

Outcomes and Evaluation of Flexor Tendon Repair

Jin Bo Tang, MD

KEYWORDS

- Flexor tendon • Primary repair • Secondary repair • Outcomes • Assessment criteria
- Level of expertise of the surgeons

KEY POINTS

- Most reports document a good or excellent recovery of the function of the repaired digits of more than about 80% from fine hand units over recent years, but outcomes in general hospital settings can be more disappointing.
- Over recent years, although rupture of the primarily repaired flexor tendons is still seen in the reports, a few have reported not having ruptures after strong surgical repair, judicious venting of the pulley, and early active postoperative tendon motion.
- The Strickland criteria remain the most commonly used to record the outcomes.
- The author proposes modifying the assessment criteria by setting more stringent “excellent” results as recovery to or greater than 90% of the normal finger motion range and by adding “failure” to designate those digits of recovery of active range of motion less than 30%.
- The outcomes should be provided by subzones of the tendon injuries, and the level of expertise of the surgeons is reported to allow comparisons of the results.

Outcomes of flexor tendon repair are associated with (1) total range of active motion of joints, (2) rate of repair ruptures, and (3) severity of flexion or extension deficits. Outcomes of primary flexor tendon repair have improved over the past 30 years.^{1–5} However, reports of series of cases of primary digital flexor tendon repair without ruptures of the repair have emerged only very recently, indicating a leap forward toward the goal of no rupture in primary repairs. In recent years, few original reports can be found regarding outcomes of secondary reconstruction, and the outcomes have not greatly changed in several decades.

OUTCOMES DOCUMENTED OVER THE PAST 10 YEARS

The outcomes of primary flexor tendon repair between 1989 and 2004 were reviewed in an article in *Hand Clinics* in 2005.⁵ In this article, the information on outcomes with reports from recent

years is supplemented. Most recent reports of primary repair in the digital area are regarding 4-strand or 6-strand tendon repairs, made with newer repair techniques.^{6–12}

Outcome Reports from Individual Units

In 2008, *The Journal of Hand Surgery (European Volume)* published a series of reports on flexor tendon repairs using 4-strand or 6-strand core tendon sutures combined with early active flexion exercise (**Table 1**).^{6–8} These reports indicate lower rupture rates among tendons with strong core tendon repairs, but it has not always been possible to avoid repair ruptures. Caulfield and colleagues⁶ reported 416 tendons repaired with a 4-strand Strickland core suture in zones 1 to 4 in 272 patients and obtained 74% good or excellent grades by the Strickland criteria, with only 2% repair ruptures. Hoffmann and colleagues⁷ reported 51 fingers of 46 patients with zone 2 flexor

Department of Hand Surgery, The Hand Surgery Research Center, Affiliated Hospital of Nantong University, 20 West Temple Road, Nantong 226001, Jiangsu, China
E-mail address: jinbotang@yahoo.com

Hand Clin 29 (2013) 251–259

<http://dx.doi.org/10.1016/j.hcl.2013.02.007>

0749-0712/13/\$ – see front matter © 2013 Published by Elsevier Inc.

Table 1
Large case series of flexor tendon repair and controlled early active motion in the last 8 years

| Authors, Year | Number of Digits | Zones | Core Suture Methods | Results ^a | Rupture Rate |
|--------------------------------------|------------------|-------|---------------------|-----------------------------------|--------------|
| Caulfield et al, ⁶ 2008 | 416 | 1–4 | 4-strand Strickland | 74% | 2% |
| Hoffmann et al, ⁷ 2008 | 51 | 2 | 6-strand Lim/Tsai | 78% | 2% |
| | 26 | 2 | 2-strand Kessler | 43% | 11% |
| Navali & Rouhani, ⁸ 2008 | 16 (children) | 2 | 6-strand Strickland | 94% | 0% |
| | 16 (children) | 2 | 2-strand Kessler | 88% | 6% |
| Giesen et al, ¹⁴ 2009 | 50 | 1, 2 | 6-strand Tang | 78% (White) 82% (Buck-Gramcko) | 0% |
| Moehrlen et al, ¹⁰ 2009 | 40 | 1–3 | 2-strand M Kessler | 92.5% | 0% |
| Trumble et al, 2009 | 119 | 2 | 4-strand Strickland | — | 3% |
| Sandow & McMahon, ¹² 2011 | 73 | 1, 2 | 4-strand cruciate | 71% | 4.6% |

^a Good and excellent rate by Strickland criteria except those given in parentheses.

tendon repair using the 6-strand Lim/Tsai method. Postoperatively, the fingers were moved with a combined Kleinert and Duran early motion regime and place-and-hold exercises. They had 1 (2%) tendon rupture of 51 flexor digitorum profundus (FDP) tendons. Two (4%) fingers required tenolysis. In contrast, in the cases they treated with the 2-strand modified Kessler method, they had repair ruptures in 3 fingers (11%) and tendon adhesions, or dehiscence, in 3 fingers (11%), which required secondary surgery. The good or excellent outcome rate was 78% with the Lim/Tsai method and 43% with the 2-strand Kessler method. Navali and Rouhani⁸ reported 32 flexor tendon repairs in zone 2 of 29 children using either the 2-strand modified Kessler method (16 tendons) or the 4-strand Strickland method (16 tendons). They had one rupture and one fair outcome among the tendons with the 2-strand repair, and one fair outcome after the 4-strand repair. Good or excellent outcomes were achieved in other fingers.

In children, repairs of flexor tendons have generally good or excellent results. Early motion exercise is not essential for a tendon to regain a good range of active motion. These observations were further validated in reports by Elhassan and colleagues⁹ in 2006 and by Navali and Rouhani⁸ in 2008. More recently, in 2009, Moehrlen and colleagues¹⁰ reported results of 49 flexor tendon repair in 39 children using a 2-strand modified Kessler technique. Children underwent an age-adapted early active tendon mobilization. No ruptures of the repair were found. Among 40 fingers assessed according to the Strickland criteria, 29 (72.5%) were excellent, 8 (20%) were good, 3 (7.5%) were fair, and none were poor. All 7 thumbs had excellent results. Moehrlen and

colleagues¹⁰ concluded that good results and very low complication rates can be expected in children, provided extra care is taken in the early tendon mobilization.

In 2009, Trumble and colleagues¹¹ reported a multicenter prospective randomized trial of zone 2 flexor tendon injuries in 119 digits of 103 patients conducted between 1996 and 2002 to examine the effect of early active motion and passive motion. The tendons were repaired using a 4-strand Strickland suture and a running epitendinous suture. They found significantly greater range of digital motion, smaller digital flexion contractures, and greater patient satisfaction in the active motion group than in the passive motion group. Factors leading to poor results included associated nerve injury, multiple digit injuries, and smoking. Patients treated by a certified hand therapist had better motion and less contracture. Repaired tendons in 2 digits in each group ruptured. This prospective study supports the combination of multistrand tendon repair and early active motion in zone 2 flexor tendon repairs.

In 2011, Sandow and McMahon¹² reported 73 zone 1 and 2 FDP lacerations in 53 patients repaired with a 4-strand single cross-grasp repair technique made with 3-0 braided polyester suture. After active tendon motion exercise, 71% of fingers achieved a good or excellent outcome, with 3 (4.6%) tendon ruptures.

In 2012, Starnes and colleagues¹³ analyzed results of zone 2 flexor tendon repairs in 2 groups: sharp injury group (24 fingers in 21 patients) and saw injury group (17 fingers in 13 patients), performed between 2001 and 2010. The cases with digital fractures were not included. The FDP tendons were repaired with a minimum of a 4-strand core suture technique except that one patient in

the saw group had incomplete information. In the saw injury group, 9 of 14 fingers with a 50% or greater laceration of FDS tendon were repaired; in the sharp laceration group, 15 of 18 such FDS injuries were repaired. The saw group had significantly less total range of active and passive motion of the fingers compared with the sharp group. There was no significant difference in grip strength of the hand. Tendons in one finger ruptured in the saw group; none ruptured in the sharp group. Tenolysis was required in 4 of 17 fingers in the saw group and 3 of 24 fingers in the sharp group.

Two recent reports documented no repair rupture using strong tendon repairs, pulley-venting, and early active tendon motion. In 2009 Giesen and colleagues¹⁴ reported outcomes of repair of 50 flexor pollicis longus tendons with Tang's triple Tsuge repair between 2004 and 2008. No peripheral stitches were added after core suture. They reported excellent or good results in 78% of the cases using White criteria or 82% of the cases using Buck-Gramcko criteria. No repair rupture was found in this series. In 2011, Al-Qattan¹⁵ reported repair of zone 2A and 2B FDP tendons with the "figure of eight" 6-strand suture technique in a series of 36 patients (36 fingers) with clean-cut isolated FDP tendon injuries. The pulleys proximal to the tendon laceration level were vented. Postoperatively, early active exercises were performed. There were no ruptures and a good recovery of range of finger motion.

Venting the narrow part of a major pulley is usually achieved through direct incision of a part of the pulley. Other methods besides direct incision have been used. In 2005 Bakhach and colleagues¹⁶ reported expanding the volume of the A2 or A4 pulleys (ie, omega pulley plasty) in 12 patients to allow freer tendon gliding. Through a lateral incision on the junction site of the sheath and periosteum, they released lateral attachment of the pulley and underneath the periosteum over the phalanx, but did not reach inside the sheath. Although most of the patients had good recovery of active digital flexion, 7 fingers required tenolysis. In 2010, Bunata¹⁷ presented results of zone 1 and 2 tendon repair in 9 fingers (7 patients) with a 2-strand modified Kessler and a running circumferential suture. The entire A2 or A4 pulleys were enlarged by incision and repaired with an interposed extensor retinaculum graft, because tendon repair in these cases failed to glide smoothly and without snagging through the tight-fitting pulleys. By the Strickland criteria, there were 3 excellent results, 2 good results, 2 fair results, and 2 poor results. There were no tendon ruptures, but 2 fingers required tenolysis and 2 had bowstringing. It is noteworthy that some of

Bakhach's cases needed tenolysis, and 2 among Bunata's cases had bowstringing and one had tenolysis, indicating drawbacks of these plasty procedures. The complex plasty may increase adhesions; the plasty over the entire length of the A2 pulley may cause tendon bowstringing. In our unit, the author does not perform plasty and considers venting by means of a simple incision sufficient; the venting should not involve the entire A2 pulley.

Over the last decade, few reports have been made on the outcomes of secondary repair. It is assumed that the outcomes of secondary tendon graft reconstruction or staged reconstruction have not been changed since reports of several decades ago.

Meta-Analysis of the Outcomes

In 2012, Dy and colleagues¹⁸ presented a meta-analysis of complications associated with flexor tendon repair. After extracting demographics, zone of injury, core suture technique (only modified Kessler or a combination of techniques), use of epitendinous suture, and date of publication (before or after January 1, 2000), unadjusted meta-analysis revealed rates of reoperation of 6%, rupture of 4%, and adhesions of 4%. Meta-regression analysis of 29 studies showed that core suture technique or use of an epitendinous suture does not influence rupture. Although complication rates were generally low, their data suggest no definitive changes in complication rates when repaired before 2000 than after 2000.

The decrease of the rupture rates has been seen to decrease in reports of more recent years, typically after 2005. Division of treatment period into before and after 2000 would not reveal this difference in that study. Only modified Kessler and its combination forms were included, which excluded comparison of the low-profile repair methods with the high-profile methods. In the report of Dy and colleagues,¹⁸ 4% of the tendons developed adhesions that necessitated tenolysis. The rate of formation of adhesions around the repaired tendon should be higher than 4%. Adhesions usually occur in most repaired tendons, varying in their severity and some not hampering tendon motion.

DISCREPANCIES BETWEEN REPORTED OUTCOMES AND THOSE FROM MORE GENERAL SETTINGS

Reports of primary flexor tendon repair and some secondary reconstruction procedures documented good outcomes, but in a general setting, more disappointing cases are seen than are read

about in the literature. No articles have specifically addressed this discrepancy, but the reasons may include the following:

- 1. The results of primary repair or secondary reconstruction have mostly come from hand centers with experienced or master surgeons on the team.
- 2. Surgeons tend not to make reports based on case series whereby more disappointing results are seen than other reports.
- 3. The surgical team and rehabilitation setup are not ideal, and practice guidelines or knowledge may not have been updated. The surgeons are aware that their suboptimal results stem from such conditions and think that making such reports would contribute nothing meaningful to the literature.
- 4. Current clinical outcome reports are based mainly on simple injuries, chiefly involving the laceration of tendons (and adjacent nerves), but clinically more severe injuries are encountered. Outcomes of tendon repair after complex injuries have rarely been reported.

If a repair is performed by an inexperienced surgeon (including trainees or surgeons who do not often deal with tendon repair), one who does not abide by general guidelines for tendon repair, one who has not kept up-to-date on the key issues of correct surgery, or one who practices in a unit without established postoperative care, there will be a high incidence of poor functional return, disruption of the repair, and severe finger stiffness. It is important to update surgery and postoperative care to optimize the outcomes of tendon repair. Frequently, even if the surgeons and therapists keep their knowledge up-to-date, there may be a discrepancy between what they read and how they can apply that knowledge.

The problems that should be dealt with properly with during surgery and in the early and late periods after surgery are summarized in **Fig. 1**.

Nowadays, fewer cases require secondary reconstruction than primary repair. If secondary tendon reconstruction is required for a patient, trauma to the hand of the patient is usually more severe, because (1) the tendon defect may be associated with severe hand trauma, which leads to more complex injuries involving multiple tissues; or (2) secondary repair is indicated for cases unsuitable for primary repair, including tendon bed scar and destruction of the pulley system.

KEYS FOR SUCCESSFUL REPAIRS: PRIMARY AND SECONDARY

Attention to the Details of Techniques: Quality of Surgery, Tension, and Others

Attention to the technical details of surgery is the most important consideration for tendon surgery in the hand. Atraumatic handling is an essential approach to the tendon. Understanding the biomechanics of the tendon and surgical repair is essential to successful surgery and rehabilitation.¹⁹ Many decisions are made based on a deep understanding of tendon mechanics and according to actual situations seen on the operating table. Tension should always been a concern whenever a surgeon performs a direct repair or grafting.²⁰ In primary repair, tension over the entire tendon should be as low as possible, but tension across the repair sites (in the segment encompassed by the core sutures) should be higher to resist gapping. In tendon grafting, tension should be maintained across the grafted tendon during surgery, because some elasticity of the muscle belly will return postoperatively, decreasing the tension originally set through the graft.

Strong Tendon-bone Attachment, End-to-end Repair, and Proximal Junction

“Strong” repairs are a requirement for all tendon procedures. The method of rebuilding the tendon-bone junction is now undergoing a transition from

Clinical Problems in Primary Flexor Tendon Repairs

| During Surgery | Early After Surgery | Late After Surgery |
|--|--|---|
| <ul style="list-style-type: none">• Handling of tendon• Surgical quality• Treatment judgment | <ul style="list-style-type: none">• Repair gapping during motion• Repair caught in pulley rims• Swollen tendon get stuck, unable to glide• Pain and swelling prevent digital motion | <ul style="list-style-type: none">• Finger joint stiffness• Adhesion formation• Loss of smooth tendon surface |

Fig. 1. The problems that surgeons have to deal with during surgery of primary repair, and in the early and late postoperative periods. The tendon injuries in the little fingers are sometimes particularly difficult to treat.

the pull-out suture to the newer no-button methods. Adequate mechanical strength is required for the newer methods for the tendon-bone attachment. The interweaving suture technique has been a standard and reliable way to complete a proximal junction of tendon grafting. All end-to-end tendon repairs should be mechanically sound. The driving force behind the increasing popularity of strong surgical repair is to avoid rupture of the repair in the first few weeks after surgery—at this time, the biologic tendon healing has not yet translated to a gain in mechanical strength of the tendon, so the surgical repair strength acts primarily to resist gapping or rupture of the repair. Recent development allows use of stronger sutures, such as Fiberwire (Arthrex, North Naples, FL),²¹ and of stronger repair methods, with greater care for surgical details, which act in concert to ensure a mechanically sound surgical repair.^{19,22}

Attention to the Diameter of the Pulleys and How the Tendon Fits into the Pulleys

Treatment of pulleys has been a major focus of discussion in primary repair. Partial venting of the A2 pulley is effective in allowing greater degrees of tendon motion and will not lead to bowstringing if the other annular pulleys are intact and total release of the sheath-pulley is less than 2 cm.

During secondary surgery, dealing with pulleys properly is equally important. If multiple annular pulleys are damaged, reconstructed pulleys should be strong and properly located at the A2 and A4 sites. The A2 pulley can be vented partly to allow tendon motion during tenolysis, provided most of the sheath is intact. In all tendon surgery, surgeons should consider the diameters of the pulleys and how the tendon fits inside them. It is crucial to always leave room to accommodate edema and swelling of tendons that have been operated on.

Use the Extension-flexion Test to Assure That a Repair is Appropriate for Early Active Motion

The author recommends that the surgeon always perform a simple but important test, what the author calls the “extension-flexion test”, to verify tension across the repair site and strength of the repair. This simple test should be performed immediately after surgical tendon repair and sheath-pulley venting are completed. The test consists of 3 parts (**Fig 2**). Step 1: full extension of the repaired digit to observe whether gapping occurs at the repair site. Step 2: mild to moderate flexion of the digit to observe whether the tendon can passively glide. And Step 3: marked or full flexion of the digit to observe whether the repair site of the tendon (or core suture knots, peripheral sutures) impinge upon the rim of the proximal sheath-pulley.

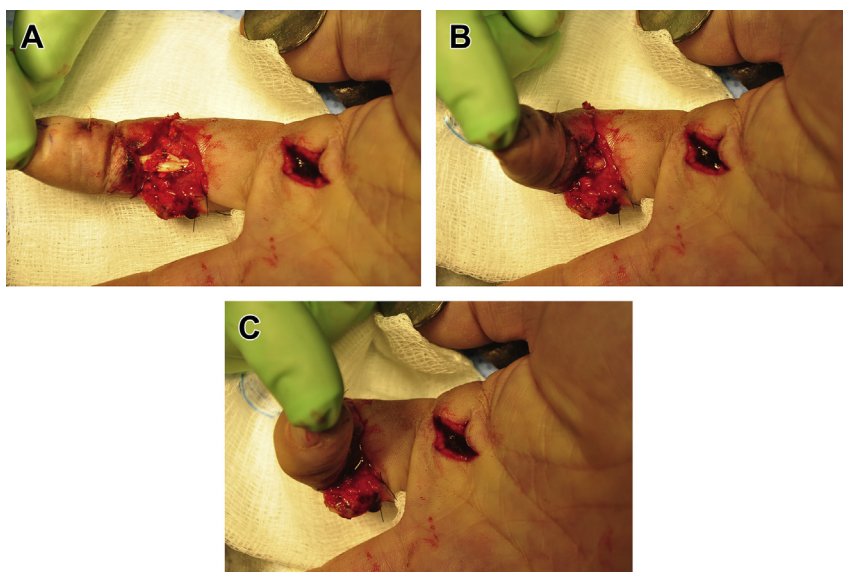


Fig. 2. The digital “extension-flexion test” consists of three parts. (A) Step 1: to make sure gapping does not occur at the repair site at full extension of the repaired digit. (B) Step 2: make sure that the tendon glides in the range of mild to moderate flexion of the digit. (C) Step 3: make sure the repair site and suture knots do not impinge upon the rim of the proximal sheath-pulley when the digit is moved to marked (or full) digital flexion. The repair should pass each of these steps before surgeon proceeds to closure of surgical incision. The surgeon should redo the repair if failed to pass the test.

upon the rim of the proximal sheath-pulley. The repair should “pass” each of these steps before surgeon proceeds to closure of skin incision. If the repair fails the test, the surgeon should either redo the repair to eliminate gapping at the repair site or ensure that the proximal sheath-pulley no longer catches the repair site. Actively extending and flexing the repaired fingers to check each above step during wide-awake surgery would provide even clearer assessment of the repair. The surgeon should clearly document the findings during the test—pass, failed, or gapping, catching—into the surgical chart, and properly inform the therapists with results of this intra-operative test. It appears that this method has been used by at least a few of the leading surgeons in this field. However, now it is time to standardize this test and to make it a necessary part of the surgery and documentation. It is hard to imagine that a repair that cannot tolerate the intra-operative extension-flexion test could tolerate early active tendon motion when the surgical incision is closed and edema develops after surgery.

Incorporation of Early Active Motion into Exercise Regime

Early tendon mobilization has been gradually extended into motion regimes after secondary repair. However, most of these regimes are not as aggressive as those after primary repair. It is reasonable to incorporate into the regimes: (1) synergistic wrist and finger motion; and (2) mid-range-only active motion. Both concepts of rehabilitation used after primary repair should be similarly applicable to secondary repair. The lack of strength of reconstructed pulleys, the lengthy skin incisions, and the greater degrees of edema in tendons and other soft tissues prevent very aggressive active tendon motion.

CRITERIA AND DOCUMENTATION OF OUTCOMES
Commonly Used Criteria

The criteria commonly used to evaluate functional recovery, whether after primary repair, delayed primary repair, secondary reconstruction, or tenolysis, is Strickland’s original method of 1980 (Table 2).²³ Popular use of this method greatly facilitates comparison of outcomes across surgeons, clinics, and geographic areas. The Buck-Gramcko method is probably the second most popular method, used more frequently by German-speaking hand surgeons. The total active range-of-motion method, which includes the motion range of the metacaphaleagel joint,²⁴ is not popular, and other methods are used only occasionally.

| Table 2 Strickland criteria of assessment of functional outcomes of flexor tendon repairs | |
|--|---------------------------------|
| Function Grade | % Return of Motion ^a |
| Excellent | 85–100 (>150°) |
| Good | 70–84 (125°–149°) |
| Fair | 50–69 (90°–124°) |
| Poor | 0–49 (<90°) |

^a The sum of active ranges of motion of the PIP and DIP joints. % is the comparison to the contralateral side (or 175°). The motion ranges given in parentheses can be used for judgment if the contralateral side is not compared.

Distal Interphalangeal Joint (DIP)-only Criteria for Zone 1 Injury

Moienem and Elliot²⁵ used a DIP joint-only method to assess the recovery of DIP joint motion after zone 1 tendon repair. This method is in addition to evaluation of either flexor or extensor tendon repair distal to the DIP joint. Use of this method alone would amplify the weight that the DIP joint carries and does not reflect the impact of the tendon injury on the entire digit. Therefore, the criteria are better used in combination with the Strickland criteria, which include both proximal interphalangeal (PIP) and DIP joint active motion.

How to Assess the Range of Finger Motion

In assessing the range of active motion of the fingers, a powerful and persistent grip would produce flexion by as much as 5° to 10° while the range of hand motion is in the process of recovery and some joint stiffness is present. Active flexion range should be measured when the patient comfortably flexes the finger, not after persistent and painful attempts at a greater active range. The measurement is intended to record the active range of motion that is efficient and easy for daily use. The functional evaluation should be finalized after recovery is complete, which may be a year after surgery.

Criteria with More Stringent Scales

Making a more stringent “excellent” category and separately recording the fingers fail to reach 30% return of active range of motion (Table 3) are proposed.²⁶ The method grades the outcomes into excellent, good, fair, poor, and failure categories. These criteria are user-friendly, which can be used to areas other than zone 2. For repairs in zone 2, by this method the overall good to excellent rate is comparable to that in the previous reports using the Strickland criteria.

Table 3
A more stringent criteria of assessment of results of flexor tendon repairs (Tang, 2007)²⁶

| Function Grade | % Return of Motion ^a |
|----------------|---------------------------------|
| Excellent | 90–100 |
| Good | 70–89 |
| Fair | 50–69 |
| Poor | 30–49 |
| Failure | <30 |

^a % Total active motion of the contralateral side: for zone 2 injury, only the PIP and DIP joints are included into evaluation. 175° is sum of the motion of the normal PIP and DIP joints.

Data from Tang JB. Indications, methods, postoperative motion and outcome evaluation of primary flexor tendon repairs in zone 2. *J Hand Surg Eur* 2007;32:118–29.

Strickland used another criteria in 1985,²⁷ that is considered lenient. The concern about raising the stringency of excellent category has been echoed by other surgeons. Therefore, a more stringent excellent category seems necessary as the results move toward more ideal outcomes.

Inclusion of Report of Level of Expertise

Including a report on the level of expertise of the surgeon is another consideration in reporting outcomes. Results of flexor tendon repairs are expertise-dependent. Unfortunately, the need for

reporting expertise is a topic rarely addressed and is not usually included in reports. Flexor tendon repairs are a perfect example of such needs. The need for reporting expertise, however, is not limited to the reports of outcomes of tendon repairs, but extends to many other procedures. Because experience with implemented techniques is not paralleled by job title, simply categorizing surgeons as residents, attending surgeons, or consultants, and so on provides little or no scientific information regarding their expertise in specific techniques. For treatments that rely heavily on proficiency of involved technique, a report of the level of expertise is very beneficial to interpretation of the outcomes. This concept holds particular importance in comparing studies conducted in different institutions or geographic areas.

An example of such criteria is given by which expertise levels of the surgeons who *conduct* the treatment are reported succinctly using a grade, perhaps under “Methods” (Table 4).²⁸ The documented expertise levels are those of the surgeons performing the procedure, rather than the expertise of the senior authors of the report. The expertise levels should also relate to *specific techniques under investigation*, not to the surgeons’ overall expertise in practice.

Documentation of Exact Injury Locations

To present clearly to the readers the outcomes of treatment, documenting the sites of tendon injuries

Table 4
Levels of expertise of the surgeons in reporting outcomes of surgical treatment

| Levels/Category | Criteria |
|----------------------------------|--|
| 1. Nonspecialist | A surgeon who is in training or is a general practitioner |
| 2. Specialist—less experienced | A surgeon who has completed training, but who has not yet acquired in-depth knowledge or high-volume experience in the use of the techniques pertinent to the report. Less degree of experience, judged by shorter duration of practice (eg, less than 5 y) as a specialist, or limited exposure to the investigated disorder |
| 3. Specialist—experienced | A surgeon who has obtained sufficient experience in use of the techniques pertinent to the report, practiced as a specialist over a longer period (eg, 5 y or beyond), with reasonably greater exposure to the disorder |
| 4. Specialist—highly experienced | A specialist who possesses in-depth knowledge or treatment experience with use of the relevant techniques This experience is best indicated by having performed, or been involved in, scholastic studies relevant to the disorder or techniques |
| 5. Expert | A highly experienced specialist who has made a recognized contribution to knowledge or treatments related to the disorder being investigated, or who has pioneered the technique in the report |

according to refined anatomic nomenclature (eg, subzones of the tendons from the fingertip to the distal palm) is recommended. There are 7 subzones in zones 1 to 2.^{25,26} Documentation of injuries and repairs in subzones facilitates interpretation and comparisons of outcomes. Such reports have been seen in recent years.^{14,15,29,30}

SUMMARY

Over the past 10 years, surgeons have reported good to excellent results in about 80% or more of the tendons that underwent 4-strand or 6-strand core suture repair, with 2% to 5% repair ruptures. This period saw the first widespread use of multi-strand core suture repairs, but in most reports disruption is still seen during early active motion. Reports of no repair rupture in case series have just emerged, suggesting progress toward the goal of primary repair without rupture. The Strickland criteria remain the most common method used to record outcomes. Modifying it by setting a more stringent excellent standard to include only recovery to or greater than 90% of normal finger flexion range and adding a "failure" category to designate cases of functional recovery less than 30% are proposed. Describing the outcomes by subzones of the tendons and reporting the level of expertise of the surgeons offer clear documentation and allow comparisons of the results among different units.

REFERENCES

1. Lister GD, Kleinert HE, Kutz JE, et al. Primary flexor tendon repair followed by immediate controlled mobilization. *J Hand Surg Am* 1977;2:441–51.
2. Tsuge K, Ikuta Y, Matsuiishi Y. Repair of flexor tendons by intratendinous tendon suture. *J Hand Surg Am* 1977;2:436–40.
3. Small JO, Brennen MD, Colville J. Early active mobilisation following flexor tendon repair in zone 2. *J Hand Surg Br* 1989;14:383–91.
4. Tang JB, Shi D, Gu YQ, et al. Double and multiple looped suture tendon repair. *J Hand Surg Br* 1994;19:699–703.
5. Tang JB. Clinical outcomes associated with flexor tendon repair. *Hand Clin* 2005;21:199–210.
6. Caulfield RH, Maleki-Tabrizi A, Patel H, et al. Comparison of zones 1 to 4 flexor tendon repairs using absorbable and unabsorbable four-strand core sutures. *J Hand Surg Eur* 2008;33:412–7.
7. Hoffmann GL, Büchler U, Voeglin E. Clinical results of flexor tendon repair in zone II using a six-strand double-loop technique compared with a two-strand technique. *J Hand Surg Eur* 2008;33:418–23.
8. Navali AM, Rouhani A. Zone 2 flexor tendon repair in young children: a comparative study of four-strand versus two strand repair. *J Hand Surg Eur* 2008;33:424–9.
9. Elhassan B, Moran SL, Bravo C, et al. Factors that influence the outcome of zone I and zone II flexor tendon repairs in children. *J Hand Surg Am* 2006;31:1661–6.
10. Moehrlen U, Mazzone L, Bieli C, et al. Early mobilization after flexor tendon repair in children. *Eur J Pediatr Surg* 2009;19:83–6.
11. Trumble TE, Vedder NB, Seiler JG 3rd, et al. Zone-II flexor tendon repair: a randomized prospective trial of active place-and-hold therapy compared with passive motion therapy. *J Bone Joint Surg Am* 2010;92:1381–9.
12. Sandow MJ, McMahon M. Active mobilisation following single cross grasp four-strand flexor tenorrhaphy (Adelaide repair). *J Hand Surg Eur* 2011;36:467–75.
13. Starnes T, Saunders RJ, Means KR. Clinical outcomes of zone II flexor tendon repair depending on mechanism of injury. *J Hand Surg Am* 2012;37:2532–40.
14. Giesen T, Sirotakova M, Copsey AJ, et al. Flexor pollicis longus primary repair: further experience with the Tang technique and controlled active mobilization. *J Hand Surg Eur Vol* 2009;34:758–61.
15. Al-Qattan MM. Isolated flexor digitorum profundus tendon injuries in zones IIA and IIB repaired with figure of eight sutures. *J Hand Surg Eur* 2011;36:147–53.
16. Bakhach J, Sentucq-Rigal J, Mouton P, et al. The Omega pulley plasty. A new technique to increase the diameter of the annular flexor digital pulleys. *Ann Chir Plast Esthet* 2005;50:705–14 [in French].
17. Bunata RE. Primary pulley enlargement in zone 2 by incision and repair with an extensor retinaculum graft. *J Hand Surg Am* 2010;35:785–90.
18. Dy CJ, Hernandez-Soria A, Ma Y, et al. Complications after flexor tendon repair: a systematic review and meta-analysis. *J Hand Surg Am* 2012;37:543–51.
19. Tang JB. Flexor tendon repair. In: Neligan P, Chang J, editors. *Plastic surgery*, Vol. 6. Philadelphia: Elsevier Saunders; 2012. p. 178–205.
20. Wu YF, Tang JB. Effects of tension across the tendon repair site on tendon gap and ultimate strength. *J Hand Surg Am* 2012;37:906–12.
21. Gan AW, Neo PY, He M, et al. A biomechanical comparison of 3 loop suture materials in a 6-strand flexor tendon repair technique. *J Hand Surg Am* 2012;37:1830–4.
22. Fufa D, Osei DA, Calfee RP, et al. The effect of core and epitendinous suture modifications on repair of intrasynovial flexor tendons in an in vivo canine model. *J Hand Surg Am* 2012;37:2526–31.
23. Strickland JW, Glogovac SV. Digital function following flexor tendon repair in zone 2: a comparison of

- immobilization and controlled passive motion techniques. *J Hand Surg Am* 1980;5:537–43.
24. Kleinert HE, Verdan C. Report of the committee on tendon injuries. *J Hand Surg Am* 1983;8(Suppl): 794–8.
25. Moiemien NS, Elliot D. Primary flexor tendon repair in zone 1. *J Hand Surg Br* 2000;25:78–84.
26. Tang JB. Indications, methods, postoperative motion and outcome evaluation of primary flexor tendon repairs in Zone 2. *J Hand Surg Eur* 2007; 32:118–29.
27. Strickland JW. Results of flexor tendon surgery in zone 2. *Hand Clin* 1985;1:167–79.
28. Tang JB. Re: levels of experience of surgeons in clinical studies. *J Hand Surg Eur* 2009;34:137–8.
29. Al-Qattan MM. Zone 2 lacerations of both flexor tendons of all fingers in the same patient. *J Hand Surg Eur* 2011;36:205–9.
30. Dowd MB, Figus A, Harris SB, et al. The results of immediate re-repair of zone 1 and 2 primary flexor tendon repairs which rupture. *J Hand Surg Br* 2006;31:507–13.