Strong Digital Flexor Tendon Repair, Extension-Flexion Test, and Early Active Flexion: Experience in 300 Tendons

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KEYWORDS

• Flexor tendon • Multistrand repair • Digital extension-flexion test • Early active motion

KEY POINTS

- The mainstays of Asian practice in primary tendon repair are a strong core tendon repair with sufficient venting of the critical pulleys, followed by a combined passive and active exercise program incorporating early active digital flexion.
- We are moving toward freer early motion, without protection from a splint during exercises.
- Interim clinical data indicate that slight or modest bulkiness of the repair site is not harmful to outcomes, although marked bulkiness should always be avoided. Such bulkiness appears unavoidable, because the core repair has to be tensioned to resist gapping.
- A slightly lengthy venting in the sheath and pulley is preferred by some surgeons to allow tendon motion; these surgeons have not observed adverse effects on hand function.
- The digital extension-flexion test has become routine and is an important step in checking the quality of the repair during surgery.

INTRODUCTION

Over the past 2 decades, repair and rehabilitation methods of primary repair of the digital flexor tendon have changed. Key techniques developed over this period include strong tendon repair methods (typically multistrand), venting of the critical pulleys, an intraoperative digital extension-flexion test of repair quality, and early postoperative active motion.[1–5] Improvements in repair outcomes have been demonstrated by hand centers with a history of tendon-related research.[6–8] However, improved outcomes are limited to teams with established reputations or track records in hand tendon repair. In addition, the number of repairs reported is usually not large and reports often do not incorporate all the critical techniques.

In this article, we outline the interim results from ongoing investigations in several units. Surgeons in these units now perform digital flexor tendon repairs according to a treatment protocol. Before they adopted the protocol, they had no history of tendon-related research; they had not used any of the repair and rehabilitation methods described in the protocol. The surgeons involved are junior or

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midlevel attending surgeons. At the end of this article we outline current practice of digital flexor tendon repair in Asian countries.

CLINICAL METHODS AND PROTOCOL

Four years ago, the lead author (JBT) formulated a protocol that is a simple list of techniques and principles to guide the repair of a digital flexor tendon. This protocol is translated into English as follows.

Indications and Inclusion of Patients

The protocol is used for any zone 1 to 3 acute digital flexor tendon injury, whether clean cut or with severe soft tissue injury, requiring direct repair, without a lengthy tendon defect.

Operative Methods

Tendons should ideally be repaired on the day of injury; if not on that day, certainly within 1 or 2 weeks of injury with temporary skin closure on the day of injury. A Bruner zig-zag incision is made to expose the tendons. The flexor digitorum profundus (FDP) tendon or flexor pollicis longus (FPL) tendon is repaired with an M-Tang repair (6-strand) (Fig. 1) as the core suture using 4-0 looped sutures (Holycon, Nantong, Jiangsu, China).[1,5] In some cases, at the surgeon's discretion, a U-shaped Tang repair (4-strand) can be used instead. A 5-0 or 6-0 suture is used to make a simple running peripheral suture. The key points in performing a core tendon suture are (1) to ensure 0.7 to 1 cm purchase in both tendon stumps, as too short a purchase decreases repair strength; and (2) to keep tension across the core suture, avoiding a loose suture repair. Some bulkiness in the repair site is common and typically presents no major problem. In repairing an FDP tendon close to the A2 pulley, the pulley should be vented through its midline over one-half or two-thirds of its length. When the tendon is cut close to the A4 pulley, the pulley may need to be vented completely (Fig. 2). It is important is to identify the A2 and A4 pulleys correctly during surgery. All surgeons who adopt this protocol should consult relevant publications to master the locations and lengths of both pulleys. The other annular pulleys should be retained as often as possible, but may be vented if required to enhance tendon gliding. The overall length of pulley-sheath venting should not exceed 2 cm. The flexor digitorum superficialis (FDS) tendon may be left unrepaired if the surgeon finds it overly difficult (or the surgeon may not repair the FDSs in all cases, which is also acceptable).

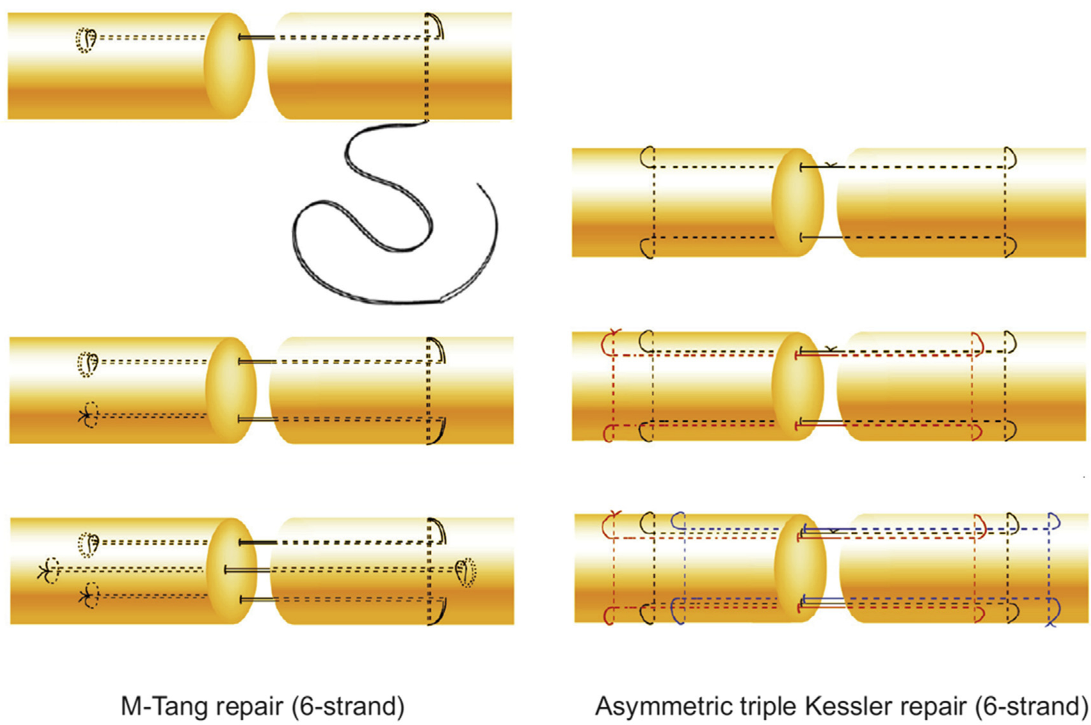

Fig. 1. Methods of making a strong tendon repair are on the left: M-Tang method; U-Tang method is a 4-strand repair (shown in the middle), which omits 2 strands of the M-Tang repair. Right: The asymmetric triple Kessler method was listed in the protocol as a backup for the occasion when looped sutures are unavailable.

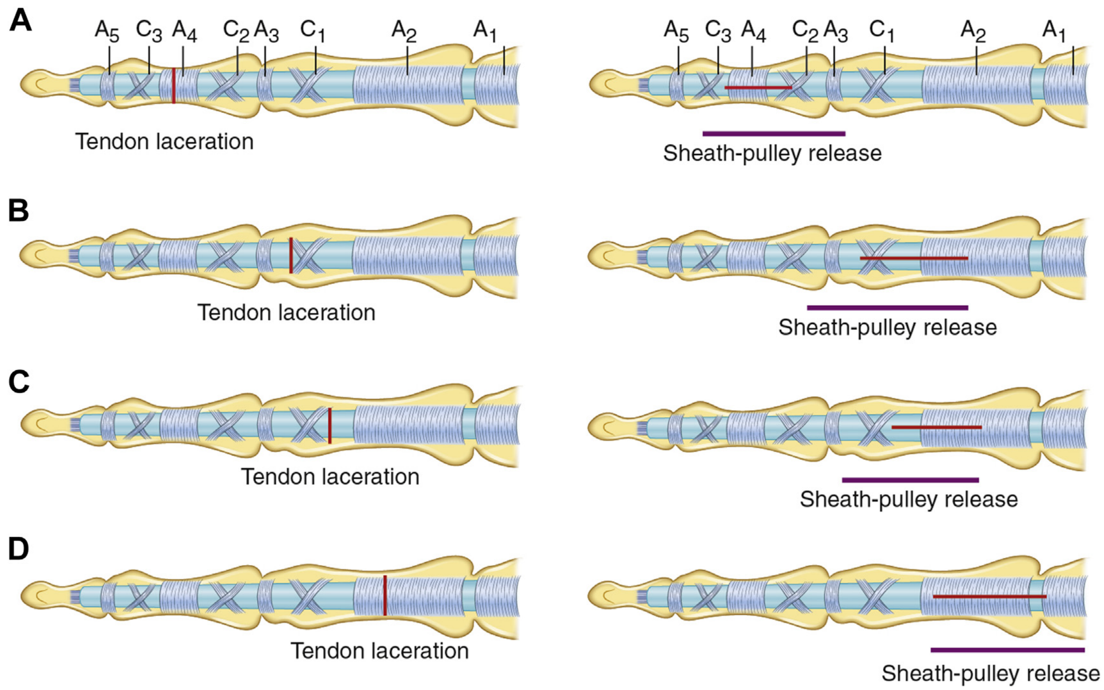

Fig. 2. On the right column under each drawing of the finger, the red lines directly over the pulleys show the original proposal of the lengths of the pulley venting; the lengths of pulley-venting in real-world practice of surgeons in 3 units are shown in dark red. The corresponding tendon cut sites are shown on the left column.

Digital Extension-Flexion Test During Surgery

This test is performed immediately after completion of the tendon repair to check quality of the repair. The test consists of 3 parts (**Fig. 3**): passive full extension of the digit to ensure the tendon repair site shows no gapping; then passive flexion of the digit to confirm that gliding is smooth; and finally pushing the digit to almost full flexion to check whether the tendon repair site (usually a bit bulky) impinges against the edge of the sheath or a pulley. If the repair is loose, the repair site will gap; such a repair should be strengthened with the addition of a tighter 2-strand or 4-strand repair. If the repair site is catching on the sheath or pulley edges, the pulley or sheath should be vented further, until smooth, unrestricted motion of the repair site is confirmed.

After surgery, a short dorsal forearm splint is applied with the wrist in neutral or a slightly flexed position, and the metacarpophalangeal (MP) joint in a moderately flexed position. The splint should be straight beyond the MP joint and should extend past the finger or thumb tip. The wrist position for splinting is not important, but should avoid marked wrist flexion (which will be uncomfortable) or marked extension (which will add unnecessary tension to the repaired tendon).

Full Range of Passive Digital Motion with Early Active Flexion After Surgery

Motion exercises should start 3 or 4 days after surgery, which is usually the time of the first dressing change. Exercise sessions should occur every 2 hours during both daytime and evening. Out-of-splint digital motion is encouraged in each session; multiple passive motion is performed first, followed by active digital flexion and extension no fewer than 30 to 40 times. However, in the first 3 to 4 weeks, only partial active digital flexion is allowed, which can be performed with or without the splint, but during the intervals between exercises and at night, the hand should be protected with a splint. Starting in weeks 4 or 5, a full range of active flexion is allowed; the splint is discarded after week 6. Active use of the hand is allowed over the next 3 weeks, but not against resistance. Passive digital flexion and extension over the full range of motion is stressed from week 1 to 6, which is key to decreasing joint stiffness. Therapy continues as long as necessary.

PRACTICE AND VARIATIONS AMONG 3 HAND-REPAIR UNITS

The previously described protocol was given to the surgeons in 3 units in 3 different cities, along with recent literature to update the surgeons' knowledge

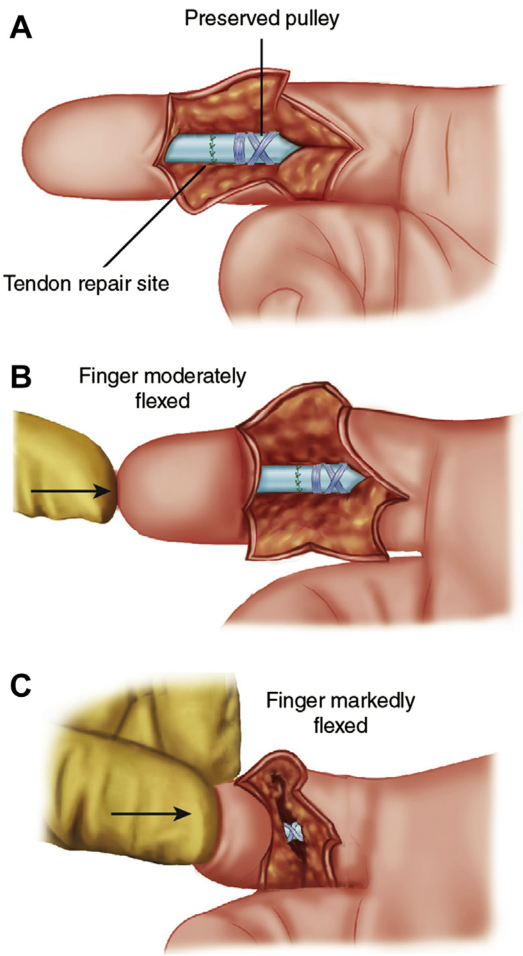

Fig. 3. The digital extension-flexion test has 3 parts: (*A*) full extension; (*B*) moving from full extension to moderate flexion; and (*C*) moving toward full flexion.

and, importantly, to help them understand the protocol and its key techniques. They were also offered a book in Chinese (published by the lead author) containing detailed explanations in plain Chinese of why and how a repair should be performed.[9] In addition, the surgeons were given a video of a 6-strand repair for training purposes.

The surgeons took intraoperative photographs and videos of selected patients to allow the lead author to assess technical variations among the surgeons in their use of the protocol as well as to make detailed assessments of the methods of these surgeons, which might differ from those of the lead author. The following are some noteworthy variations in their real-world practice, as noted from the intraoperative and postoperative photographs and videos:

1. Repair sites are usually much bulkier or less even compared with the lead author's usual practice
2. The pulley and sheath venting is in some cases much longer than what the lead author usually allows (**Fig. 2**); the lead author usually vents through a confined area
3. Out-of-splint motion exercise is common

Except for a small percentage (<5%) of patients who could not be called back for examinations after 6 months, photographs were taken of all patients during follow-up, showing maximal digital flexion and extension. Photographs were reviewed by a surgeon on the team and an additional independent reviewer (who is a hand surgeon but not in any of the 3 units assessed). **Table 1** summarizes the patient data and the distribution of repairs in the digits. Because of the large number of patients involved and because the investigation is ongoing,

Table 1
The numbers of digits of flexor tendons treated in Jiangyin Hospital (January 2014–April 2017), Yixing Hospital (January 2014–February 2017), and Tianjing Hospital (August 2016–May 2017) according to the protocol

Digits and Zones	Jiangyin Hospital	Yixing Hospital	Tianjing Hospital
Fingers, flexor digitorum profundus tendons			
Zone 1	11	10	6
Zone 2	116	83	7
Zone 3	14	9	0
Total	141 (114 patients)	102 (67 patients)	13 (8 patients)
Thumbs, flexor pollicis longus tendons			
Zone 1	2	3	0
Zone 2	16	14	2
Zone 3	5	2	0
Total	23 (23 patients)	19 (19 patients)	2 (2 patients)
Total digits	164 (137 patients)	121 (86 patients)	15 (10 patients)

only finger repairs in zone 2 were reviewed in detail. The excellent or good outcomes in the 3 units were 83%, 87%, and 86% based on follow-up of the first sets of consecutive sets of patients with flexor tendon cuts in the fingers (54, 60, and 7 fingers, respectively) according to the Strickland criteria. Only 1 rupture occurred, in a finger of a male worker who regained full use of his hand at week 2 after surgery. This is the first rupture out of 300 repairs in the 3 and half years since implementation of this protocol; it happened because the patient did not follow instructions. Otherwise, poor results with severe adhesions or stiffness occurred in 5% of fingers, requiring tenolysis.

VARIATIONS IN PRACTICE AND THEIR RELATIONSHIP TO OUTCOMES

In practice, the surgeons in the 3 units repaired tendons slightly differently from each other, although they all followed the protocol as strictly as they could. After examining intraoperative videos and photographs, slight differences were noted in the surgeons' practice, which is very reasonable and reflects the nature of real-world practice; the techniques used by practicing surgeons, with varying levels of technical proficiency, are often not as "standard" as textbooks would imply.

However, it is intriguing that the surgeons in 3 units obtained outcomes equivalent to the best outcomes reported in the English literature. Reports of surgical details, outcomes, and the analysis of factors affecting outcomes from each of the 3 teams have just begun to appear.[10,11] As they accumulate further cases, we expect other reports in years to come. The details of techniques and outcomes from each team will be included in future reports from the teams. Here we outline a few of their practices, which appear to contradict common teachings; however, despite these technical "flaws," they obtained good outcomes. These findings indicate that those techniques or principles may not be as important as previously believed.

Their Repair Sites are Usually Much Bulkier Than Those of the Lead Author

An often-taught repair principle is to ensure a smooth tendon repair site and to avoid bulkiness. However, according to the results from these units, bulky repairs also lead to good outcomes. The surgeons explained to the lead author that avoiding a bulky repair is difficult in real-world practice. In fact, most surgeons are not very proficient in tendon repair; despite doing their best to avoid a very bulky repair, slightly to moderately bulky repair sites are common and unavoidable in their practice. It is not practical to expect junior surgeons to make as smooth a repair as a very experienced surgeon.

It appears that sufficient tensioning of the repair site through tightening the core suture will always compromise the smoothness of the repair to some degree (**Fig. 4**). Very likely, a slightly or moderately bulky repair is not harmful (or at least not as harmful as previously thought). Because the critical pulleys are vented at the time of surgery, a slightly bulky repair can glide without much difficulty. The repaired tendon tolerates a certain amount of roughness after the pulleys are vented properly. The final outcomes may not be affected by a slightly bulky repair, which is often unavoidable in practice, especially by junior surgeons.

Pulleys Can Be Vented Through a Rather Lengthy Sheath-Pulley Segment, or Sometimes the Entire A2 Pulley if Necessary

Venting a lengthy sheath-pulley or the entire A2 pulley is not recommended. However, some of these surgeons vent the sheath beyond 2 cm, and their patients have not reported bowstringing. Although we do not recommend venting the sheath-pulley longer than 2 cm or the entire A2 pulley, extended venting improves tendon gliding; tendon bowstringing may not be severe enough to cause functional problems. However, this remains an assumption that deserves future investigation. Surgeons should keep in mind that the longer the venting, the greater the risk of tendon bowstringing. There should be a length limit; if not 2.0 cm as suggested previously,[1,5] it might instead be a range (ie, 2.0 to 2.5 cm), but should not exceed 2.5 cm.

Out-of-Splint Motion

The surgeons in these units told the lead author that even though patients actually move more aggressively than instructed, the repairs are strong enough to avoid rupture. These surgeons tend to allow the patients to move rather aggressively. They found that out-of-splint active motion is safe even starting from week 1 or 2. These surgeons have never allowed the patients to move the digits against resistance or move too vigorously when the digits are very swollen and the patients feel marked resistance to motion, which is a key point in instructions to patients.

Not Repairing the Flexor Digitorum Superficialis Tendon Causes No Adverse Outcomes

The surgeons in the 3 units found that not repairing the FDS tendon does not lead to hyperextension of the finger joints. In fact, not repairing the FDS

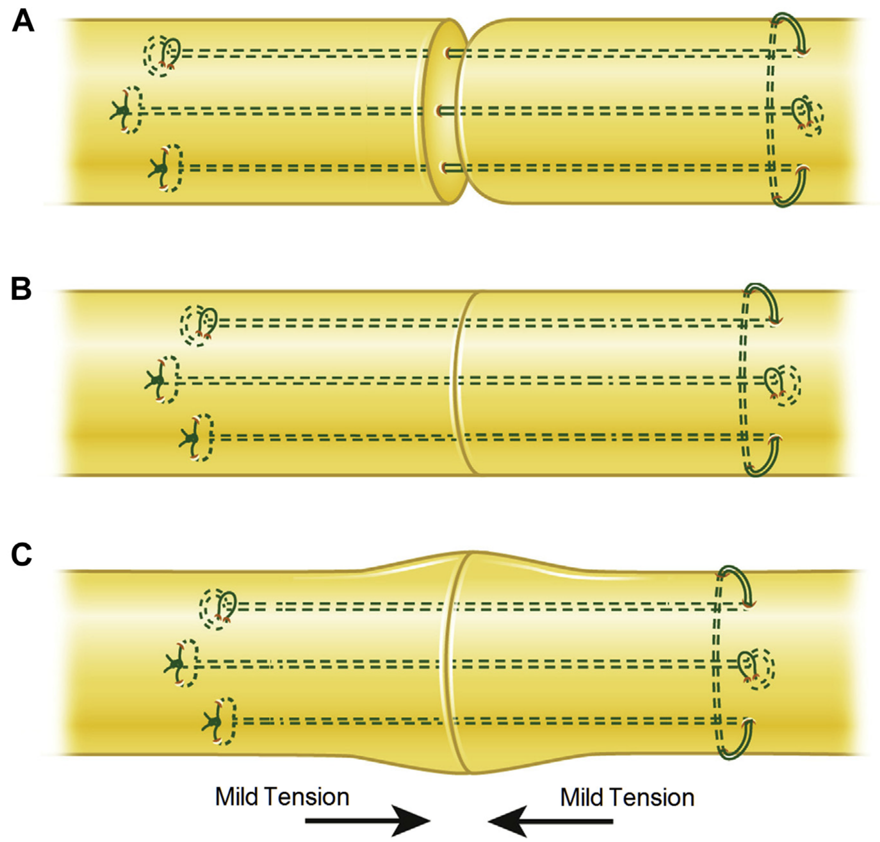

Fig. 4. Bulkiness versus tension across the repair site. (*A*) A loose repair or a repair with gapping should always be avoided. (*B*) Tension-free repair is not an ideal repair. (*C*) Certain bulkiness is always not avoidable in real-world practice. Mild bulkiness at repair site (shown in [*C*]) forming after adding tension to the repair site is not a major problem to tendon gliding with proper pulley-venting. An increase in the repair site diameter by one-fifth to one-fourth is tolerable after completion of the repair, before removal of the temporary fixation needle to the proximal tendon stump. This degree of tension is necessary to ensure no gapping at the repair site during early active digital flexion. *Ensure that tension is not traded for decreasing the bulkiness*. However, remarkable bulkiness at the repair site should always be avoided.

tendon simplifies surgery and makes postoperative finger motion easier. All the surgeons believe that repairing the FDS tendon(s) should not be mandatory and prefer not to repair this tendon when it retracts, the wound is not clean, or if repair is delayed.

The Treatment of Pulleys in the Thumbs Has Not Been Standardized

In the protocol, the methods for pulley treatment in the thumb were not specified, because the literature offers no clear conclusions on which pulleys should be vented. Therefore, surgeons in each unit treat thumb pulleys according to their own preference. All surgeons in these units consider this a topic still awaiting clear guidelines, and anticipate accumulating a larger number of FPL tendon repairs before making any analysis.

Motion Regimen for the Thumb Has Not Been Standardized

The surgeons in each unit instruct patients with an FPL repair to actively flex the thumb with reference to the regimen used in finger tendon repairs. As the thumb differs anatomically from the fingers, the details of exercise instructions to the patients with FPL repairs varied among these surgeons.

OVERALL OUTCOMES AND CONSIDERATIONS

Based on the outcomes in these units, we believe that a multistrand core suture repair, with sufficient release of the sheath and pulley, followed by intraoperative digital extension-flexion, ensures good outcomes. These practices eliminate the risk of repair ruptures when early active motion is practiced appropriately.

We stress that a multistrand repair (for example, 6-strand Tang repair) alone is not sufficient to eliminate the risk of repair rupture. The pulley(s) should be vented to decrease resistance and avoid catching the repair site on the sheath or pulleys. In addition, an intraoperative digital extension-flexion test is especially important for repairs performed by junior surgeons, who should check the quality of the repair via this test. Surgeons must revise their repairs if this test indicates that quality is poor. Therefore, this test is a critical quality check during surgery.

We also suggest that some conventional teachings and suggestions can be revised, because venting of the critical pulleys has become a part of surgery. We believe that the practice of venting the pulleys greatly changes the biomechanics of gliding of a repaired flexor tendon.

Slight Repair Site Bulkiness is Allowed with Tension in Core Suture

The goal of making the repair site as smooth as possible can now be revised: *slight repair site bulkiness is not harmful and can be allowed*. Adding tension to the repair site, a principle not often stressed in the past, should be given sufficient attention and is a technical priority. A strong repair with sufficient tension in the core suture repair, which should be verified through a digital extension-flexion testing, should be key. These 2 measures, adding tension across the repair and performing a digital extension-flexion test, are much more critical than keeping the repair site smooth. Rather, a well-tensioned multistrand repair is beneficial; a multistrand repair without sufficient tension or increased bulk, is harmful. This is not to say that we encourage a bulky repair; a very bulky repair should always be avoided, but a slightly bulky repair causes no hindrance to tendon gliding when the pulleys are properly vented. Surgeons should not trade bulkiness for lack of tension across the repair site. We believe loose sutures without tension are detrimental. Slight bulkiness is neither harmful nor avoidable in the real-world practice of tendon repair.

Wrist Positioning Is No Longer Important

Strong repair methods and pulley-venting decrease the resistance to tendon gliding and increase the ability of the tendon to resist gapping and rupture. We suggest that wrist position is no longer important in postoperative protection. Obviously, one should not place the wrist in marked flexion or marked extension, because both are uncomfortable. Essentially, the patient's wrist can be placed in any position from slight flexion to slight extension; slight flexion to a neutral position appears to be best.

Out-of-Splint Active Motion Is Preferred and Encouraged

Active motion can be performed out of the splint; 1 or 2 weeks after surgery, out-of-splint exercise should be encouraged for efficiency of motion. With the splint's protection, passive extension of the fingers is often insufficient. It becomes hard to achieve "full" extension as required, and splinting adds resistance to active finger flexion, depending on the type and materials of the splint and the amount of dressing on the hand.

PRACTICES IN ASIAN COUNTRIES

In Japan, looped nylon is predominately used to make a tendon repair. The popular method is a Kessler-type 4-strand repair using looped nylon, followed by an additional Tsuge suture repair, making a total 6-strand repair called the Yoshitzu #1 repair.[12,13] Early active flexion is popular. Japanese hand surgeons also vent annular pulleys.[12,13] According to a report, rupture rates of zone 1 and 2 repairs are 6.1% and 5.1%, respectively.[7] In Singapore, a looped nylon suture used to make a 6-strand Lim-Tsai suture is the most frequent method of repairing flexor tendons. In an unpublished audit by Chao and colleagues, the rupture rate was 3% in zone 2 repairs from 2002 to 2007. Both Japanese and Singaporean surgeons have actively performed mechanical studies on repair strength and reported valuable data.[14,15] In Taiwan and Hong Kong, 4-strand repairs are used more often. Surgeons in these regions adopt early active digital flexion and believe the strong repairs in current use can withstand the force of active digital motion.[16] A 2-strand repair has been abandoned for its high rupture rate. Across different regions of the world, surgeons prefer strong core suture repairs.[17–23] Chemical adhesion barriers, barbed sutures, and biological glue are not used.[24–26]

FUTURE PERSPECTIVES

Based on experience from Asian countries, multistrand repairs, especially a 6-strand core suture,[1,7,13,20,27] ensures a strong tendon repair that almost completely prevents repair rupture. Rupture was noted only in rare patients who returned to unrestricted hand use too soon or who had accidents. Venting parts of pulleys is common and considered as important as a strong repair.

Based on findings from 3 surgical centers in this article, it appears that venting the sheath-pulley a bit longer than previously recommended is not harmful and appears to cause no symptomatic tendon bowstringing. Venting can exceed 2 cm if truly needed, although the length limit remains undetermined and apparently varies among fingers and hands of different sizes. Certainly the A2 and A4 pulleys should not both be vented. A report from Japan describes venting the entire A2 pulley in some cases.[13] Canadian surgeons vent the A2 pulley as needed as judged by intraoperative active motion in a wide-awake surgical setting; they do not emphasize keeping even a part of the A2 pulley.[28,29] The best practice for pulley-venting in the thumb is still under question and remains a topic for further research. To evaluate the strength of repair and motion of the tendon, either a passive digital extension-flexion test or active digital extension-flexion test in a wide-awake setting under local anesthesia without a tourniquet[28–32] should be performed routinely.

Early active motion is a popular method in Asia. Out-of-splint motion from the very initial days or the first week of starting exercises is another step forward in pursuing active motion. It is a common impression among many surgeons who use strong repairs that early active motion can be more aggressive than what is currently recommended. Provided no resistance is used and a too-forceful grip is avoided (ie, full active flexion is not attempted), any active motion appears to be safe, with very low rates of rupture. More aggressive pursuit of tendon motion is likely to become a future direction for research. The current strong repairs have given greater freedom to splint-free active motion and more aggressive motion.

Fewer problems are now associated with primary flexor tendon repair than 2 decades ago. Repair rupture does not appear to be a major concern if repair quality has been confirmed through intraoperative digital extension-flexion testing. With early active motion, adhesions are decreased, but tenolysis is still needed in a small percentage of patients; this deserves further investigation. Severe adhesions, although less frequent in clean-cut patients with early active flexion, still develop in the presence of severe trauma or when swelling prohibits adequate passive motion or initiation of active motion. In addition, tendon injuries with loss of a series of major pulleys or tendon defects require secondary pulley and tendon reconstruction.

SUMMARY

The mainstays of Asian practice in primary flexor tendon repair are a strong tendon repair with sufficient venting of the critical pulleys, followed by a combined passive and active exercise program incorporating early active digital flexion. We are moving toward freer active motion, without the protection of a splint during motion exercises; splinting is used between exercise sessions, at a wrist position that patients find comfortable.

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