have definitely improved. Biomolecular modulation of tendon repair and tissue engineering are now the upcoming fields for future research. This review article focuses on the current concepts in the management of flexor tendon injuries in zone 2.

Key words: Hand injuries, rehabilitation, tendon repair, tendon injuries

Introduction

Flexor tendon injuries account for <1% of all hand injuries.[1] Management of these injuries often poses a surgical challenge because the results remain unpredictable results despite the best efforts. The management in view of zone 2 flexor tendon injuries, is a highly debatable topic. Most of the hand surgeons use the Verdan`s classification[2] based upon chances of adhesion formation, for localisation of the site of flexor tendon injury [Figure 1]. Zone 2 is also called as no man's land. The historic derivation of "no man's land" dates back to 14th century. It was used to describe an area outside London used for executions. Sterling Bunnel used this term in hand surgery who most probably derived it with his experience in the World War 1. Sterling Bunnell's first published use of the term appeared in a figure legend in both the second[3] and third[4] editions of his book, *Surgery of the Hand*; the legend read, "Primary suture of the flexor tendon between the distal crease in the palm and the middle crease in the finger (no man's land)." He described it as no man's land because of perennial anatomical characteristics. This zone has a fibro osseous digital canal where both the tendons interweave in a complex manner. The multiple pulleys increase its complexity because minimal swelling of the epitenon can impair free motion of the tendon. The margin of error, therefore, in this zone is very small. The term was first indexed in the fourth edition[5] of *Surgery of the Hand*, authored by Boyes. Any infection, fibrosis, cicatrix, overcrowding etc can lead to dense adhesions and hence compromising the results. Flexor digitorum sublimis (FDS) and flexor digitorum profundus (FDP) have large amplitude, the loss of which will result in marked diminution of either finger flexion or extension or both.

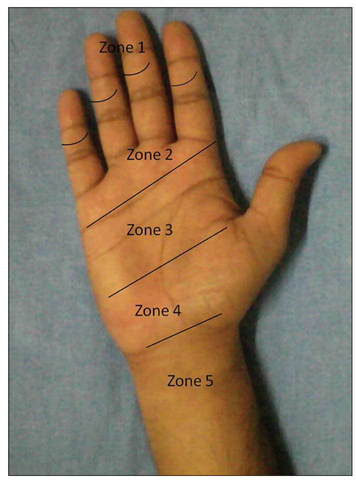

Figure 1: Clinical photograph showing zones for localization of flexor tendon injury (Verdan)[2]

The era of hand surgery can be divided on either side

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of 1960. The era before 1960 also includes the period when the use of antibiotics was not prevalent. Hence the surgeons had to keep in mind the risk of infection that usually compromises the results. The use of antibiotics for prevention of postoperative infections became prevalent after 1960 leading to decrease in infection rates. Three prominent surgeons of the era before 1960 named Bunnell, Mason, and Boyes preferred secondary tendon grafting as compared to primary repair in the "no man's land". The recommendations of Sterling Bunnel in 1922 for the treatment of cut flexor tendon injuries in zone 2 were as follows: 1. Close the skin, 2. Wait for the wound to heal, 3. Perform secondary procedures: (a) Excise both the flexor tendon. (b) Undertake tendon grafting of the flexor digitorum profundus tendon only.

Boyes noted that primary flexor tendon repair in what he then called the "critical zone" (the same anatomic area as no man's land) usually fails for 1 of 3 reasons: Infection, excessive scarring and cicatrix from ill performed surgery, and poorly placed incisions that cause flexion contractures.[6,7] The poor results in zone 2 were also reported by other several authors.[8-10]

The satisfactory results started to appear in 1960.[2,11] Kleinert submitted his controversial report to the annual American society for surgery for the hand (ASSH) meeting in which he reported an astounding 87% good to excellent results on private service patients.[12] This lead to a lot of flutter among the hand surgeons as these were the most sound results ever produced. The findings of Louisville group were reconfirmed in a later publication.[13] A lot of development has taken place in tendon repair ever since. The primary focus has been shifted for stronger repairs, meticulous surgical techniques, rehabilitation protocols and development of surgeons who can operate in emergency department with these skills leading to development of hand surgery as a separate surgical specialty.

Acute Flexor Tendon Injuries

The functional outcome for the tendon injuries in zone 2 are worst in view of more chances of adhesions formation.[14] Before repairing the tendon it is essential to ascertain other possible injuries which include fracture of the phalanx and metacarpal, as well as the neurovascular damage to the involved digit. Guarded prognosis is expected in presence of these injuries. Ultrasonography of the hand is quite helpful in localization of the proximal cut ends as shown in a cadaveric study and it may help in planning the length of incision.[15]

Surgical exposure

The standard midlateral incision or Bruner`s zigzag incision is commonly employed. The midlateral incision prevents scar formation directly over the tendon, is less likely to breakdown during physiotherapy but requires surgical dissection directly over the neurovascular bundle and is therefore a surgically demanding procedure. Bruner`s zigzag incision provides excellent surgical exposure but there may be scar formation directly over the tendon and may break in case of infection thereby affecting the physiotherapy. There is no study comparing the two methods of surgical exposures and both the methods are used commonly by their proponents. It therefore largely depends upon the surgeon's preference and expertise. Whichever surgical exposure is used, it is essential that thick flaps are raised and the tissue handling is very meticulous to prevent adhesion formation.

Surgical repair

Zone 2 flexor tendon repairs have improved with advances in the understanding of flexor tendon anatomy, biomechanics, nutrition, and healing.[16] The method of repair however is controversial. The following are the different options of treatment: (1) repair of the FDP tendon only with debridement of the FDS stump; (2) repair of both tendons; or (3) repair of FDP with repair of one slip of FDS tendon. Repair of both tendons in zone 2 is ideal but may be technically demanding. The proximal cut ends of the tendons may be retracted considerably into the palm and can be brought into the wound by milking the palm from proximal to distal end [Figure 2A (a)]. The distal ends of the tendons can be brought into the wound by passively flexing the DIP joint [Figure 2A (b)]. At times the digital nerve may be found cut [Figure 2A (c)] which can also be repaired along with both the flexor tendons [Figure 2B (a)]. Good results can be obtained following a good postoperative therapy programme [Figure 2B (b)].The repair of the FDP tendon alone with debridement of the FDS stump is a good option but carries a risk of failure if the only repaired tendon breaks down during physiotherapy or if there is cut through the suture line. Several authors prefer to repair of FDP alone with debridement of the FDS tendon stump in late presentations and also in old infected cases.[17] Henry repairs only the FDP tendon if both the slips of FDS tendon are to be repaired underneath A2 pulley and repairs FDS if the injury is proximal or distal to A2 pulley in zone 2.[18] Most hand surgeons prefer to repair the FDP and one slip of FDS.[19] This is also a reasonably good option as the repair of both slips of FDS may produce overcrowding within the sheath and pulleys and compromise the results. If only one slip of FDS is cut then the chiasma should be opened from that side and the FDP should be delivered from the same side. In cases of zone 2 injuries where only one slip the FDS is cut; it is the surgeon's choice whether to repair it or not. Authors prefer to repair only the cut

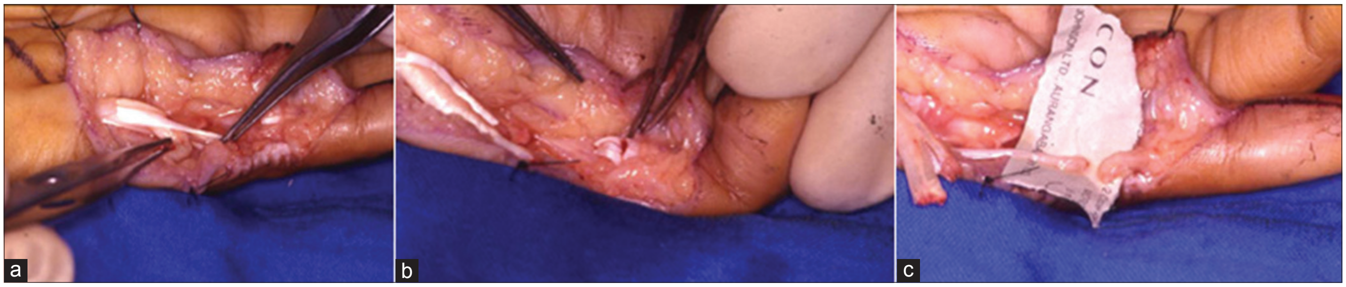

Figure 2A: Peroperative photographs showing (a) delivered ends of both the tendons in zone 2 (b) delivery of the distal ends by flexing the DIP joint (c) injured digital nerve, not an uncommon finding during the repair

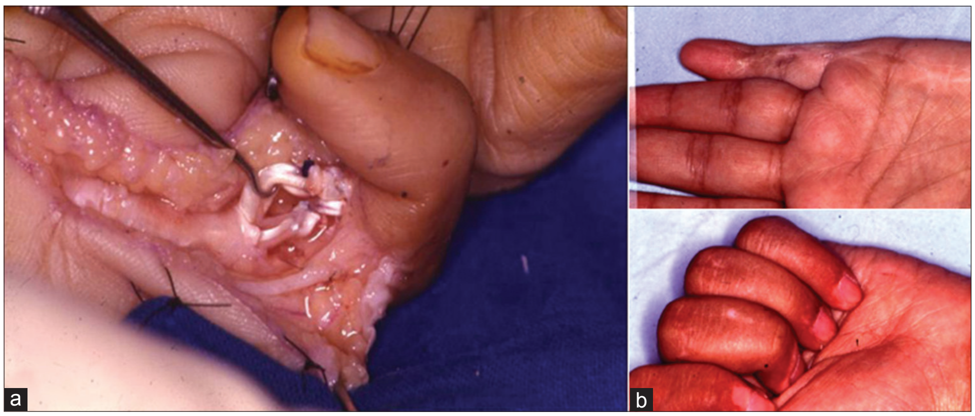

Figure 2B: Peroperative photographs showing (a) Meticulous repair of both the tendons and digital nerve (b) Good postoperative reults obtained with supervised physiotherapy

slip. The number of core strands that cross the repair site will increase the strength of the repair.[20] The number of suture strands passing through the repair should be 4-6 [Figure 3]. Increasing the number of strands to more than four has not shown to improve the results in clinical settings although cadaveric models show greater loads for failure for multistrand sutures (four or more than that).[21] Increasing the number of strands to >4 leads to more tissue handling with increase in the surgical time. Different suture techniques have been described by different authors [Figure 4].[16,22-24] The two-strand Kessler core with a simple peripheral suture remains the most popular flexor tendon suture technique and that most surgeons favour sheath closure.[25] Although this study was published five years back but the trend continues even today. The double modified Kessler and cruciate repairs (Adelaide technique)[26] are being utilized more commonly than before. Single knotted core suture techniques (e.g., Cruciate) have been shown to be biomechanically superior to double-knotted techniques (e.g., Double Kessler, modified Becker, Tsuge).[27] The length of suture purchase directly influences the strength and should be at least 1 cm on either side.[28] The suture material used for the core suture is usually nonabsorbable, 3/0 or 4/0 braided or monofilament material. The use of a recently developed 4-0 Fibre Wire (Anthrex, Naples, FL) is also gaining popularity.[29] The multifilament stainless steel's lower elongation and better knot-holding ability may result in a greater force to produce a 2-mm gap and a greater ultimate tensile strength in a tendon repair.[30] Other technical points that should be followed are a locking loop configuration with the knot placed outside the repair site, a peripheral suture placed deep into the tendon and far from the cut tendon end.[31] The peripheral epitendinous suture is 6/0 nonabsorbable suture, it contributes to the strength of the repair apart from making the repair neat. The primary repair of flexor tendons is contraindicated in cases of severe multiple tissue injuries to the fingers, when the wounds are dirty or contaminated, or when there has been skin loss overlying the flexor system.[16]

Secondary flexor tendon reconstruction

Carroll first described the use of silicone rod for use in two stage flexor tendon reconstruction in 1963. The technique was modified by Hunter in 1970 and has been used extensively since then with satisfactory results.[32] The indications of secondary tendon reconstruction have decreased as the results of primary reconstruction have improved. The indications for secondary tendon reconstruction are: failed primary repair, neglected injuries, segmental tendon loss and complicated injuries (Boyes grade 2-5, Table 1).[7]

It has to be decided whether to do single stage tendon reconstruction or to proceed for two stage tendon

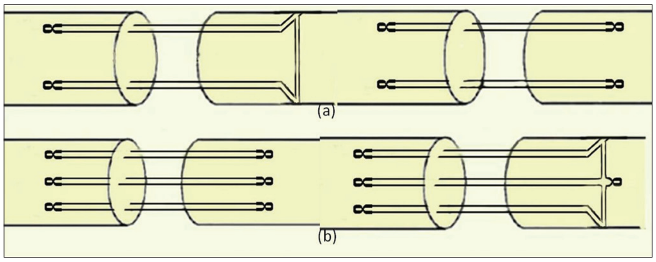

Figure 3: Line diagram showing (a) conventional two strand suture techniques (b) (a) conventional four strand suture techniques

Table 1: Boyes[5] grading for tendon injuries

Grade	Preoperative condition
I	Good, minimal scar and mobile joints
II	Notable scar tissue formation, mild contracture
III	Joint damage with decreased passive/active range of motion
IV	Nerve damage
V	Multiple system injury (combination of II, III, and IV)

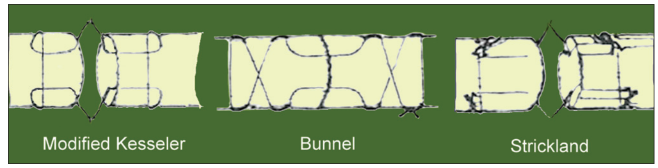

Figure 4: Sketches of different types of the commonly used suture techniques for repair of the flexor tendon

Figure 5: Peroperative clinical photograph showing excessive scaring in neglected cases

reconstruction. There are certain prerequisites that have to be fulfilled before undertaking single stage reconstruction; these include: supple joints, wounds healed without contracture or much scarring, intact neurovascular structure, willingness and understanding to participate in rehabilitation programmes. It is important to adhere to the strict surgical technique of minimal tendon handling with preservation of the existing pulley system and tendon sheath. If excessive scarring is found in the tendon bed [Figure 5] or pulleys are contracted leading to constriction of the graft; then procedure should be converted for two stage tendon reconstruction as the single stage reconstruction will fail in these circumstances. It was recommended that only portions of the annular pulleys be retained, but current recommendations include preserving as much of the sheath as possible.[33] If FDS is found to be intact then it should not be debrided rather the decision to repair the FDP alone should be taken with due consideration only; as many patients do quite well with only FDS functioning. Tenodesis or arthodesis of the DIP joint are good surgical options available in the presence of functioning FDS. Reconstruction of the FDP alone can be considered in young adults with very fine requirement of the fingers e.g., young musicians.

Surgical technique of two stage tendon reconstruction

Before undertaking two stage tendon reconstruction, the scars should have healed and the joints should be supple. Controversy for surgical exposure stays similar for tendon reconstruction also. Brunner zigzag or midlateral exposures can be used for the reconstruction. Debridement of the cut tendons is done the silicone rod is placed with suturing the distal end to the distal phalanx [Figure 6] and the proximal end is left free in the distal forearm. The pulleys are reconstructed over the silicone rod. Different tissues are described for the reconstruction of the pulleys. Sheath of extensor retinaculam has the advantage of synovial lining leading to fewer chances of adhesions.[34] Debrided tendons are commonly used for reconstruction of the pulleys. Palmaris longus or Plantaris can also be used for reconstruction of the pulleys. Different surgical techniques have been described for the reconstruction of pulleys. Making a double loop beneath the extensor tendon encircling the proximal phalanx in its proximal one third is the commonly used method for reconstruction of the A2 pulley. A4 Pulley is also reconstructed over the middle phalanx by encircling around the extensor apparatus. Using the remnants of the pulley, instead of encircling the phalanx has also been described.[35] Use of volar plate as the pulley was described by Karev; he makes incisions distal and proximal in the volar plate, and the tendon is passed through it.[36] Due to nonelasticity of the volar plate, the tendon glide is impaired. There have been few case reports of the proximal phalanx fracture post pulley reconstruction.[37] Due to the concern of overcrowding and adhesion formation, a few surgeons do reconstruct the pulley as third stage procedure under local anaesthesia. Proper tightness is essential to prevent the constriction of the tendon and to allow gliding. As the procedure for pulley reconstruction is done under local anaesthesia proper tightness can be ensured more reliably. Authors prefer reconstruction of the pulleys simultaneously at stage one. It has to be ensured that the implant glides smoothly and does not buckle with passive flexion. It is advisable to place nonabsorbable sutures at the proximal end of the prosthesis so that identification becomes easier during stage 2. If nerve repair is indicated it is done at this

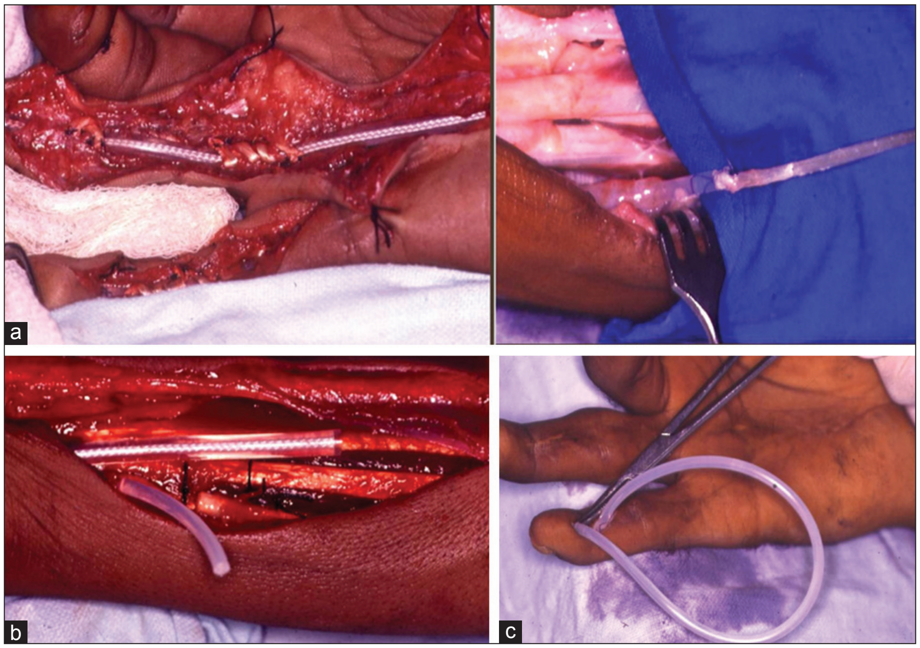

Figure 6: Peroperative photograph showing (a) Well placed silicone rod at zone 2 along with the reconstructed pulleys (b) Silicone rod brought into proximal forearm (c) Silicone rod is replaced by a free tendon using two minimal incisions and rail-road technique

stage. The joints are mobilised in the postoperative period. The mobilisation is started depending upon the repair of the nerves. It may be started immediately or after two weeks. The second stage involves the replacement of the silicone rod with the tendon graft. The various types of tendon grafts will be discussed later. A pseudosheath must be formed before replacing the silicone rod with a graft. The second stage is usually performed after three months as during this period the scars mature and a suitable gliding sheath forms around the implant. Few surgeons perform the second stage procedure at six weeks.[38] Authors prefer to wait for three months as that is generally agreed on as adequate time by most surgeons and it is not worth taking risk at six weeks for a procedure that is usually done as last surgical option for moving small natural joints. The proximal end of the graft is tied to the adjacent FDP tendon, if that is not suitable then the FDS is selected. The graft is pulled through the pseudosheath by stitching to the silicone rod at the proximal site and pulling the rod at the distal end. The graft is stitched distally first with a Bunnel's pull through suture over a button or with anchor sutures. The proximal end of the graft is stitched to the motor unit with an interweave fish mouth suture.

Choice of graft

All patients have to be evaluated during preoperative period for the availability of donor tendons. Palmaris longus is the most commonly used graft as it is usually found in the extremity being operated. The presence of palmaris longus has to be confirmed as it is absent in 25% of the population. The approximate useable length is 16cm hence usual problem with palmaris longus is its short length if repair is done in forearm. Plantaris is the second most commonly used tendon. It is absent in 20% of the population.[39] The approximate usable length is 35 cm and because of its thinness it can be passed easily through the newly constructed tendon sheath. The long extensors of foot (middle three extensors) and flexor digitorum longus of second toe have been used with little morbidity of the toes. The problem with long extensors of foot is their thickness due to which they are difficult to pass with newly constructed sheath. Flexor digitorum longus is the only intrasynovial tendon, used for reconstruction. The results with use of intrasynovial tendon are expected to be better than the use extrasynovial tendon as graft. The chances of adhesions are expected to be lower because of intrasynovial property.[40] Flexor digitorum longus of the second toe is usually 12-13 cm long and its short length may pose a problem despite being an intrasynovial tendon. Extensor indicis proprius is another graft that can be used with little morbidity of the second metacarpophalangeal joint. However, Palmaris longus is still preferred by most surgeons as clinical trials have shown satisfactory results in clinical trials.[41,42]

Rehabilitation

The goals of rehabilitation after tendon repair are to promote intrinsic tendon healing and minimize extrinsic scarring to optimize tendon gliding and functional range of motion.[43] Utmost care is taken to avoid complications of re-rupture, adhesion formation, flexion contracture, pulley failure/bowstringing/ and triggering. There is controversy regarding certain rehabilitation issues such as early/late mobilisation, position and type of the splint and mobilisation protocols (controlled passive motion, active extension/passive flexion or controlled active motion). There is still insufficient evidence to define the best mobilization strategy.[44] Experimental studies suggest that motion enhances tendon repair especially the strength of repair by reducing oedema and preventing adhesions.[45] The old concept of 2-3 weeks of immobilisation in splint and then starting the mobilisation has been abandoned as that lead to unacceptable results. Most hand surgeons start mobilisation by the 3-5th postoperative day. Different types of protocol of early mobilisation have been employed by different authors leading to better results.[46-49] There is however no general consensus at present.

Kleinert's classical description of controlled active extension with passive flexion utilizing elastic band traction has been used by most hand surgeons who are proponents of immediate controlled mobilization.[46] In the opinion of some surgeons the Kleinert's regime has gone into disrepute as it causes flexion contracture at the PIP and DIP joints if the patient keeps the splint on during the night time also. The flexion contractures appear since the resting position of the PIP joint is maintained in 60-90 of flexion.[50] The controlled passive motion regimen of Duran and Houser employs a use of dorsal splint to keep the PIP and DIP joints in extension with no elastic band for passive flexion, Rather the patient uses another hand to move the PIP, DIP, and MCP joints passively; active extension is also done by the patient.[51] It has been associated with a poor capacity for differential gliding between the superficialis and profundus tendons, particularly in Zone II. This eventually leads to adhesion formation that compromises the functional result.[52] Early active motion programmes have been employed since early 1990; multistrand suture use has lead to strong repair leading to more aggressive protocols.[53] Early active motion results in good effect over tendon healing.[54] MCP joint flexion with wrist extension results in maximum differential glide between the FDS and FDP tendon thereby minimising the chances of adhesions.[55] Strickland introduced an early active motion protocol (Indiana Hand Centre) for a four-strand repair with an epitendinous suture for which good patient motivation and comprehension are required. No tissue oedema and minimal wound complications are the prerequisite for early active motion protocols.[56] The active motion protocols have to be weighed against the risk of tendon rupture. It becomes essential on the part of surgeon to inform the physiotherapist about the type of repair used for every individual patient. The incidence of rupture, regardless of the method of postoperative mobilization regimen, is consistently quoted at 4%-6%.[57] It appears prudent to use the mix-up protocol so that beneficial effects can be taken from every regimen. Authors use the combined regimen which employs both the Kleinert`s regimen and early active motion protocol in the presence of the physiotherapist. We use the dorsal splint involving the wrist in 20-30 degree of flexion with MCP joints at 80-90 degree of flexion and keeping the PIP and DIP joints in extension for night time. During day time we follow Kleinert`s regimen of controlled active extension with passive flexion. Active motions are done in the presence of the physiotherapist only with 25% of total movement of the joint at first two weeks which is increased further during the course. The splint is discontinued at six weeks and strengthening of the forearm muscles is started in further course of treatment.

Conclusion

During this decade the hand surgeons have employed the use of multistrand sutures leading to stronger repairs and giving the hand physiotherapist the window for controlled active mobilisation protocols. Reoperation rates are found to be higher in older age group or in cases of workmen compensation issues.[58] Biomolecular modulation of tendon repair and tissue engineering remain the upcoming fields for showing the future research direction.[59]

References

1. Hill C, Riaz M, Mozzam A, Brennen MD. A regional audit of hand and wrist injuries. A study of 4873 injuries. J Hand Surg Br 1998;23:196-200.
2. Verdan CE. Primary repair of flexor tendons. J Bone Joint Surg Am 1960;42:647-57.
3. Bunnell S. Surgery of the hand. 2nd ed. Philadelphia: JB Lippincott; 1948. p. 627.
4. Bunnell S. Surgery of the hand. 3rd ed. Philadelphia: JB Lippincott; 1956. p. 712.
5. Boyes JH. Bunnell's surgery of the hand. 4th ed. Philadelphia: JB Lippincott; 1964.
6. Boyes JH. Immediate vs delayed repair of the digital flexor tendons. Ann West Med Surg 1947;1:145-52.
7. Boyes JH. Flexor-tendon grafts in the fingers and thumb; an evaluation of end results. J Bone Joint Surg Am 1950;32:489-99.
8. Kelly AP Jr. Primary tendon repairs: A study of 789 consecutive tendon severances. J Bone Joint Surg Am 1959;41:581-98.
9. Siler VE. Primary tenorrhaphy of the flexor tendons in the hand. J Bone Joint Surg Am 1950;32:218-25.
10. Posch JL. Primary tenorrhaphies and tendon grafting procedures in hand injuries. AMA Arch Surg 1956;73:609-24.
11. Lindsay WK, Mcdougall EP. Direct digital flexor tendon repair. Plast Reconstr Surg Transplant Bull 1960;26:613-21.
12. Kleinert HE, Kutz JE, Ashbell TS, Martinez E. Primary repair of lacerated flexor tendons in "No Man's Land". J Bone Joint Surg Am 1967;49:577.
13. Kleinert HE, Kutz JE, Atasoy E, Stormo A. Primary repair of flexor tendons. Orthop Clin North Am 1973;4:865-76.

14. Karlander LE, Berggren M, Larsson M, Söderberg G, Nylander G. Improved results in zone 2 flexor tendon injuries with a modified technique of immediate controlled mobilization. J Hand Surg Br 1993;18:26-30.
15. Ravnic DJ, Galiano RD, Bodavula V, Friedman DW, Flores RL. Diagnosis and localisation of flexor tendon injuries by surgeon-performed ultrasound: A cadaveric study. J Plast Reconstr Aesthet Surg 2011;64:234-9.
16. Strickland JW. Flexor tendon repair. Hand Clin 1985;1:55-68.
17. Kotwal PP, Gupta V. Neglected tendon and nerve injuries of the hand. Clin Orthop Relat Res 2005;431:66-71.
18. Henry M. Zone II: Repair or resect the flexor digitorum superficialis? J Hand Surg Am 2011;36:1073-4.
19. Coats RW 2nd, Echevarría-Oré JC, Mass DP. Acute flexor tendon repairs in zone II. Hand Clin 2005;21:173-9.
20. Savage R, Risitano G. Flexor tendon repair using a 'six strand' method of repair and early active mobilisation. J Hand Surg Br 1989;14:396-9.
21. Gill RS, Lim BH, Shatford RA, Toth E, Voor MJ, Tsai TM. A comparative analysis of the six-strand double-loop flexor tendon repair and three other techniques: A human cadaveric study. J Hand Surg Am 1999;24:1315-22.
22. Kessler I. The 'grasping' technique for tendon repair. Hand 1973;5:253-5.
23. Barrie KA, Wolfe SW, Shean C, Shenbagamurthi D, Slade JF 3rd, Panjabi MM. A biomechanical comparison of multistrand flexor tendon repairs using an *in situ* testing model. J Hand Surg Am 2000;25:499-506.
24. Taras JS. Primary flexor tendon repair. Oper Techniques Orthop 1993;3:270-7.
25. Healy C, Mulhall KJ, Bouchier-Hayes DJ, Kneafsey B. Practice patterns in flexor tendon repair. Iran J Med Sci 2007;176:41-4.
26. Peltz TS, Haddad R, Scougall PJ, Nicklin S, Gianoutsos MP, Walsh WR. Influence of locking stitch size in a four-strand cross-locked cruciate flexor tendon repair. J Hand Surg Am 2011;36:450-5.
27. Rees L, Matthews A, Masouros SD, Bull AM, Haywood R. Comparison of 1- and 2-knot, 4-strand, double-modified Kessler tendon repairs in a porcine model. J Hand Surg Am 2009;34:705-9.
28. Cao Y, Zhu B, Xie RG, Tang JB. Influence of core suture purchase length on strength of four-strand tendon repairs. J Hand Surg Am 2006;31:107-12.
29. Miller B, Dodds SD, deMars A, Zagoreas N, Waitayawinyu T, Trumble TE. Flexor tendon repairs: The impact of fiberwire on grasping and locking core sutures. J Hand Surg Am 2007;32:591-6.
30. McDonald E, Gordon JA, Buckley JM, Gordon L. Comparison of a new multifilament stainless steel suture with frequently used sutures for flexor tendon repair. J Hand Surg Am 2011;36:1028-34.
31. Kim HM, Nelson G, Thomopoulos S, Silva MJ, Das R, Gelberman RH. Technical and biological modifications for enhanced flexor tendon repair. J Hand Surg Am 2010;35:1031-7.
32. Hunter JM, Salisbury RE. Flexor-tendon reconstruction in severely damaged hands. A two-stage procedure using a silicone-dacron reinforced gliding prosthesis prior to tendon grafting. J Bone Joint Surg Am 1971;53:829-58.
33. Strickland JW. Delayed treatment of flexor tendon injuries including grafting. Hand Clin 2005;21:219-43.
34. Lister GD. Reconstruction of pulleys employing extensor retinaculum. J Hand Surg Am 1979;4:461-4.
35. Klinert HE, Bennett JB. Digital pulley reconstruction employing the always present rim of the previous pulley. J Hand Surg Am 1978;3:297-8.
36. Karev A, Stahl S, Taran A. The mechanical efficiency of the pulley system in normal digits compared with a reconstructed system using the 'belt loop' technique. J Hand Surg Am 1987;12:596-601.
37. Sanger JR, Buebendorf ND, Matloub HS, Yousif NJ. Proximal phalangeal fracture after tendon pulley reconstruction. J Hand Surg Am. 1990;15:976-9.
38. Moore T, Anderson B, Seiler JG 3rd. Flexor tendon reconstruction. J Hand Surg Am 2010;35:1025-30.
39. Wehbé MA. Tendon graft donor sites. J Hand Surg Am 1992;17:1130-2.
40. Leversedge FJ, Zelouf D, Williams C, Gelberman RH, Seiler JG 3rd. Flexor tendon grafting to the hand: An assessment of the intrasynovial donor tendon-A preliminary single-cohort study. J Hand Surg Am 2000;25:721-30.
41. Smith P, Jones M, Grobbelaar A. Two-stage grafting of flexor tendons: Results after mobilisation by controlled early active movement. Scand J Plast Reconstr Surg Hand Surg 2004;38:220-7.
42. Finsen V. Two-stage grafting of digital flexor tendons: A review of 43 patients after 3 to 15 years. Scand J Plast Reconstr Surg Hand Surg 2003;37:159-62.
43. Elliot D, Barbieri CH, Evans RB, Mass D, Tang JB. IFSSH Flexor Tendon Committee Report 2007. J Hand Surg Eur 2007;32:346-56.
44. Thien TB, Becker JH, Theis JC. Rehabilitation after surgery for flexor tendon injuries in the hand. Cochrane Database Syst Rev 2004;4:CD003979.
45. Riaz M, Hill C, Khan K, Small JO. Long term outcome of early active mobilization following flexor tendon repair in zone 2. J Hand Surg Br 1999;24:157-60.
46. Lister GD, Kleinert HE, Kutz JE, Atasoy E. Primary flexor tendon repair followed by immediate controlled mobilization. J Hand Surg Am 1977;2:441-51.
47. Chow JA, Thomes LJ, Dovelle S, Milnor WH, Seyfer AE, Smith AC. A combined regimen of controlled motion following flexor tendon repair in 'no man's land'. Plast Reconstr Surg 1987;79:447-55.
48. Strickland JW. Development of flexor tendon surgery: Twenty five years of progress. J Hand Surg Am 2000;25:214-35.
49. Kitsis CK, Wade PJ, Krikler SJ, Parsons NK, Nicholls LK. Controlled active motion following primary flexor tendon repair: A prospective study over 9 years. J Hand Surg Br 1998;23:344-9.
50. Bainbridge LC, Robertson C, Gillies D, Elliot D. A comparison of postoperative mobilization of flexor tendon repairs with 'passive flexion active extension' and 'controlled active motion' techniques. J Hand Surg Br 1994;19:517-21.
51. Duran R, Houser R, Coleman C, Postlewaite D. A preliminary report in the use of controlled passive motion following flexor tendon repair in zones II and III. J Hand Surg 1976;1:79.
52. Silfverskiöld KL, May EJ, Törnvall AH. Flexor digitorum profundus tendon excursions during controlled motion after flexor tendon repair in zone II: A prospective clinical study. J Hand Surg Am 1992;17:122-31.
53. Strickland. Flexor tendon injuries: II. operative technique. J Am Acad Orthop Surg 1995;3:55-62.
54. Iwuagwu FC, McGrouther DA. Early cellular response in tendon injury: The effect of loading. Plast Reconstr Surg 1998;102:2064-71.

55. Savage R. The influence of wrist position on the minimum force required for active movement of the interphalangeal joints. J Hand Surg Br 1988;13:262-8.
56. Skirven TM. Rehabilitation after tendon injuries in the hand. Hand Surg 2002;7:47-59.
57. Baktir A, Türk CY, Kabak S, Sahin V, Kardaş Y. Flexor tendon repair in zone 2 followed by early active mobilization. J Hand Surg Br 1996;21:624-8.
58. Dy CJ, Daluiski A, Do HT, Hernandez-Soria A, Marx R, Lyman S. The epidemiology of reoperation after flexor tendon repair. J Hand Surg Am 2012;37:919-24.
59. Chang J. Studies in flexor tendon reconstruction: Biomolecular modulation of tendon repair and tissue engineering. J Hand Surg Am 2012;37:552-61.

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