Clinical Outcomes Associated with Flexor Tendon Repair

Jin Bo Tang, MD *

Department of Hand Surgery, Hand Surgery Research Center, Affiliated Hospital of Nantong University, 20 West Temple Road, Nantong 226001, Jiangsu, China

Boston University School of Medicine, 715 Albany Street, Boston, MA 02118, USA

Surgical Research and Gene Therapy, Roger Williams Medical Center, 133 North Campus, 825 Chalkstone Avenue, Providence, RI 02908, USA

Flexor tendon injuries in the hand are a frequent clinical problem. Restoration of function after flexor tendon injuries has long been a challenge and a frustration to hand and orthopedic surgeons. In recent decades, laboratory and clinical investigations focused on flexor tendon biomechanics, refinement of repair methods, and optimization of rehabilitation regimens have remarkably improved functional outcomes [1–8]. Repair ruptures and adhesion formation are still unpredictable in some cases [8–15], however, and are believed to be attributed to inherent weakness in the healing capacity of tendons, particularly those in intrasynovial areas.

Worldwide, repair rupture occurs in 4%–10% of repaired fingers. Another 10% are estimated to develop restrictive adhesion requiring secondary tenolysis or a tendon graft. Stiffness of the interphalangeal joints occurs to some extent in more than half of patients. Repair rupture, adhesions, and joint stiffness after primary tendon surgery require secondary operations, and functional disability remains (which may persist even after secondary surgery), affecting patients’ ability to work and their daily lives. Optimal treatment of tendon injuries and achieving a satisfactory outcome after surgery and postoperative care remain topics of debate and challenge to hand surgeons.

Outcomes of flexor tendon repair: an overview of experience over the past 15 years

The past 15 years have seen more than 20 major reports in English language journals on outcomes of primary flexor tendon repair from hand surgery centers worldwide [9–33].

A series of reports by Small et al [9], Cullen et al [10], and Savage and Risitano [11] were published 15 years ago, documenting clinical outcomes of controlled active finger flexion exercise after flexor tendon repairs. These promising preliminary reports summoned the expenditure in the years following to more aggressive exercise incorporating active finger flexion to the motion regimen. Small et al [9] presented 114 patients with 138 zone II flexor tendon injuries treated over a 3-year period. Early active mobilization of the fingers was commenced within 48 hours after surgery. Ninety-eight patients with injuries of 117 fingers were followed and graded using the total active range of motion (TAM) method. The active range of motion was graded excellent or good in 77% of the digits, fair in 14%, and poor in 9%. Repair rupture occurred in 11 digits (9.4%). The ruptures were re-repaired immediately and a similar early motion program was applied. Cullen et al [10] treated 34 adult patients with 70 zone II tendon lacerations in 38 fingers. Seventy-eight percent of fingers were rated excellent or good by Strickland criteria after a mean follow-up of 10 months. Two tendons ruptured during controlled active finger flexion exercise. Savage and Risitano [11] used a six-strand method of repairs to treat 36

* Correspondence. Department of Hand Surgery, Affiliated Hospital of Nantong University, 20 West Temple Road, Nantong 226001, Jiangsu, China.
E-mail address: jinbotang@yahoo.com.
fingers with flexor tendon lacerations followed by protective active mobilization. Sixty-three percent of lacerations were zone II and 27% were zone I; 69% and 100%, respectively, achieved an excellent or good result using Buck-Gramcko’s assessment method. Tang and Shi [14] reported the results of treatment of 72 flexor tendon injuries in zone II primarily or at the delayed primary stage. In 80.4% of the fingers, excellent or good results were achieved, as evaluated using Strickland and Glogovac criteria. Silfverskiöld and May [15] reported outcomes of use of cross-stitch epiten- dinous sutures combined with a modified Kessler core suture in treatment of flexor tendon injuries in zone II in 46 consecutive patients with 55 injured digits. For the first 4 weeks after operation, fingers were mobilized with a combination of active extension and passive and active flexion. Two tendons were reported as having ruptures. In the remaining fingers, the mean active distal interphalangeal (DIP) and proximal interphalangeal (PIP) range of motion was 63° and 94° 6 months after surgery, respectively. Elliot et al [19] reported a series of 233 patients with complete divisions of the flexor tendons in zones I and II. These included 203 patients with 317 divided tendons in 224 finger injuries and 20 patients with 30 complete divisions of the flexor pollicis longus (FPL) tendon of the thumb. The patients underwent a controlled active motion regimen postoperatively. Thirteen (5.8%) fingers and five (16.6%) thumbs suffered tendon rupture during the mobilization. Follow-up of the patients treated during the last year of the study showed that 10 of 16 (62.5%) fingers with zone I repairs, 50 of the 63 (79.4%) fingers with zone II repairs, on assessment by Strickland and Glogovac criteria. Emphasis on the needs and application of four- or six-strand core repairs in clinical tendon repairs appeared first in Savage and Risitano’s report [11] in the late 1980s, followed by the report of Tang et al [20] in 1994, and then a series of reports in Atlas of Hand Clinics by Taras [21], Sandow and McMahon [22], and Lim and Tsai [23] in 1996. Tang et al [20] reported using double- or multiple-looped sutures for primary tendon repairs with combined early active and passive mobilization for 3 weeks. In 51 fingers from 46 patients with zone II flexor tendon lacerations, doubled threads of the looped suture were placed to repair injured flexor digitorum profundus (FDP) or superficialis (FDS) tendons, or three threads of the looped suture to repair the FDP tendons. The results were good or excellent in 76.5% using White’s criteria, with two repair ruptures (4%) during the postoperative motion program. Taras et al [21] applied double-grasping and cross-stitch peripheral sutures in 21 flexor tendon repairs of 14 digits. These included three FPL, four FDP zone I, and 14 FDS or FDP zone II repairs. The postoperative therapy regimen included active motion initiated on the first postoperative day, including place-hold exercise three times weekly under supervision. Between therapy sessions, a standard elastic-thread traction passive flexion and active extension program was maintained. Overall recovery of digital motion was graded as excellent in 12 and good in 2. The seven fingers with FDP and FDS repairs in zone II averaged 83% recovery of motion. Sandow and McMahon [22] reported 37 consecutive FDP tendons in zones I to V using a modified single-cross six-strand repair based on the original Savage method. Of 23 zone II tendon injuries in 18 patients, 78% were rated as good or excellent using Strickland and Glogovac criteria. There were no ruptures or secondary surgery in any patient in their series. Lim and Tsai [23] used six-strand tendon repairs with looped suture to repair the tendon injuries in zone II with good functional outcomes.

There were two reports on the outcomes of the largest series of flexor tendon injuries in this period, both of which came from England. Kitsis et al [25] treated 339 divided flexor tendons affecting 208 fingers. The tendons were repaired with a modified Kessler core and a Halsted peripheral stitch. Overall results by Strickland and Glogovac criteria were 92% excellent or good, 7% fair, and 1% poor. There were 43 complications in 31 patients, including five zone II ruptures (5.7%) and one rupture in zone V. Harris et al [27] reviewed results of 440 patients with 728 primary zone I and zone II flexor tendon repairs in 526 fingers. Overall, 23 patients ruptured 28 tendon repairs. A total of 129 fingers with zone I injuries had a rupture rate of 5% (6 fingers). A total of 397 fingers with zone II injuries had a rupture rate of 4% (17 fingers) (Table 1).

Sirotakova and Elliot [31] analyzed the results of primary repairs of the FPL tendon followed by early active motion with only the thumb splinted. The first 30 patients were repaired with a Kessler suture and simple epitenodinous suture. The last 49 patients underwent repair with a Kessler suture and a reinforced epitenodinous suture, but in a splint with the thumb position altered and the fingers also splinted. More recently, they reported 0% rupture rate in 48 patients with strengthened
core and peripheral sutures [7]. Other reports include those from Percival and Sykes [28], Noonan and Blair [29], Nunley et al [30], Fitoussi et al [32], and Kasashima et al [33]. Reported results of FPL repairs are detailed in Table 2.

Review of the outcomes of clinical flexor tendon repairs reported over the 15 years showed excellent or good functional return in more than three-fourths of primary tendon repairs followed by a variety of postoperative passive/active mobilization treatment. Repair ruptures nevertheless were documented in most of the reports and rupture rates ranged from 4%–10% in the finger flexors (see Table 1) and from 3%–17% in FPL of thumbs (Table 2). Most of these reports came from the finest hand surgery centers in the world and these teams were supervised by at least one expert hand surgeon with experience in treating flexor tendon injuries. One may reasonably assume that the outcomes in a general hospital setting might have actually reflected a lower level of success. In other words, flexor tendon repairs might have been unsatisfactory in a larger proportion of patients.

Factors affecting outcome of flexor tendon repair

Adhesion formation

Adhesion formation, like scar formation in cutaneous wounds, was believed to be inevitable after tendon surgery and postoperative

---

**Table 1**

Summary of the reports of primary finger flexor tendon repairs in the past 15 years

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Number of digits</th>
<th>Zones</th>
<th>Excellent and good</th>
<th>Rupture rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>Small et al</td>
<td>117</td>
<td>II</td>
<td>77% (TAM)</td>
<td>9.4%</td>
</tr>
<tr>
<td>1989</td>
<td>Cullen et al</td>
<td>38</td>
<td>II</td>
<td>78%</td>
<td>6.4%</td>
</tr>
<tr>
<td>1989</td>
<td>Savage and Risitano</td>
<td>36</td>
<td>I,II,III,IV</td>
<td>81% (Buck-Gramcko)</td>
<td>2.8%</td>
</tr>
<tr>
<td>1989</td>
<td>Pribaz et al</td>
<td>43</td>
<td>II</td>
<td>70% (White)</td>
<td>7.0%</td>
</tr>
<tr>
<td>1992</td>
<td>Tang and Shi</td>
<td>54</td>
<td>II</td>
<td>80%</td>
<td>—</td>
</tr>
<tr>
<td>1994</td>
<td>O’Connell et al</td>
<td>95 (children)</td>
<td>I,II</td>
<td>69%</td>
<td>0%</td>
</tr>
<tr>
<td>1994</td>
<td>Silfverskiodt and May</td>
<td>55</td>
<td>II</td>
<td>90%</td>
<td>3.7%</td>
</tr>
<tr>
<td>1994</td>
<td>Grobbelaar and Hudson</td>
<td>38 (children)</td>
<td>All zones</td>
<td>82% (Lister)</td>
<td>7.9%</td>
</tr>
<tr>
<td>1995</td>
<td>Berndtsson and Ejeskar</td>
<td>46 (children)</td>
<td>II</td>
<td>77%</td>
<td>—</td>
</tr>
<tr>
<td>1994</td>
<td>Elliot et al</td>
<td>244</td>
<td>I,II</td>
<td>79%</td>
<td>5.8%</td>
</tr>
<tr>
<td>1994</td>
<td>Tang et al</td>
<td>51</td>
<td>II</td>
<td>77% (White)</td>
<td>4.0%</td>
</tr>
<tr>
<td>1996</td>
<td>Baktir et al</td>
<td>88</td>
<td>II</td>
<td>81%</td>
<td>4.5%</td>
</tr>
<tr>
<td>1996</td>
<td>Sandow and McMahon</td>
<td>23</td>
<td>II</td>
<td>78%</td>
<td>0%</td>
</tr>
<tr>
<td>1998</td>
<td>Kitsis et al</td>
<td>208</td>
<td>All zones</td>
<td>92%</td>
<td>2.9%</td>
</tr>
<tr>
<td>1998</td>
<td>Yii et al</td>
<td>161</td>
<td>V</td>
<td>90% (TAM)</td>
<td>0%</td>
</tr>
<tr>
<td>1999</td>
<td>Harris et al</td>
<td>526</td>
<td>I,II</td>
<td>—</td>
<td>4.0%</td>
</tr>
<tr>
<td></td>
<td>(129)</td>
<td></td>
<td>I</td>
<td>—</td>
<td>5.0%</td>
</tr>
<tr>
<td></td>
<td>(397)</td>
<td></td>
<td>II</td>
<td>—</td>
<td>4.0%</td>
</tr>
</tbody>
</table>

* The criteria of evaluation was Strickland and Glogovac criteria unless otherwise specified.

**Table 2**

Summary of the major reports of flexor pollicis longus tendon repairs

<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Number of digits</th>
<th>Zones</th>
<th>Excellent and good</th>
<th>Rupture rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>Percival and Sykes</td>
<td>51</td>
<td>I–III</td>
<td>53% (White)</td>
<td>8%</td>
</tr>
<tr>
<td>1991</td>
<td>Noonan and Blair</td>
<td>30</td>
<td>All zones</td>
<td>IP 71%, MP 82% normal</td>
<td>—</td>
</tr>
<tr>
<td>1992</td>
<td>Nunley et al</td>
<td>38</td>
<td>I,II</td>
<td>Average IP 35%</td>
<td>3%</td>
</tr>
<tr>
<td>1996</td>
<td>Thomazeau et al</td>
<td>20</td>
<td>All zones</td>
<td>85% (Tubiana)</td>
<td>5%</td>
</tr>
<tr>
<td>1999</td>
<td>Sirotakova and Elliot</td>
<td>30 (1st period)</td>
<td>I,II</td>
<td>70% (White)</td>
<td>17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>73% (Buck-Gramcko)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>67% (White)</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>72% (Buck-Gramcko)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>76% (White)</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80% (Buck-Gramcko)</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>Kasashima et al</td>
<td>29</td>
<td>I–III</td>
<td>63% (Japanese for surgery of the hand)</td>
<td>0%</td>
</tr>
</tbody>
</table>
immobilization [34,35]. The early motion regimen advocated in the past decades substantially decreased adhesions around repaired tendons and restored smoother gliding surface to the tendon. Tendon healing, though not ideally strong, satisfied the tendon motion program. In many instances, it is unrealistic to expect a tendon to heal without any adhesions, because some loose adhesions may develop after surgery even with exercise. Three distinct concepts are pertinent to healing and function, intrinsic healing, participation of extrinsic cells in healing, and formation of restrictive adhesions. Tendon healing exclusively through intrinsic cellular-activity occurs only in in vitro experimental situations. Clinically, it is not extrinsic interference (through cell seeding or formation of filmy adhesions) but the formation of restrictive adhesions that affects the outcomes of tendon repairs. The goals of a postoperative motion program are to disrupt or prevent adhesions that restrict tendon motion and to prevent joint stiffness, both vital to recovery of active range of finger motion.

Adhesions influence tendon movement depending on their density, which is determined by the tissues from which the adhesions arise. Adhesions are generally categorized as either loose or dense adhesion. As the preservation of the sheath becomes a consideration in tendon repairs, adhesions arising from the sheath structures are of a density between loose and dense. Three types of adhesions therefore can be seen in tenolysis: (1) loose adhesions arise from the subcutaneous tissue and are largely movable; repaired tendons glide fairly easily within such adhesions; (2) adhesions of moderate density arise from the synovial sheath or pulleys and are remarkably restrictive of tendon motion; and (3) dense adhesions arise from the bony floor or volar plates, and penetrate to the dorsal aspect of the tendons. Dense adhesions allow minimal tendon motion and severely jeopardize the healing of the tendon and the intratendinous structures. With an appropriate rehabilitation program, loose adhesions can be disrupted or modified so as to avoid reducing the amplitude of motion. Moderate or dense adhesions, however, should be prevented through careful surgical manipulation or postoperative treatments, because it is difficult to alter once they have developed.

**Repair rupture**

Among all the consequences of flexor tendon surgery, repair ruptures are of prime concern to hand surgeons, because they require secondary operations. If ruptures occur soon after primary repair, direct resuture of the ruptured tendons may be attempted; if ruptures occur at the late period, a secondary tendon graft is indicated [36]. Rupture of the primary repairs occurred in 4%–10% of the fingers in the reports referenced earlier. Limited healing ability and consequent weakness in the post-healing strength underlay the failure of achieving solid union of intrasynovial flexor tendons. The following factors may trigger the ruptures: (1) Overload of the repaired tendons: active flexion or extension of the fingers may subject the repaired tendons to a load exceeding the limit of the tensile resistance of the repairs. (2) Tendon edema or bulky tendons: edema of the tendons is inevitable after surgery, though severity varies among patients. Severely traumatized wounds, extensive soft tissue injuries, long duration of surgery, and poor surgical repair maneuvers all contribute to postsurgical edema. Edema makes the tendon bulky. In addition, excessive suture materials also contribute to bulkiness. A bulky tendon increases the pressure of the tendon on the surrounding tissues and its friction against the sheath or pulleys during tendon mobilization after surgery. A greater force must be applied to the finger to move the bulky tendons within the sheath, increasing the likelihood of ruptures. (3) Triggering in pulleys or edges of opened sheath: annular pulleys, particularly those of the distal and middle portions of the A2 and A4, are narrow and compress the tendon gliding beneath. Edematous or bulky tendons are easily entrapped by these pulleys. Incising the sheath leads to a certain measure of tendon bowstringing. At the edge of sheath openings, the tendons assume a greater degree of angulation during motion. Edematous and bulky tendons can be triggered at the edge of the sheath openings, halting the finger flexion or extension and causing patients to feel a sudden increase in resistance to finger motion. A forceful pull to overcome the resistance frequently leads to rupture of the repairs. (4) Unexpected finger motion: during the period of wearing protective splints or casts, patients may have some unexpected finger actions, such as falling down on outstretched hands and sudden gripping. These actions impose a sudden increase in the force transmitted through the repaired tendons and may subject tendons to a higher risk for ruptures. (5) Misuse of the fingers: analysis of the causes of ruptures in previous reports indicates that in approximately half of patients with ruptures, the
rupture followed an ill-advised action [19,27]. Misuse of the repaired fingers, such as using the hand to lift a heavy object, may exceed the repair strength of the tendon and cause rupture. (6) Unprotected active motion: it is not an appropriate and accepted way of postoperative care after primary tendon repairs. Only some surgeons indicate the possibility of using this sort of exercise regimen. There are not sufficient data to justify the use of this type of regimen and its effect on strength of tendon healing. Active motion of the repaired fingers can cause ruptures if not properly applied or if used without protection. Surgical repairs and tendon healing are not sufficiently strong to accommodate unprotected active motion at present.

Joint stiffness

Stiffness of the DIP and PIP joints frequently is observed during the rehabilitation after primary flexor tendon repair. Stiffness of small joints after trauma to the joints is a troublesome disorder for hand surgeons. Clean-cut flexor tendon injuries themselves, however, usually do no trauma to finger joint structures. It is the postoperative protective finger position that causes joint contracture. It is obvious that modifications in the postoperative motion regimen, in particular the position of protective splints or casts and the maneuvers to move the joints, might lessen the chance of developing joint stiffness. Return of function to the tendons depends on sufficient gliding amplitude of the tendons and normal passive range of motion of the joints. To improve the outcome of tendon repair, greater emphasis should be placed on moving the joint. More specific physical therapeutic procedures to prevent or correct joint stiffness need to be incorporated in future motion protocols.

Original Kleinert traction frequently leads to loss of PIP joint extension. The fingers of patients were protected by rubber bands, and the PIP joint was flexed for long periods. With modified rubber band traction or with modification of dorsal splint with no protective palmar bars, larger degrees of PIP joint extension were achieved, but achieving full extension of the PIP joint and elimination of contracture of the volar plate remain an unsolved problem in rehabilitation after primary flexor tendon repairs in zone II. At present, eliminating joint stiffness is still an essential goal of physical therapy after removal of protective fixation 3–4 weeks after surgery.

Extent of injuries

The relative severity of injuries to peritendinous soft tissues affects the outcome of tendon repair. Extensive soft tissue destruction and epitendinous abrasion are associated with poorer functional outcome. A primary surgical repair is clearly indicated in clean-cut tendon injury. It is difficult to judge whether primary tendon repairs are justified for wounds that do not involve clean cuts, but in which direct approximation of the severed stumps is still possible. These wounds, which are typified by loss of soft tissues (sometimes with a short segment of flexor tendons and a portion of pulleys) over a limited area of the fingers or palm and defects of soft tissues, should be repaired with a local or distant flap, and have as borderline indication primary flexor tendon repairs. Are primary repairs of the tendons indicated in these wounds? Some surgeons (including this author) may prefer to repair the tendons followed by secondary tenolysis rather than wait for secondary free tendon grafts. In case reconstruction of multiple pulleys in these wounds is called for, however, primary tendon repairs are not justified. Digital nerve injuries are a frequent complication of tendon injuries in zone II. In the author’s clinic, digital nerves are directly repaired when there are no defects or reconstructed with a vein conduit when there is a small (<3.0 cm) gap.

Surgical skills

Adequate surgical skills are a factor that cannot be overemphasized. The flexor tendon system is made of anatomic structures in an intricate biomechanic relationship. Simply reconnecting severed tendons is a simple procedure, but satisfactory repairs of the tendons and associated structures, particularly those in the intrasynovial regions, remain a challenge even to an experienced surgeon. In practice, these difficult injuries are treated not infrequently by residents or general orthopedic (or plastic) surgeons without sufficient expertise in flexor tendon surgery. With currently available knowledge and technical advances, favorable outcomes may be achieved by an experienced surgeon, but an individual who lacks expertise may effect repairs no better than those seen decades ago. Surgery based on poor mastery of anatomic knowledge and repair techniques can destroy the tissue structures and make delayed primary tendon repairs by an expert surgeon impossible. When no surgeons experienced in tendon surgery are available, patients should be
referred to hand centers with more experience in dealing with flexor tendon injuries. Alternatively, after primary closure of the skin wounds, tendon injuries may be repaired at a delayed primary stage by an experienced surgeon.

Adhesion formation, repair rupture, and joint stiffness ultimately determine the measure of outcome of the repair, whereas the latter two, extent of injuries and surgical skills, relate to the wound and surgical factors. Relation between these factors and outcomes is illustrated in Fig. 1.

**Evaluation of outcome and possible modifications**

Three methods of evaluating outcome after flexor tendon repair are used popularly: Strickland and Glogovac criteria [37] (Table 3), the TAM method, proposed by the American Society for Surgery of the Hand [38], and the Buck-Gramcko method [38], used largely by German-speaking hand societies. Most investigators have adopted the Strickland and Glogovac criteria in their documentation of outcome of flexor tendon repair in zones I and II. The author found these criteria (in fact, a modified TAM method) more practical than the TAM method. In the original TAM method, only the fingers whose total range of active motion is the same as that of the contralateral hand can be rated as excellent. The author has found that varying degrees of joint stiffness are invariably present after tendon repair and protective motion exercise; patients who entirely satisfy the criteria as excellent are extremely rare. The Strickland and Glogovac criteria give a more practical assessment of finger function than the original TAM method. Excellent functional status requires a sufficiently ample total range of active motion, but not necessarily a range of active motion equal to that of the contralateral side. TAM of the joints over 80% of the normal motion range usually gives excellent function to the fingers. Exclusion of the motion range of the metacarpophalangeal (MP) joint also gives more accuracy of documentation of motion ranges of the PIP and DIP joints in the Strickland and Glogovac criteria than the original TAM method. Among the less popular methods currently used are White’s criteria, the Tubiana method, and tip-to-palm distance method. White’s criteria and tip-to-palm distance were popular 15–20 years ago, and the Tubiana method is used mostly in France.

The length of follow-up affects the recorded outcome of the flexor tendon repair. Flexor tendon healing and collagen remodeling usually take longer than 2–3 months, and correction of interphalangeal joint contracture may require even longer. Outcome of flexor tendon repair should be determined appropriately not earlier than 3 months after surgery, when postoperative therapy is complete and before most patients would return to work.

---

**Table 3**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Total active range of motiona (degrees)</th>
<th>Functional return (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&gt;150</td>
<td>85–100</td>
</tr>
<tr>
<td>Good</td>
<td>125–149</td>
<td>70–84</td>
</tr>
<tr>
<td>Fair</td>
<td>90–124</td>
<td>50–60</td>
</tr>
<tr>
<td>Poor</td>
<td>&lt;90</td>
<td>0–49</td>
</tr>
</tbody>
</table>

*a* Sum of the active range of motion of the DIP and PIP joints.

---

![Fig. 1. Relation between factors affecting clinical outcome of flexor tendon repairs.](image-url)
Several questions remain in identifying an evaluation system that best reflects the performance of hands following repair of the flexor tendon or in developing a universally acceptable methodology for comparison of surgical repair results: (1) Which of the existing methods is the evaluation system best reflecting outcome of tendon repair? Currently, no specific studies on this point are seen in the literature. It thus would be meaningful to carry out studies to evaluate or compare assessment systems. (2) Would it be more informative to record the result of flexor tendon repair within the sheath area by subdivisions of the tendons in the fingers? Moiemen and Elliot [39] subdivided zone I into three subdivisions and recorded the results of the FDP tendon repair in these areas. Tang et al. [40,41] subdivided zone II into four subdivisions and reported the results of repairs of the FDS and FDP tendons in these regions. Both systems use pulleys and FDS insertion as landmarks (Fig. 2). Recording results of the flexor tendon repair in subdivisions of the finger flexor tendons may facilitate more precise evaluation of the results and thereby provide valuable information about the outcome in specific regions and for specific components of the flexor tendon system. (3) Would it be more reasonable to evaluate separately the motion of all finger joints (TAM) and function of a single joint most pertinent to a tendon cut? Moiemen and Elliot [39] proposed evaluating the results of zone I tendon injuries with the original Strickland criteria and with a method to record only the range of motion of the DIP joint separately. They suggested the addition of an evaluation of function in the motion of the joint most relevant to the flexor tendon injury. (4) Are current evaluation items sufficient? The existing assessment systems include items regarding tip-to-palm distance and active range of joint motion, which relate to angulation of finger joints only. The function of the flexor tendon includes grip and pinch strength, however. Clinically, the repair of both of the FDS and FDP tendons in fingers would produce greater grip strength. In addition, digital flexor tendons contribute to deviation of the fingers. Existing criteria reflect none of the functions of the tendon except range of finger flexion-extension. A question therefore is whether these functions should be considered in evaluating repair results. (5) Should coordinated finger motion or wrist motion be considered? In flexor tendon injuries involving multiple fingers or multiple sites, injuries in zones III, IV, and V, or secondary tendon transfer, coordinated motion of multiple fingers or of fingers with the wrist often are disturbed. Coordination of the motion of multiple fingers and joints is important to the function of the entire hand; however, disturbance on this aspect is not reflected in the existing evaluation systems. For a more precise evaluation, such functional loss might be included as an integral part of the evaluation system in selected patient groups to reflect postoperative functional performance.

**Approaches to improve outcome**

*Stronger surgical repairs*

Pursuit of a stronger yet less strangulating tendon suture configuration has been a focus of
biomechanic studies over the past decade [3–6, 42–48]. The conventional two-strand repair methods withstand a tension of 20–30 N, with the force to produce remarkable gaps (>2 mm) less than 20 N. It is true that most tendons repaired with the conventional two-strand repairs survived early postoperative exercise. Though the studies identified earlier seem to reflect a recent declining trend in rupture rates of repaired tendons after use of multiple strand repairs, however, there is no direct evidence of such a correlation, and no randomized prospective clinical trails have been performed on this particular issue. Early reports of active motion of the tendons repaired with conventional two-strand repair documented rupture rate of nearly 10% [9,10,12]. Such high rupture rates were not seen in more recent reports. The merits of multiple-strand tendon repair include increasing the safety margin to withstand the tension of postoperative motion exercise. This does not mean that most tendons repaired with two-strand techniques necessarily fail during motion or that multistrand repairs completely prevent repair ruptures. Rather, increasing repair strength through multistrand repairs decreases the likelihood of rupture in cases that may rupture when repaired conventionally with two-strand techniques. In addition, an increase in baseline surgical repair strength might allow one to apply a more aggressive exercise regimen and disrupt more adhesions, thus resulting in a better return of tendon motion and mobile joint range to the injured fingers.

In the author’s experience, four-strand repairs seem to be the most appropriate choice for the tendon from zones I to IV. In addition, the author has performed six-strand repairs in zone II of the flexor tendon and in fact does not use conventional two-strand repair technique in zones I and II flexor tendon repair. Eight-strand repairs seem unnecessary, because four- or six-strand repairs already provide sufficiently high tensile strength to the tendon and eight-strand repairs are technically more difficult within the digital sheath area. The variety of multistrand repair techniques the author used over the past 15 years are illustrated in Fig. 3. In the last 2 years, a modified six-strand looped (M-Tang) method and a modified four-strand looped repair have become the methods of choice in the author’s clinic. Over the past 2 years, we repaired FDP tendons in 36 fingers with zone II flexor tendon lacerations with the M-Tang method. We achieved 90% excellent or good recovery rate by Strickland and Glogovac criteria with combined protective active and passive motion for 3 weeks after surgery, with no repair rupture.

Sheath/pulley management

There is no longer controversy among hand surgeons regarding whether the synovial sheath should be closed after tendon repairs. Closure of the synovial sheath is not vitally required to tendon healing and gliding function [49–51]. Closure of the synovial sheath may be attempted in clean-cut injury without presence of sheath defects or abrasion. It is now agreed that the integrity of major pulleys is critical to tendon function, and avoiding compression of the edematous tendons by the sheath after surgery is important to tendon healing [51–53]. With major annular pulleys and a major part of the synovial sheath intact, opening a part of synovial sheath

Fig. 3. Four tendon suture methods used in the author’s clinic. Two original designs of 4-strand and 6-strand repairs using independent looped sutures (left) and two more recent modifications using fewer looped sutures and knots (right).
has no significant effects on tendon function and healing. On the other hand, when other pulleys or synovial sheaths are intact, incision of one single annular pulley or a critical part of the major annular pulley (A2 or A4 pulleys) does not significantly affect tendon gliding, but may release the compression of an edematous tendon by these constrictions, thus fostering the tendon healing process [53–58].

Clinically, the A4 or A2 pulley occasionally constitutes an obstacle for the repaired tendon to glide through, which is likely a cause of repair rupture during postoperative motion exercise. Releasing the A4 pulley entirely and releasing part of the A2 became accepted clinical practice in recent years. In the author’s clinic, when the repaired FDP tendons are found tightly entrapped by the A4 pulley after testing during surgery, we completely release the A4 pulley (Fig. 4). Part of the A2 pulley, either proximal or distal (approximately one half to two thirds of the entire length of the A2 pulley), is cut when the FDS and FDP tendons are repaired in the area overlapping the A2 pulley.

Optimization of rehabilitation regimen

Optimization of the rehabilitation regimen has been a focus of clinical investigations. There seems to be a long way to go, however, before general agreement is reached. More likely, as understanding of the intricate relationship between tension on the flexor tendons during finger motion increases, the hand posture that affords the best postoperative protection with the least possible tension on the tendon will be identified, ultimately revolutionizing rehabilitation. Unprotected active motion of the fingers does not seem likely to be generally accepted in the near future, because even protected motion can cause certain repair ruptures. Science cannot yet bring about the healing necessary to support unprotected active motion. Protected combined active/passive motion is the option that most surgeons currently...
adopt. The use of rubber bands is no longer a requirement and is known to cause contracture and extension lag of the joints. The trend is toward a rehabilitation regimen combining an ideal protective position of the hand, with intermittent active–passive finger flexion–extension, using no rubber bands.

Another area in which there is not yet agreement is the timing of rehabilitation and frequency of finger motion, either in a particular day or during each exercise episode. Theoretically, tendon adhesion develops starting from 2–3 weeks after surgery. Rehabilitation can begin anytime within 1 week following repair. Most studies report the initiation of rehabilitation as immediate or starting the first day after surgery. No studies have yet proven the need of starting the exercise on the first day after surgery. It seems equally reasonable to commence the exercise later, though within 1 week after surgery. Commencement of rehabilitation at the third or fourth day causes less pain and likely does not affect results compared with starting on the first day. We have not yet identified optimal frequency of motion in each exercise episode or whether more frequent exercise leads to better results. Similarly, we also do not know what sequences of active and passive motion are best for the tendons and whether the range of each motion cycle affects the outcome. Answering these questions is essential for optimization of rehabilitation programs for repaired tendons.

**Biologic approaches**

Flexor tendons, particularly those in the intrasynovial area, lack sufficient cellularity and generally have low growth factor levels. These are the basic reasons that adhesions or ruptures occur after surgery and that outcomes are less than perfect. Delivery of growth factors to proliferating tenocytes in vitro significantly enhanced their proliferation rate and collagen production [59–65]. Growth factors generally have a short biologic half-life, however, and continuous supplementation of exogenous growth factors to healing flexor tendons is not practical. Transfer of growth factor genes therefore would provide the tendons with continuous supplementation of the growth factors critical to the healing process. Delivery of growth factor genes through plasmid vectors has been shown to promote the expression of type I collagen gene in the tenocytes [66]. What systems are the safest and most efficient to deliver growth factor genes to healing tendons? How do we augment tenocytes’ capacity to produce collagen to the healing process while limiting the occurrence of adhesions? Answering these questions is likely to be among the critical steps in future in vivo investigation. In addition, transplantation of stem cells to the healing tendons would provide sources of progenitor cells to promote the healing process of the tendon. Gene therapy and stem cell transplantation are two emerging fields of modern biology that offer new approaches to difficult problems in flexor tendon repairs. Future efforts to combine stem cell therapy and gene therapy would provide the tendons not only with a fresh source of progenitor cells (which may differentiate into tenocytes to aid in healing) but also with the growth factors required to promote the healing process.

**Summary**

Review of the outcomes of clinical flexor tendon repairs reported over the past 15 years showed advances in the outcomes with excellent or good functional return in more than three fourths of primary tendon repairs following a variety of postoperative passive/active mobilization treatments. Strickland and Glogovac criteria are the most commonly adopted methods to assess function. Repair ruptures (4%–10% for zone II finger flexors and 3%–17% for the FPL tendon), adhesion formations, and stiffness of finger joints remain frustrating problems in flexor tendon repairs and rehabilitation. Four approaches are suggested to improve outcomes of the repairs and to solve these difficult problems, which include stronger surgical repairs, appropriate pulleys or sheath management, optimization of rehabilitation regimens, and modern biologic approaches.

**References**


[37] Strickland JW, Glogovac SV. Digital function following flexor tendon repair in zone II: a comparison of immobilization and controlled passive


