Innovative trends in flexor tendon repair using the first annular pulley as a graft for pulley reconstruction
Gilberto O'Hara, MD*, Osvandré Lech, MD†, and Antônio Severo, MD†

Flexor tendon laceration in zone II remains a difficult problem for the hand surgeon. Pulley reconstruction is essential for the accurate gliding mechanism of the repaired tendon. We present new options for the reconstruction of the A2 pulley using the A1 pulley as a graft. The A1 pulley can be dissected at the volar plate of the metacarpophalangeal joint, obtaining one or two segments approximately 5 mm long to be used as a graft. There are different techniques for harvesting the pulley graft, such as the tubular, open, slide, and strip techniques.

Much of the current literature regarding flexor tendon injury has centered around repair techniques [1,2,3,4] and postoperative management [5,6,7,8]. Although these have aided in the management of tendon injury acutely, one area that has not received much attention is management of chronic flexor tendon injuries [9,10,11,12,13,14,15,16,17,18,19].

Chronic flexor tendon rupture/laceration/adhesion in Zone II have proven to be a formidable challenge for hand surgeons because of the necessity to reconstruct the lacerated or adherent flexor tendons and the pulley system simultaneously.

Doyle and Blythe [20] showed that the A2 and A4 pulleys are essential and necessary for complete excursion of the profundus flexor tendon in the digits. Bennell et al. [11], Kleiner and Bennett [11], Wray and Weeks [19], Bader et al. [9], and Lister [12], among several others, use different techniques and materials to reconstruct the A2 and A4 pulleys; however, each one of these techniques has shown advantages and disadvantages.

Ohara [16] demonstrated by anatomic studies that is possible to obtain a tubular segment of the undamaged A1 pulley. Thus, it can be used as a pulley graft to provide repair of another damaged pulley (A2 or A4).

The purpose of this article is to present the surgical technique and to verify the feasibility of using an A1 pulley graft for treatment of chronic flexor tendon lesions in the Zone II of the hand with destruction of the pulley system.

Technique
The A1 pulley is a 20-mm fibrous tunnel structure that maintains the flexor tendon in contact with the underlying skeletal architecture. It can be carefully dissected at the volar plate of the metacarpophalangeal joint, obtaining one or two segments of approximately 5 mm long that can then be used as a graft.

The reconstruction of the A2 and A4 pulleys using A1 pulley as a donor graft can be done by four different methods—tubular, open, slide, and strip. They can be positioned and sutured to the remaining soft tissue at the desired place to reconstruct the A2 pulley, A4 pulley, or both.
The clinical status of the damaged flexor tendons (intact but adherent, profundus and/or superficialis rupture, absent) and pulley system (intact but adherent, partially destroyed, absent) determines which model should be used. When the A1 pulley of the finger to be repaired is also damaged, it is possible to obtain it from the adjacent, undamaged finger using the same techniques. The greatest advantage of this technique is that both procedures (tendon and pulley system reconstruction) can be done at the same time.

**Tubular graft**

In the chronic ruptured flexor tendon lesion with A2 or A4 pulley destruction, when the A1 pulley is preserved, one or two 5-mm-long tubular segments can be obtained. Then it is positioned and fixed to the remaining soft tissue bed of the damaged A2 or A4 pulley. After that, the profundus flexor tendon or a tendon graft is passed through the inner part of the new pulley system and repaired (Figs. 1 and 2).

**Open graft**

When the flexor tendon is not ruptured, a graft from the A1 pulley can be obtained by dividing it longitudinally and harvesting. Then the graft is placed in the desired A2 or A4 position, sutured back to recover its tubular structure, and fixed to the remaining soft tissue bed of the damaged pulley system (Figs. 3 and 4).

**Slide graft**

When fibrous adhesions of an undamaged or repaired flexor tendon limit tendon excursion and hence active motion and the A2 or A4 pulley is damaged, a primary tenolysis is performed first; then, a tubular graft of the A1 pulley is dissected and detached, sliding it to the desired location. Again, it is sutured to the remaining soft tissue of damaged pulleys (Fig. 5).
Fig. 4. Open graft type. A, A1 pulley graft is incised longitudinally to be harvested. B, Inferior view of the inner part of the open graft type. C, At the desired A2 or A4 place, the graft covers the flexor tendon and is sutured back, recovering its tubular format. The graft is then turned around to keep the dissected plane in contact with the bone surface.

Fig. 5. Side graft type.

Fig. 6. A, Strip graft type. B, The upper part of A1 pulley (dotted lines) can be used as a strip graft.
Table 1

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Sex</th>
<th>Digit</th>
<th>Surgical Procedure</th>
<th>Result at 4–6 mo. (grip - palm distance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 HO</td>
<td>23</td>
<td>F</td>
<td>Index</td>
<td>FDS/FPD tenolysis, two slip grafts to A2/A4</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>2 MO</td>
<td>37</td>
<td>F</td>
<td>Small</td>
<td>FDP tenolysis, tubular graft to A4</td>
<td>3.0 cm</td>
</tr>
<tr>
<td>3 MAN</td>
<td>29</td>
<td>F</td>
<td>Index</td>
<td>Tendon graft to FDP, tubular graft to A2</td>
<td>2.0 cm</td>
</tr>
<tr>
<td>4 AMY</td>
<td>42</td>
<td>F</td>
<td>Index/middle</td>
<td>FDP Tenolysis, two tubular grafts to A2/A4</td>
<td>3.0 cm/index 2.5 cm middle</td>
</tr>
<tr>
<td>5 ACM</td>
<td>41</td>
<td>M</td>
<td>Ring</td>
<td>FDS/FPD tenolysis, open graft to A4</td>
<td>Contact</td>
</tr>
<tr>
<td>6 WS</td>
<td>27</td>
<td>F</td>
<td>Index</td>
<td>Tendon graft to FDP, two open grafts (from the middle) to A2/A4 of the index</td>
<td>4.0 cm</td>
</tr>
<tr>
<td>7 ENF</td>
<td>35</td>
<td>M</td>
<td>Middle</td>
<td>FDP tenolysis, strip graft to A4</td>
<td>2.5 cm</td>
</tr>
<tr>
<td>8 EHA</td>
<td>58</td>
<td>M</td>
<td>Index</td>
<td>Tendon graft to FDP, two strip grafts to A2/A4</td>
<td>5.0 cm</td>
</tr>
</tbody>
</table>

Strip graft
When the floor of the A2 or A4 pulley is preserved, a strip of 5 mm to 7 mm of the upper part of the A1 pulley is obtained and sutured to the remaining portion of the damaged pulley, restoring the needed retinacular tunnel. This technique is most applicable for pulley reconstruction in a pediatric hand because of technical difficulties of obtaining a tubular graft at this age (Fig. 6).

Material and methods
This technique has been used in eight clinical cases described later in this preliminary report. All patients were involved in the same postoperative rehabilitation program, which consisted of 2 weeks of immobilization followed by a dynamic Kleinert splinting program; active motion was started at the fourth or fifth week. Several variables influenced the final clinical results: the type of lesion according to Boyes [1], the elapsed time since the injury; the use of tendon graft; joint stiffness; and contractures. All patients are listed in the Table 1.

Although total active motion as limited in many patients, active tendon excursion without “bowstringing” was demonstrated in all cases and represented a significant improvement over the preoperative state of no excursion. Patient satisfaction was high, and no incidence of donor site morbidity occurred.

Discussion
Reconstruction of the essential pulleys (A2 and A4) using the technique described here has proven to be a good option in the hand surgeon armamentarium [16,17]. Because of its versatility, the surgeon is able to choose among four different, easily accessible graft types (i.e., tubular, open, slide, and strip graft), according to the specific damage to the flexor system (tendon and pulley).

Another important aspect is that the pulley replacement is performed by a similar tissue, not by the palmaris longus, superficialis tendon, or another material that can lead to further adherence.

It has been the authors’ experience that when one chooses the A1 pulley as a graft, either from the injured or the adjacent, undamaged digit, he or she can feel comfortable that minimal functional impairment at the donor site area will occur. The series presented is still small but promising. With a longer follow-up, a better understanding of the new technique will be possible.

Conclusions
The authors present a technique for reconstruction of the A2 and A4 pulleys of the hand using the A1 pulley as a graft. Four models are described—tubular, open, slide, and strip. They can be chosen according to the clinical situation found at the time of the exploratory surgery.

References and recommended reading
Papers of particular interest, published within the annual period of review, have been highlighted as:
- Of special interest
- Of outstanding interest


To determine the loss of tensile strength with varying degrees of partial laceration, tensile tests were performed on two matched groups of human cadaver flexor tendons. One group had 50%, whereas the other had 75% transverse laceration of the long flexor tendon. The mean failure load of the 50% lacerated tendons was 9.6% higher than that of the 75% lacerated tendons. The study demonstrates that the threshold load levels to rupture of 90% and 75% lacerations are higher than physiological load levels measured during active motion, suggesting that partial flexor tendon lacerations of up to 75% can withstand in two forces associated with active, uninterrupted mobilization of the digital flexor tendon.


Zone II is historically the most challenging one for the surgeon attempting repair, largely owing to the high propensity of scarring between the pulleys in this area, which can lead to a compromised result after primary repair. They state that better clinical results are obtained when both flexor digitorum sublimis and flexor digitorum profundus are repaired compared with only flexor digitorum profundus was repaired. Based on the available clinical information and most recent laboratory studies, surgical repair should be carried out on partial tendon lacerations of 60% or more, and tendons with less than 30% laceration should not be repaired. They state that the Tsaia modification of the Kessler “gripping core suture” is superior in strength to a horizontal mattress suture technique for repair for zone II flexor digitorum sublimis tendon injuries.

Two new suture methods, double and triple (modified) Kessler, were compared with the Savage, Indiana and modified Kessler techniques. All were core suturing without epidermal sutures. The study found the Savage technique strongest, followed by the triple Kessler, then the double Kessler, and finally the Indiana. The double Kessler was almost twice as strong as the modified Kessler. This study also compared two four-stranded techniques (the Indiana and double Kessler) and found the double Kessler stronger. The double Kessler is a simple yet strong suturing method and may be useful for flexor tendon repairs.


The authors compared the outcome of 17 partially lacerated (less than 75% of cross-sectional area) flexor tendon in zones II and III in children treated by surgical repair to that of 19 tendon lacerations treated conservatively by early mobilization. Magnetic resonance imaging, a noninvasive method of diagnosis, could be used in cooperation with children in whom there was doubt about the size of the tear, thereby avoiding unnecessary surgical exploration. The outcome of both groups was similarly favorable. No complications such as triggering or complete tendon tear were observed in either group. They suggested that mobilization in children in whom a partial division of flexor tendon is diagnosed clinically. Exploration should be carried out only in doubtful cases to exclude complete division of the tendon.


The purpose of this experimental study was to evaluate the mechanical and histologic healing of flexor tendon repairs in the early postoperative mobilization. The authors report the results of nine two-stage tendon reconstructions using the palmaris longus tendon graft inserted into a tunnel that had been previously created by a silicone spacer. Early active motion was commenced 46 weeks after surgery according to a previously described protocol. All patients were seen at a minimum of 3 months, and the results were evaluated using the modified Quick score system. Comparing the results of the modified Quick score criteria with other scores, the authors found that the active motion results were influenced by the method of tendon fixation. They believe that the distal and proximal junctions in the tendon graft can withstand the forces involved in early mobilization without resistance. The advantage of mobilization in preventing adhesions of the tendon apply equally to tendon grafts and primary tendon repair, and no benefit is obtained from immobilizing digits after tendon grafting.


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The authors report their results in a study proposed to determine the range of motion of the flexor tendons in zone V and to compare the range of motion between active (Bellot's) and passive (modified Duran's) flexor mobilization regimes postoperatively. The measurement was done in two cadavers and two patients at four different times: preoperatively and at the 10th, 21st, and 45th postoperative days. The results demonstrated an increased excursion of the repaired flexor tendons in zone V following an active flexor mobilization regime as compared to the passive one.


This paper describes a new method of reconstruction of the pulley system of the thumb using the extensor retinaculum. It also mentions the use of silicone pulleys and underlays in tendon surgery.


The authors reviewed retrospectively the clinical outcome of flexor tendon grafting in 15 patients with isolated flexor digitorum profundus rupture. The mean follow-up was 31.3 months. All patients achieved active distal interphalangeal joint flexion greater than 30°, and four patients (26%) had greater than 40°. Total active motion ranged from 145° to 280° (mean 180.2°), which accounted for 86% to 100% (mean 98.9%) of the normal total active motion. According to the criteria of Stark et al., 12 patients (80%) had satisfactory results, and 3 had unsatisfactory outcomes. Flexor tendon grafting in the management of an isolated rupture of the flexor digitorum profundus should be performed in properly selected patients and, with full passive motion of all joints, minimal scarring of the finger, and normal function without these criteria, flexor digitorum profundus tendons or distal interphalangeal joint fusion should be considered.