If a suture is not sufficiently strong to endure very early use, this connective tissue may seriously fix the tendon to the surrounding tissue … No splint is used. Active motion is started as soon as the patient has recovered from the anaesthetic.

—Harmer, Boston, 1917¹

Repair of the divided flexor tendon to achieve normal, or near normal, function is an unsolved problem, with each result still uncertain. Over and above the actual technical difficulties of repairing the tendons, for a century this field has been dominated by the complications of adherence of repairs and rupture during early healing. Adhesion of the repairs occurs because the body creates a soup of fibrin-loaded edema in any area of healing, which Watson-Jones called “physiologic glue.” The fibrin later converts to fibrous tissue to heal the injured tissues and achieve repair strength. This “gluing” process affects every structure in the vicinity, with little consideration of the particular need of certain tissues to glide within the interstitial connective tissue layers. Commonly, fibrin carried onto the dorsum of the digits with the edema fluid restricts movement of the digits into flexion after flexor tendon surgery both passively and actively, by tethering the extensor tendons to prevent their distal movement as the digits flex.² Adhesion can also occur anywhere along the flexor tendons with loss of active flexion and is a particular problem in the fingers, where the flexors are confined within the tendon sheath in a system as finely bored as the pistons in an engine. Avoiding this requires that the tendons be mobilized throughout the period immediately after repair, risking rupture, as the tendon repair takes about 3 months to achieve full strength.

THE BASIS OF MODERN SURGICAL TREATMENT

Although there is ongoing debate about the details of technique, the central tenet of modern flexor tendon surgery is to increase tendon healing, and to avoid adhesion formation between the repaired tendon and the surrounding tissues by making a repair that is strong enough to move within a few days of injury, as first suggested nearly 100 years ago and pioneered in the modern era by Verdan,
Young, and Harman and Kleinert.1,3,4 There follows an unproven assumption that the results will be better with increasing early movement through the first 5 weeks, albeit within the protective environment of a dorsal splint, provided the sutures hold and rupture does not occur. Better tendon healing and adhesion limitation are 2 major goals of tendon surgery. Most methods to limit adhesions remain experimental.5,6 In the authors’ unit, the main interest over the last 20 years has been to eliminate the seemingly unconquerable rupture rate while maintaining a policy of enthusiastic early active mobilization.

FLEXOR TENDON REPAIR: AN OVERVIEW

In their unit, over the past 2 decades the authors have carried out approximately 90 to 100 simple primary flexor tendon repairs in all digits in adults each year, and have analyzed the outcomes and published several reports throughout this time.7–17 The techniques of surgical repair and postoperative rehabilitation have been repeatedly modified, based on ongoing analysis of the clinical outcomes included in these reports. This article summarizes the authors’ opinion of the basic essentials of surgical repairs and rehabilitation, followed by a brief description of their current surgical practice and preferred method of rehabilitation.

BASIC CONSIDERATIONS OF SURGICAL REPAIRS

Strengthening of Sutures: The Core Suture

The main drive of the mechanical way forward in the last 20 years has been by modification of the suturing of the divided tendon, in particular the core suturing (Tables 1 and 2). A variety of materials have been used but no best suture material identified. Various core-suture techniques have also been described over the years. Through the 1990s and the early years of this century, the Tajima and Strickland variations of the (2-strand) Kessler suture, whereby the knot, or knots, are buried in the tendon, were probably the most commonly used core-suture technique in Europe, whereas the Tsuge suture or, more recently, Tang’s triple variation of it, were more likely to be used in the Far East.18 Availability and historical factors, rather than measured strength, were probably the main determinants of which suture material and configurations were used in individual units and countries. As most of the published series of 2-strand core-suture zone 2 repairs in civilian populations from all over the world had roughly the same results, it would seem that most materials and most core-suture techniques in common use at that time worked equally well. Almost all had a rupture rate of between 2% and 9%, with an average of 5%. At the time, it was estimated that repairs needed to have a strength of 15 to 20 N to withstand early mobilization. However, in 1992 Schuind and colleagues measured forces of 120 N being transmitted through the flexor tendons at the wrist during strong pinch. In 1989, Savage and Risitano19 increased the core-suture strength substantially using a Kessler-type suture with 6 strands across the tendon ends. This approach stimulated a great deal of laboratory work and publication of a smaller number of clinical articles, which has continued unremittingly since that time, leaving us with a very confusing multitude of core-suture options and no clear “winner.” Savage’s suture has seldom been surpassed for strength, but is difficult to insert. For this reason it is widely avoided in clinical practice. Research since might be viewed with a cynical eye as attempting to devise a multistrand core-suture technique with the strength advantage of the Savage suture while being more practical for clinical use. The array of options is well documented in a recent book chapter by Tang and colleagues.20

Although suture material does not seem to be of particular importance, Tang’s review identifies 10 other factors of importance.20 Modification of the number of strands of the core suture, and the various ways of achieving this, has attracted most attention, whereas another option, namely use of a larger caliber of core suture, is discussed rarely, although appearing simpler, at least at first glance. The benefits of increased suture size have been shown fairly convincingly in the laboratory.21,22 However, thicker sutures become cumbersome to tie and the knot is bulky within the tendon with sutures thicker than 3/0 in size. This situation is avoided if the knot is taken out of the tendon and onto the tip of the digit, as in the Mantero technique,23,24 probably based on a technique of distal tendon suture fixation described by Georgio Brunelli 20 years earlier. This technique originally used a 2/0 2-strand core suture with the suture attached through the proximal tendon using half of a Kirchmayer/Kessler suture3,25 and to the distal tendon over a button at the tip of the digit, avoiding a knot within the flexor tendon itself. The technique and this suture size are still used routinely in many units in southern Europe, including Mantero’s own unit, although some now use a smaller suture. Although the authors have no personal experience of the Mantero technique, it would seem most suited for use in cases where the flexor tendons are cut in the fingers beyond the A2 pulley, that is, in zone 112 and in Tang’s zones 2A and 2B,26 and in flexor pollicis longus (FPL)
Table 1

Methods and results of primary repair of simple finger flexor tendon injuries in adults from the authors’ unit (*) and some other major reports

<table>
<thead>
<tr>
<th>Authors, Ref., Year</th>
<th>Core Suture/Circumferential Suture/Rehabilitation</th>
<th>No. of Fingers</th>
<th>Zones</th>
<th>Excellent and Good Results (%)</th>
<th>Mechanical Rupture Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lister et al, 33 1977</td>
<td>2-Strand/simple/KM</td>
<td>28 tendons</td>
<td>2</td>
<td>75</td>
<td>5</td>
</tr>
<tr>
<td>Small et al, 51 1989</td>
<td>2-Strand/simple/EAM</td>
<td>117</td>
<td>2</td>
<td>77</td>
<td>9</td>
</tr>
<tr>
<td>Savage and Risitano, 19 1989</td>
<td>6-Strand/simple/EAM</td>
<td>31</td>
<td>2</td>
<td>69</td>
<td>4</td>
</tr>
<tr>
<td>Saldana et al, 1991</td>
<td>2-Strand/simple/KM</td>
<td>60</td>
<td>2</td>
<td>93</td>
<td>5</td>
</tr>
<tr>
<td>Tang and Shi, 51 1989</td>
<td>2-Strand/simple/EAM</td>
<td>117</td>
<td>2</td>
<td>77</td>
<td>9</td>
</tr>
<tr>
<td>Savage and Risitano, 19 1989</td>
<td>6-Strand/simple/EAM</td>
<td>31</td>
<td>2</td>
<td>69</td>
<td>4</td>
</tr>
<tr>
<td>*Elliot et al, 7 1994</td>
<td>2-Strand/simple/EAM</td>
<td>166</td>
<td>2</td>
<td>79</td>
<td>5</td>
</tr>
<tr>
<td>Bainbridge et al, 59 1994</td>
<td>i. 2-Strand/simple/KM</td>
<td>58</td>
<td>2</td>
<td>52</td>
<td>3</td>
</tr>
<tr>
<td>Tang et al, 18 1994</td>
<td>4- or 6-Strand (Tsuge)/simple/EAM</td>
<td>51</td>
<td>1, 2</td>
<td>77 (White)</td>
<td>4</td>
</tr>
<tr>
<td>Silfverskio¨ ld and May, 30 1994</td>
<td>2-Strand/complex/KM + EAM + HOLD</td>
<td>55</td>
<td>2</td>
<td>96</td>
<td>4</td>
</tr>
<tr>
<td>Baktir et al, 61 1996</td>
<td>i. 2-Strand/simple/KM</td>
<td>41</td>
<td>2</td>
<td>78</td>
<td>5</td>
</tr>
<tr>
<td>Peck et al, 62 1996</td>
<td>2-Strand/simple/EAM</td>
<td>82</td>
<td>2</td>
<td>71</td>
<td>12</td>
</tr>
<tr>
<td>Olivier, 63 2001</td>
<td>i. 2-Strand/simple/KM</td>
<td>7</td>
<td>2</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Baer et al, 32 2003</td>
<td>2-Strand (Mantero)/simple/EAM</td>
<td>65</td>
<td>1, 2</td>
<td>91 (with FPL)</td>
<td>0</td>
</tr>
<tr>
<td>Klein, 64 2003</td>
<td>4-strand/simple/KM</td>
<td>40</td>
<td>2</td>
<td>95</td>
<td>2</td>
</tr>
<tr>
<td>Golash et al, 65 2003</td>
<td>i. 2-Strand/simple/EAM</td>
<td>20</td>
<td>2</td>
<td>68</td>
<td>20</td>
</tr>
<tr>
<td>Su et al, 67 2005</td>
<td>i. 4-Strand/simple/KM</td>
<td>51</td>
<td>2</td>
<td>70</td>
<td>18</td>
</tr>
<tr>
<td>Caulfield et al, 69 2008</td>
<td>i. Absorbable 4-strand/simple/EAM</td>
<td>72</td>
<td>1, 2</td>
<td>74</td>
<td>8</td>
</tr>
<tr>
<td>Hoffmann et al, 70 2008</td>
<td>6-Strand/simple/complex</td>
<td>51</td>
<td>2</td>
<td>78</td>
<td>2</td>
</tr>
<tr>
<td>Al-Qattan and Al-Turaiki, 71 2009</td>
<td>6-Strand/simple/EAM</td>
<td>50</td>
<td>2</td>
<td>98</td>
<td>2</td>
</tr>
<tr>
<td>De Aguiar et al, 72 2009</td>
<td>2-Strand/simple/EAM, Botulinum</td>
<td>34</td>
<td>2</td>
<td>87</td>
<td>0</td>
</tr>
<tr>
<td>Kitis et al, 73 2009</td>
<td>i. 2-Strand/simple/KM</td>
<td>137</td>
<td>2</td>
<td>87 Excellent</td>
<td>0</td>
</tr>
<tr>
<td>Trumble et al, 74 2010</td>
<td>i. 4-Strand/simple/KM + PM</td>
<td>52</td>
<td>2</td>
<td>—</td>
<td>4</td>
</tr>
<tr>
<td>Georgescu et al, 75 2011</td>
<td>2-Strand (Mantero)/simple/EAM</td>
<td>58</td>
<td>2</td>
<td>70</td>
<td>0</td>
</tr>
<tr>
<td>Sandow and McMahon, 76 2011</td>
<td>4-Strand/simple/EAM</td>
<td>73</td>
<td>1, 2</td>
<td>71</td>
<td>5</td>
</tr>
</tbody>
</table>

Results were assessed by the original Strickland method or the Buck-Gramcko method, except if given otherwise.

Abbreviations: EAM, Belfast or other early active mobilization (EAM) without rubber bands; FPL, flexor pollicis longus; IM, immobilized; KM, Kleinert-type mobilization with rubber bands; PM, Duran and Houser passive mobilization alone.
tendon division within the thumb, as the needles have to be passed within the distal tendon from the site of division to the top of the digit. This approach probably becomes more difficult as the length of distal tendon increases.

The FPL tendon was researched very little in the second half of the last century, but the extensive literature of an earlier era (1937–1960) clearly identified a much higher rupture rate after primary repair of the FPL than that after repairing the finger flexors.27,28 Surgeons at that time recognized this and debated whether to repair this tendon by insertion of a tendon graft or by lengthening of the proximal tendon.28 When the authors reported the results of zones 1 and 2 finger flexors in 19947 they also looked at the FPL results, and found an alarming rupture rate of 17% in 30 thumbs when mobilized in the Belfast regimen of active flexion/active extension of the repairs (Table 2). At that time, we recommended that this technique of mobilization should not be used in its present form after repair of the long thumb flexor. However, the authors realized that the higher rupture rate might make the FPL a good clinical model to examine possible ways forward in respect of the finger flexors. Ultimately, these clinical experiments with the divided FPL achieved zero rupture rates using 2 different suture techniques, namely, a combination of a 4-strand core suture,29 a Silfverskiod circumferential suture,30 and Tang’s triple-Tsuge suture repair.18 This work showed that both the core and the circumferential suture could have a place in eliminating rupture. However, during the same period, 2 other units reported no mechanical ruptures of FPL repairs using 2-strand core sutures and simple circumferential repairs31 or a Mantero repair,32 albeit in small numbers of patients.

As seen in Tables 1 and 2, increasing the number of core-suture strands suggests a slight advantage in terms of reduction of ruptures of primary repairs, but not a total solution to the problem. However, nearly 50% of the articles published since 2000 report 50, or fewer than 50, repaired fingers. With such small numbers of cases, a difference of one rupture, more or less, would change the percentage ruptures by 2% or even 3%.

**Strengthening of Sutures: The Circumferential Suture**

The circumferential suture, which is never strictly “epitendinous,” even in its simplest form, was originally introduced as an attempt to smooth down

<table>
<thead>
<tr>
<th>Authors, Ref. Year</th>
<th>Core Suture/Circumferential Suture/Rehabilitation</th>
<th>No. of Thumbs</th>
<th>Excellent and Good Results (%)</th>
<th>Mechanical Rupture Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Sirotakova and Elliot,11 1999</td>
<td>i. 2-Strand/simple/EAM</td>
<td>30</td>
<td>1, 2</td>
<td>70 White, 73 Buck-G</td>
</tr>
<tr>
<td></td>
<td>ii. 2-Strand/simple/EAM</td>
<td>39</td>
<td>1, 2</td>
<td>67 White, 72 Buck-G</td>
</tr>
<tr>
<td></td>
<td>iii. 2-Strand/complex/EAM</td>
<td>49</td>
<td>1, 2</td>
<td>76 White, 80 Buck-G</td>
</tr>
<tr>
<td>Kasashima et al,31 2002</td>
<td>i. 2-Strand/simple/IM</td>
<td>16</td>
<td>1, 2, 3</td>
<td>50 (JSSH 1994)a</td>
</tr>
<tr>
<td></td>
<td>ii. 2-Strand/simple/KM</td>
<td>13</td>
<td>1, 2, 3</td>
<td>77 (JSSH 1994)a</td>
</tr>
<tr>
<td>Peck et al,66 2004</td>
<td>2-Strand/simple/KM</td>
<td>23</td>
<td>1, 2</td>
<td>—</td>
</tr>
<tr>
<td>Baer et al,32 2003</td>
<td>2-Strand (Mantero)/simple/ EAM</td>
<td>22</td>
<td>1, 2</td>
<td>91 Buck-G (with FDP)</td>
</tr>
<tr>
<td>*Sirotakova and Elliot,15 2004</td>
<td>4-Strand/complex/EAM</td>
<td>48</td>
<td>1, 2</td>
<td>73 White, 77 Buck-G</td>
</tr>
<tr>
<td>*Giesen et al,17 2007</td>
<td>6-Strand (Tang)/nil/EAM</td>
<td>49</td>
<td>1, 2</td>
<td>78 White, 82 Buck-G</td>
</tr>
<tr>
<td>Schaller,77 2010</td>
<td>2-Strand (Mantero)/simple/EAM</td>
<td>21</td>
<td>1, 2</td>
<td>66 Buck-G</td>
</tr>
</tbody>
</table>

Abbreviations: Buck-G, Buck-Gramcko method; EAM, Belfast or other early active mobilization (EAM); FDP, flexor digitorum profundus; IM, immobilized; KM, Kleinert-type mobilization; PM, Duran and Houser passive mobilization alone.

a JSSH, criteria of Japanese Society for Surgery of the Hand (similar to the White assessment, uses interphalangeal range of motion only).
loose ends and improve gliding of the repair. In 1986, Wade and colleagues realized that it had considerable strength in itself. This notion led to a description of about 5 or 6 variants of the circumferential suture in the 1990s and several laboratory trials of the various alternatives. Broadly, these showed that the simple running suture (which surgeons mostly still use) is the weakest of these sutures and that some of the new ones were as strong as the core sutures. In 1996, Manske’s team looked at tendons repaired with circumferential sutures only, and recorded breaking strengths of up to 63 N. The multiple gripping bites of the newer circumferential sutures are not unlike core sutures in principle. Initially these new circumferential sutures were perceived as a possible alternative to elaborate core sutures rather than a way of augmenting the latter. However, the Kubota study also showed that the more material there is on the surface of the tendon, the more friction there is on mobilization, identifying an upper limit to how much one can elaborate the circumferential suture.

**Treatment of the Sheath: Venting of the Pulleys**

In retrospect, a factor in the results achieved by the authors in the 1990s, which received no attention at the time but was, possibly, of significance, was that from the earliest of these studies, it has been routine to “vent” pulleys as necessary to allow repairs to travel through a full range of excursion, without impinging on the A2 or A4 pulleys, on passive movement of the finger before skin closure. For the senior author (D.E.), the conviction that this “made sense” followed a private conversation as a trainee in the mid-1980s at the Derby Hand Course with Dr Strickland. At the time, Dr Lister and others were quite adamant that these pulleys should remain entirely intact. Dr Strickland seemed less certain and the senior author, knowing the problems experienced personally in the emergency theater, was certain that venting was correct and necessary in many cases. Venting the sheath was not new: in the 1950s, and before, adhesions were thought necessary to achieve tendon healing, and surgeons cut windows in the sheath. Aware of the need to compensate for the tendon repair making the tendon bulkier, they cut the windows to allow a full passive range of motion of the repairs. In the 1970s, following research by Lundborg and others, synovial fluid was believed to be the most important healer of the tendons, and surgeons moved to obsessive closure of the sheath. However, at that time and before, various investigators had pointed out that repaired and thickened flexor tendons might not move freely in a closed sheath, and research work supported this view. Others could find no evidence of any benefit from sheath closure, and many among the best results in the world were being achieved in series where the sheath had not been sutured. Consequently the enthusiasm for complete closure eventually diminished, and most surgeons now simply lay the sheath back in place without suturing it. Catching of repairs on the edges of the pulleys was another practical problem that went largely unmentioned throughout the era of complete sheath closure. In 1975, Duran and Houser had suggested partially releasing one side of any pulley on which any repair was catching. Strickland elaborated the technique and probably introduced the term “venting” the pulley, meaning cutting the side of it. There was a reluctance to admit to a need to vent pulleys because, in practice, this usually entailed partial division of the A2 or A4 pulley, the complete integrity of which was believed to be of overriding importance to the mechanical efficiency of the flexor system. This notion has its origin in a curious twist of logic: it had been recognized for a long time that when doing secondary flexor surgery, for the new flexor to achieve its mechanical intention of flexing the finger with power, the minimum one needed to preserve, or reconstruct, was an A2 and an A4 pulley. This tenet was carried over into primary flexor surgery as a mandate to preserve these 2 pulleys in their entirety at all costs. More recently, several research articles have shown that there is no absolute need to preserve the A2 or the A4 pulley so completely, or even at all, when most of the remainder of the sheath is intact. The authors confirmed the need for venting of both the A2 and the A4 pulley to achieve a full passive range of motion after tendon injury between zone 1 and the distal edge of the A2 pulley, in Tang’s zones 2A and 2B. With the onset of postoperative edema, it is likely that the need for venting would be accentuated. This problem also becomes more likely if more complex repairs are used, as these are likely to have greater bulk than simpler repairs. The discussion of venting was taken to its logical conclusion in 2 review articles, the second of which analyzed the sites along the tendon sheath where tendon injury commonly occurs, and described appropriate pulley releases for each injury. This opinion is updated in more recent book chapters, and both reviews accord this process of pulley venting equal importance regarding the use of stronger repairs in increasing the margin of safety for early active mobilization. The authors believe that the results of zone 1 primary flexor tendon surgery are equally dependent on judicious venting of the A4 pulley.
**BASIC CONSIDERATIONS OF REHABILITATION**

**Current Rehabilitation Protocols**

In general, this is done in 1 of 2 ways, namely using either Kleinert rehabilitation, whereby extension of the fingers is active and flexion is passively achieved by rubber bands, or Belfast rehabilitation, whereby both extension and flexion are achieved actively (see Tables 1 and 2). Both regimes are mostly used with the fingers being protected from sudden or full movement into extension by a dorsal splint. Although there seems to be an almost infinite number of individual unit variations of the detail of the splinting shape, time of starting movement, and the ongoing regime, most commonly all fingers are protected by the splint and the splint is worn for 4 to 5 weeks, the period during which rupture of the repair is most likely. The degree of flexion of the metacarpophalangeal (MCP) joints and wrist in the splint is less than was used 25 years ago. Many have reduced the wrist flexion (from that akin to a Phalen test used then) to a straight wrist, or even the extended wrist position logically suggested by Savage many years ago.

Passive mobilization, introduced by Duran and Houser in 1975 and supported by Strickland and Glogovac in 1980, whereby the fingers were only mobilized passively by a therapist or the patient’s other hand, is now used in most units, to help Kleinert and Belfast regimes to push for better results at the extremes of movement. This regime, used alone, is very labor (therapy) intensive, with no seeming advantage over the alternatives.

**CURRENT SURGICAL PRACTICE**

**Timing of Primary/Delayed Primary Repair**

Primary repair of the flexor tendons should be as early as possible after the injury. However, there is a body of evidence that delay of 24 to 72 hours is not followed by poorer results, and it is likely that delayed primary repair by an experienced surgeon will achieve a better result than immediate surgery by an inexperienced surgeon. Transfer of patients to specialist units and delay in investigating, or even treating, more pressing problems is acceptable practice. Although primary treatment is generally carried out within 72 hours, this surgery need not be considered an emergency, and extension of this period is considered later.

**Surgical Approach**

The authors approach the flexor tendons through zig-zag (modified Bruner) skin incisions, which are deepened through the subcutaneous tissue. In zones 1 and 2 the tendon sheath has to be circumvented, and this is done with as little disruption as possible while providing sufficient exposure to examine, then repair, the injury to the tendon(s). A window of 2 to 4 mm in length is created by enlarging the primary wound in the sheath to a transverse opening across its full width, then splitting the lateral attachments of the sheath proximally, distally, or in both directions, to allow it to be folded back, exposing the tendons. Where the tendons have been cut with the finger in extension it is often unnecessary to open the sheath more than this, as the tendon injury lies directly below the original breach of the sheath. Where the tendons have been cut with the finger in flexion, the tendon injury will lie distal to the original cut in the sheath with the finger extended. The skin incision is extended and the window in the sheath is either enlarged or, if this would involve undue division of the pulley system, the sheath is opened through a second window overlying the distal end of the tendon with the finger extended. The sheath is opened in such a way as to preserve as much of the A2 and A4 pulleys as possible. However, it is often necessary to divide one lateral attachment of the A2 or A4 pulley along part of the pulley length (Fig. 1), either to effect repair of the tendons or to allow the repair to glide freely through a full range of motion without snagging on the edge of a pulley, because a flexor tendon repair is inevitably of greater diameter than the original tendon, and the uninjured tendons already fit very tightly within the sheath. Fortunately the A2 pulley is of sufficient length that one-third, or slightly more, of its length can be released laterally when necessary without resulting dysfunction. The whole A4 pulley can be released laterally, without tendon bowstringing.
provided a sufficient part of the A3 and C pulleys have been retained.

**Core and Peripheral Suture Methods for End-to-End Profundus Tendon Repairs**

Over the last 20 years, surgeons have been bombarded with different methods of core and circumferential suturing. Many units still use a 2-strand core suture, although some have changed to, at least, a 4-strand suture (see Table 1). Of these, the authors find the very simple technique of inserting two 2-strand Kirchmayr/Kessler sutures in planes at right angles to each other, as recommended by Smith and Evans,29 the simplest of these (Fig. 2). When a continuous suture is used to create 4 strands across the tendon junction, there remains a question as to whether all 4 strands are bearing load during movement of the repair, particularly when braided sutures are used or attempts are made to lock each pass of the suture through the tendon. The Tang (triple-Tsuge) suture technique, using a looped nylon suture, is the simplest and quickest means of achieving a 6-strand core suture, at the same time obviating a circumferential suture (Fig. 2).18 The authors believe this suture to be considerably simpler than the traditional “core and circumferential” combinations in routine use in Western countries. When using a 4-strand core suture the authors have reverted to a simple running circumferential suture, after using one of Silfverskiöld’s circumferential sutures30 for a time and coming to a realization that this suture is difficult to use for most training surgeons, particularly on the posterior aspect of the repair.

**Repair of Profundus Tendon Close to its Insertion (Zone 1a)**

The classic method of attachment of the flexor digitorum profundus (FDP) tendon to the distal phalanx with a suture passed through 1, or 2, bone holes and tied over a button at the end of the finger, or, more commonly, on the nail, works without problems in most instances. The first attempt to be rid of the button was suggested in 1965 by Pulvertaft. Various methods of avoiding the button have been devised more recently.53 As all seem to have worked for their innovators, the argument over which is “the best” is probably futile. More pertinent is which is easiest, cheapest, and has fewest side effects: the authors prefer their own version (see Fig. 3)!54 Where the profundus tendon has been divided within 0.5 to 1 cm of its insertion, many surgeons are happy to excise the distal part under the assumption that the finger compensates for the slight profundus shortening. The authors see no reason to do this, and simply pass the 2 core sutures through the distal tendon segment then attach them to bone, apposing tendon to tendon and retaining the full length of the profundus.

**Repair of the Retracted Tendons**

Proximal retraction of the tendons from the proximal part of the finger under the A2 pulley is common. If the tendon end cannot be retrieved quickly with a fine arterial forceps passed proximally into the flexor sheath from the finger wound to grip the FDP tendon, a process that may be aided by milking the tendon from the forearm to the base of the finger with the wrist and MCP joints flexed, this should be quickly abandoned. The mid-palm is then opened, and a fine pediatric plastic tube passed distally will either carry the tendons with it to the finger wound or can be passed through...
the sheath to the finger wound, then sutured side-to-side to the tendons in the palm. Tension on the distal end of the tube will then draw the proximal tendons out of the finger wound. The advancing profundus tendon will carry the superficialis tendon along with it.

Frayed and Diagonally Divided Profundus Tendon Ends

Trimming of frayed and/or diagonally divided tendon ends to make repair easier and/or neater should be avoided if possible, as any degree of shortening of the flexor tendons risks creating a finger that cannot extend fully at the 2 interphalangeal joints. This statement would be contested by many and the line drawn at resection of, possibly, 0.5 cm or 1 cm. A problem of trimming ragged tendon ends is that the fraying usually extends back into the tendon ends by 0.5 to 1 cm, and resection is unlikely to be less than 1 cm. Flexion of both of the interphalangeal joints in a finger synchronously, as usually occurs in these circumstances, creates a troublesome “hook finger,” which usually causes more problems than are seen when only one of the interphalangeal joints cannot extend fully. Should tendon trimming lead to a hook finger, it will almost invariably cause the patient inconvenience. Particularly if the finger is insensate following concomitant nerve injuries, it is dangerous to a machine operator. The problem should be recognized at primary surgery and rectified by tendon lengthening using Le Viet tendon lengthening in the forearm muscles, or conventional tendon lengthening at the wrist for more extreme hooking of the fingers.

Superficialis Tendon Repair

Fifty years ago Kleinert and Verdan showed that it was possible and preferable to repair both flexor tendons at primary surgery, and so surgeons carry on repairing both flexor tendons under nearly every circumstance. Repair of the flexor digitorum superficialis (FDS) can be difficult in certain circumstances, as it is not always tubular. At its bifurcation the FDS is flat, it surrounds the profundus tendon, and it lies under the A2 pulley, in the so-called Tang zone 2C, making any repair likely to stick. If only half the tendon is intact, the other half can be excised proximally and distally. Proximally this is taken back to the palm, and the cut half of the FDS removed obliquely so it cannot snag on the A1 or proximal A2 pulley edges. Distally it only needs be cut back to where the FDS lies flat behind the profundus tendon.

The authors’ method of repair of the FDS depends on whether it has been cut in a flat or a round part of the tendon. (1) When the FDS injury is close to its insertions to the middle phalanx or in the distal part of the chiasma, usually each half is sutured separately using a horizontal mattress suture with the knot outwards (laterally) and, thus, away from the profundus tendon. This approach creates a 4-strand repair, although the authors were doing this long before 4-strand repairs were topical. (2) Proximal to the chiasma, where the tendon is anterior to the FDP and still flat, traditionally the authors have sutured this with a 4/0 Prolene 2-strand Kessler plus 5/0 or 6/0 circumferential nylon or Prolene. However, one must be aware that this repair would be under the A2 pulley, so the necessary pulley resection must be sufficient to allow suturing of the FDP tendon, to enable a full range of motion passively without snagging. It is this situation, a zone 2C repair under the A2 pulley, of which Tang wrote of suturing the FDP only. The authors examined their 2C repairs at that time and did not find a problem for simple lacerations, but were aware of a definite problem of the swollen tendon repairs jamming under the A2 pulley if the greater edema likely in more traumatic injuries was not
appreciated and a switch to FDP suturing only was not made. In such situations, this switch was usually made by the senior author, either in person or on the telephone, and most flexor repairs at the time were being done by senior fellows who were aware of the writings of Tang and of the senior author. Perhaps the “FDP suture only” policy should be given more consideration here, as it is the safest thing to do and involves less understanding by less experienced surgeons. The authors also suspect it might often be difficult to get a 4-strand or 6-strand repair into this flat tendon, then follow it with a circumferential suture. (3) Once the tendon injury is more proximal and the FDS is thickening up, and moving to be situated under the proximal A2 and/or A1 pulley, putting whatever sutures one favors into both tendons becomes less of a problem.

**Repair Under the A2 Pulley**

Where both slips of the FDS are divided, the profundus is also likely to be divided, a situation that gives rise to another problem. In the 1970s, Boyes pointed out the problem of repairs sticking under the proximal A2 pulley, which is the tightest part of the sheath; more recently, Tang re-examined this problem and showed better results when only the profundus was repaired for injuries under the A2 pulley. As mentioned earlier, the authors were unable to agree with this for simple flexor tendon divisions in a later study. However, this single tendon repair is undoubtedly correct in more complex injuries of the distal palm and proximal part of the fingers, such as crush injuries at this level, distally based flaps on the distal palm, replants/revascularizations, and mutilfing injuries. During the last 20 years, the senior author has treated 10 patients with such injuries of the distal palm or bases of the fingers in whom both tendons were repaired at primary surgery and in whom it was necessary to perform a tenolysis subsequently. In all cases, the 2 flexor tendons were so edematous that they were up to double their normal diameter and, as a consequence, completely jammed under the A2 pulley, with no possibility of mobilization after the first procedure. All required removal of the FDS tendon completely to allow any movement of the profundus tendon under the A2 pulley. Tang’s single tendon repair at primary surgery would have avoided this secondary surgery, and the senior author has come to realize that this is the safest policy for these particular injuries under all circumstances, particularly in the hands of less experienced surgeons. The authors now only repair the profundus tendon in any injury in this area that is likely to produce significant edema.

**Repair Under the A4 Pulley**

Injuries under the A4 pulley, in either zone 1 or zone 2, are less problematic, as the authors consider it acceptable to completely divide the A4 pulley if necessary, provided the sheath proximally is mostly intact.

**Repair in the Carpal Tunnel**

Although severe injuries in the carpal tunnel (zone 4), are rarer, the same problem arises for multiple tendon repairs as for under the A2 pulley, namely of lack of space. If multiple tendons are divided in zone 4, the authors repair only the profundus tendons. These repairs are likely to be particularly bulky in patients who suffer glass lacerations of several tendons that penetrate the skin of the wrist in such a way that the shard of glass passes distally into the carpal tunnel, as these tendon divisions are likely to be frayed and diagonal.

**Repair of the FPL Tendon**

The principles and techniques of repair of the FPL tendon are essentially the same as those of the finger profundus tendons, other than specific actions to overcome the difficulties encountered as a result of retraction of the FPL. This may cause problems of retraction of the tendon into the carpal tunnel after division in the proximal thumb, requiring passage back through the thenar muscles, sometimes with the aid of a fine pediatric tube (see Repair of the Retracted Tendons), and difficulties of suture of the tendon ends without tendon lengthening and with increased risk of rupture.

**Preferred Rehabilitation Protocol**

In 1989, the hand surgeons in Belfast mobilized routine zone 2 flexor tendon repairs in a Kleinert traction splint, but without the elastic bands; that is, actively moving the fingers when flexing as well as when extending. Many before had never used rubber bands, or had tried to get rid of them. The desire to be free of the rubber bands had been prevalent for years, largely because of the problems arising from the flexed resting position of the proximal interphalangeal joints in Kleinert traction and, also, because of difficulties in managing Kleinert traction. It was also realized that many patients never used the rubber bands to passively flex, but simply flexed their fingers actively. The senior author repeated the Belfast experiment. Using a 2-strand core suture and a simple circumferential suture followed by rehabilitation with a modification (Figs. 4 and 5, Table 3) of the Belfast regimen (early active finger motion), a rupture rate of 5% for zone 1 injuries and 4%...
for zone 2 injuries was achieved in 440 patients with 728 complete tendon divisions in 526 fingers. Others reported a similar rupture rate using variants of the Belfast regime (see Table 1). The rupture rate was similar to that reported at the time by units worldwide using the Kleinert regimen (see Table 1), confirming the safety of this simpler and less expensive method of rehabilitation. However, the authors also reached the conclusions that (1) argument over which of the two was the better was probably unproductive, and that (2) the problem of rupture had not been solved for the fingers.

MANAGEMENT UNDER DIFFICULT CLINICAL SITUATIONS

Delayed Presentation

Largely as a result of discovering an article written back in the 1960s, the significance of which was probably not appreciated at that time, the authors are now much more enthusiastic than previously with respect to delayed primary repair. This article identified the fact that delayed primary repair is possible far more often than is thought, and for far longer after the index injury. At that time, surgeons in North America were attempting to undertake the Kleinert/Verdan/Young-Harman philosophy of immediate repair and immediate mobilization. However, the hand units were still receiving patients at fairly long times after the initial injury, as the senders were expecting them to be treated by secondary grafting in the conventional manner of that time. McFarlane and colleagues tried to carry out primary repairs in 100 patients sent slowly to them, whatever the delay. Several of these patients arrived more than 12 months after the initial injury. That the flexors in 36% of 100 fingers could be repaired directly, even months after the injury, negates the assumption that delayed presentation routinely necessitates tendon grafting. With the possibility of slight tendon lengthening in the muscles without slowing the early mobilization program, this figure might now be even higher. Nowadays, if a patient arrives later than 72 hours, and the finger is not infected and is mobile passively, the authors explore the finger immediately and try to repair the tendons. If the tendon ends will not quite come together, a Le Viet tendon lengthening within the muscle in the forearm is performed. Although the tendon is cut, the muscle has not been, and the muscle maintains the continuity needed to allow immediate mobilization. If repair still proves impossible, then a graft can be placed with no loss of time, or a silicone rod is put in place for a staged tendon grafting procedure.

Rupture of Primary Repairs

Although concern about tendon rupture had been one of the major determinants in the evolution of
tendon suture and early postoperative mobilization throughout the last 10 years of the twentieth century, there was almost no information in the literature early in this century as to whether immediate rererepair of ruptures was successful. In 1982, Leddy stated that “the preferred treatment (of ruptures) is prompt reexploration and repair,” without proof that this treatment was correct. The rupture of the tendon is most in the first month after primary repair (Table 4). In 2006, the authors reviewed all rupture rererepairs of zone 1 and zone 2 primary flexor tendon repairs in their unit between 1989 and 2003 to assess the outcome of immediate rererepair (Table 5), with a view to identifying whether this should be an invariable policy.16,79 This study identified that rupture rererepair, whenever possible, works adequately for all locations in zone 1 and 2 (Table 5) and all digits except the little finger (see later discussion).16,79

Certain preoperative factors require consideration before undertaking immediate rererepair and may preclude this, namely the general medical condition of the patient, advanced or very young age, a noncompliant patient, other hand abnormalities such as gross multijoint osteoarthritis, infection and/or skin breakdown in the involved finger, or a swollen and stiff finger, either because presentation is too long after the rupture, because the rupture occurs too late after the primary repair, or for other reasons. Patient refusal is most likely when an FDP tendon ruptures and proximal interphalangeal (PIP) joint flexion by an intact FDS tendon is adequate for his or her function. Occasionally, at surgery repair is impossible, owing to the friability of the tendons or because of the degree of scarring of the tendons and sheath.

### The Little Finger

The authors have previously discussed technical difficulties encountered in repairing the small tendons in the little finger.13 The small size of the digit also makes rehabilitation after primary repair more difficult. This experience was repeated in rerereparing ruptures of the primary repairs (Table 6).16,79 The percentage of ruptures of primary repairs was very much greater in the little finger (46%) than in the other fingers (Table 6). Rererepair had a 35% chance of creating a little

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**Table 3**
The current St Andrews rehabilitation regime

<table>
<thead>
<tr>
<th>2012 St Andrew’s Centre Early Active Mobilization Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day 1</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Week 1</strong></td>
</tr>
<tr>
<td><strong>Week 2</strong></td>
</tr>
<tr>
<td><strong>Weeks 3, 4</strong></td>
</tr>
<tr>
<td><strong>Week 5</strong></td>
</tr>
<tr>
<td><strong>Weeks 6, 7</strong></td>
</tr>
<tr>
<td><strong>Week 8</strong></td>
</tr>
<tr>
<td><strong>Week 10</strong></td>
</tr>
</tbody>
</table>

---

**Table 4**
Timing of tendon ruptures after primary tendon repair

<table>
<thead>
<tr>
<th>Time of Rupture (Weeks)</th>
<th>Number of Ruptures</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>6</td>
</tr>
<tr>
<td>1–2</td>
<td>2</td>
</tr>
<tr>
<td>2–3</td>
<td>6</td>
</tr>
<tr>
<td>3–4</td>
<td>5</td>
</tr>
<tr>
<td>4–5</td>
<td>3</td>
</tr>
<tr>
<td>6–9</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

finger that is a hindrance to grip function and a 20% chance of a second rupture. Second rupture was almost exclusively a problem of the little finger. Unfortunately, secondary surgery to the flexor tendons of this finger is no less difficult, and the only solution to the problems after primary repair is to acknowledge them and increase therapy time for these patients. The findings support a policy of no rerepair in the little finger, particularly if patient compliance or other problems have become apparent during rehabilitation. The authors believe that most ruptures of the little finger should be treated by 2-stage reconstruction, a rod being inserted into the finger as an alternative to rerepair. Rerepair of a rupture of the profundus tendon with a strong intact FDS tendon is not recommended. Unfortunately, even when only the FDP tendon of the little finger has ruptured, doing nothing may not be an option because the FDS tendon may be absent, or too weak to provide sufficient PIP joint flexion.

The Noncompliant Patient

In 1999 we established that around 50% of the ruptures that occurred between 1989 and 1996 were in noncompliant patients. Unwitting patient-related causes of rupture and bad results included some children, patients incapable of comprehending what was required of them, excessive scar formers, patients with social circumstances precluding therapy attendance, and patients with low pain thresholds. We can help these individuals more, given thought and/or adequate resources. “Uncooperative” patients include adults and children who do not comply and small children who cannot. Noncompliant adults constitute the major concern, as this injury occurs mainly in adults and does so at an age, and in a social group, where improving compliance is likely to be difficult. More time spent in therapy and psychological manipulation is the only means we have of improving the results of these patients.

The Severe Injury

Emergency referral of bad hand injuries that include flexor tendon division, or more, is inevitable for us all. We cannot redirect such injuries, but we can modify our response to them. These injuries are often added to the list of emergencies to be done by trainee surgeons, often with little expertise in this field. The consequence is inevitable, and too frequently excused as a bad result from a bad injury. These cases need the same level

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<table>
<thead>
<tr>
<th>Locations</th>
<th>Number of Ruptures</th>
<th>Results of Immediate Re-repair of Ruptures</th>
</tr>
</thead>
<tbody>
<tr>
<td>All fingers</td>
<td>37</td>
<td>Excellent (24%)</td>
</tr>
<tr>
<td>Zone 1</td>
<td>5</td>
<td>Excellent (20%)</td>
</tr>
<tr>
<td>Zone 2</td>
<td>32</td>
<td>Excellent (25%)</td>
</tr>
<tr>
<td>Zone 2A</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Zone 2B</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>Zone 2C</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Zone 2D</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5

The results of immediate re-repair and successful rehabilitation of ruptures of primary flexor tendon repairs in the different zones ($n = 37$)

<table>
<thead>
<tr>
<th>Locations</th>
<th>Number of Ruptures</th>
<th>Results of Immediate Re-repair of Ruptures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zones 1 &amp; 2</td>
<td>37</td>
<td>Excellent (24%)</td>
</tr>
<tr>
<td>Zone 1</td>
<td>5</td>
<td>Excellent (20%)</td>
</tr>
<tr>
<td>Zone 2</td>
<td>32</td>
<td>Excellent (25%)</td>
</tr>
<tr>
<td>Zone 2A</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Zone 2B</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>Zone 2C</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Zone 2D</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>


---

Table 6

Results of immediate re-repair of ruptures of primary flexor tendon repairs in zones 1 and 2 of the fingers

<table>
<thead>
<tr>
<th>Results</th>
<th>Index</th>
<th>Middle</th>
<th>Ring</th>
<th>Little</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>9 (24%)</td>
</tr>
<tr>
<td>Good</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>10 (27%)</td>
</tr>
<tr>
<td>Fair</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>5 (14%)</td>
</tr>
<tr>
<td>Poor</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>13 (35%)</td>
</tr>
</tbody>
</table>

The results are only for the 37 fingers rehabilitated successfully out of a total of 42 fingers with tendon ruptures. Assessment was by the original Strickland criteria (1980). Rerepair was done in zones 1 in 5 fingers and in zone 2 in 32 fingers. All 5 second ruptures were in zone 2.

of senior attention as amputated fingers for replanta-
tion or high-pressure injection injuries. Given our
failure to achieve normal hands after primary flexor
tendon surgery routinely in even simple cases, and
the passing of the earlier Louisville philosophy that
the sun should never set on a cut flexor tendon,
there is a case for all flexor tendon divisions being
considered difficult surgery and for their being re-
paired by more experienced hand surgeons. This
truism applies even more to complex injuries.

Multiple finger injuries present no particular
problem other than the time needed to carry out
the task. Pulley destruction and/or skin loss do
not preclude primary repair of simple flexor tendon
injuries, although the need for reconstruction of
the latter may delay mobilization slightly. However,
all of these situations may require the expertise of
a senior surgeon, for reasons of speed and/or
the reconstructive ability required. If a complex
wound, sometimes with skin and subcutaneous
tissue loss, is also very dirty, adequate debride-
ment of the flexor aspect of the hand and fingers
at a single operation without too much destruction
of vital longitudinal structures can be difficult, or
impossible. A policy of reviewing the wound in
the theater 48 hours after the first exploration (pol-
icy of “48 hour look”) has to be instigated. It may
then become clear that flexor tendon repair is
impossible and that secondary reconnection of
the tendons will be necessary. Primary repair of
flexor tendons in the presence of frank wound
infection should not be attempted.

Most reported clinical series of acute flexor
tendon repairs and rehabilitation only include
simpler cases. Our knowledge of the effectiveness
of current techniques of primary flexor tendon
repair and rehabilitation is restricted to that gained
from examination of the results of treatment of
simple injuries. However, this leaves us in a posi-
tion where we do not know whether the techniques
suitable for simple cases should be applied to
more severe injuries. More clinical articles are
required, using the same assessment techniques
but examining primary flexor tendon repair in
adversity, that is, in association with other injuries.

**Rehabilitation of More Complex Situations**

The authors use exactly the same splint and Bel-
fast regime, after simple primary flexor tendon re-
pairs, more complex primary repairs, secondary
tendon grafting, flexor tendon transfers, and
revascularization/replantation, with the start of
rehabilitation being delayed a few days in the latter.
The authors believe that rehabilitation is not only
simpler but likely to be safer and more effective if
it is standardized, whenever possible, and the
therapists do not have to apply techniques they
use rarely to the most difficult hands they are asked
to mobilize. If a flexor tendon, or its repair, is
deemed (at surgery) to be too fragile to withstand
early active mobilization, it is better to replace the
tendon rather than risk rupture in the immediate
postoperative period. It could be argued that this
regime may be relaxed in secondary surgery, as
the suture techniques are stronger than those of
primary flexor tendon surgery.

**SUMMARY**

The authors believe that the way forward in pri-
mary flexor tendon surgery clinically is by use of
strengthened but simpler sutures, appropriate
venting of the pulley system, and maintaining early
rehabilitation. However, there needs also be con-
sideration of patient factors and other aspects.
Perhaps surgeons have been too obsessed with
strengthening of sutures in the last decades, and
increasing the foreign-body suture material within
the tendon may even be deleterious.80 Research
needs to continue more widely, in both the labora-
tory and clinical environment, until better ways of
modifying adhesion of the tendon are found.

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