Surgical Outcome of One-stage and Two-stage Flexor Tendon Grafting in Children

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Background: Flexor tendon grafting represents the most common modality for secondary restoration of flexor tendon function. Tendon grafting is either performed in 1 or 2 stages. This study attempts to evaluate the clinical outcome of 1-stage and 2-stage grafting in children.

Methods: A retrospective review was performed identifying 20 children treated for secondary rupture of the flexor digitorum longus by means of a tendon graft. There were 17 boys and 3 girls with a mean age of 10.8 years (range: 3 to 15) at the time of surgery. The preoperative condition of each operated finger was graded by the digital damage classification recommended by Merle and Dautel. Functional status was obtained throughout follow-up using the Strickland classification.

Results: There were 10 children in grade 1, 6 grade 2, and 4 grade 3 according to Merle and Dautel classification. The delay between the initial trauma or primary procedure and the secondary surgical procedure averaged 7.5 months for 1-stage grafting and 9 months for 2-stage grafting (range: 1 mo to 2 y). The median Strickland index was 70 (range: 55 to 114) for 1-stage grafting and 66 (range 0 to 103) for 2-stage grafting, which was not statistically different ($P=0.1$).

Conclusions: The functional outcome seems to depend on the initial severity index. One-stage grafting is a relevant procedure when pulleys are intact and the range of motion is complete. When neurovascular bundles are injured a 1-stage grafting should not be tempted. Satisfactory results are expected with 2-stage grafting providing the principles of this procedure are carefully adhered to.

Level of evidence: Level 4.

Key Words: flexor tendon injury, secondary repair, 1-stage grafting, 2-stage grafting, children

(*J Pediatr Orthop* 2009;29:792–796)

Flexor tendons injuries in children are associated with a higher risk of delayed diagnosis.[1] Lack of technical expertize and inability of young children to cooperate with conventional rehabilitation contribute to secondary rupture.[2] Flexor tendon grafting represents the most common modality to secondary restoration of flexor tendon function when a primary suture is impossible. Tendon grafting is performed in either 1 or 2 stages. One-stage grafting is indicated when no extensive laceration and contracture of the digit are present whereas 2-stage grafting is a salvage procedure also indicated in severe digital injuries.[3] For both secondary repair procedures a high failure and complication rate is reported in pediatric series.[2,4,5] Guidelines remain unclear on when 1-stage or 2-stage grafting should be performed.[3] The 2-stage procedure could be the unique response for secondary repair of every type of flexor tendon injuries. However, 2-stage grafting is a longer procedure, and technically more demanding. A more eclectic strategy should be attempted, which would lead to performing either a 1-stage or a 2-stage grafting considering the structures involved and the contracture of the digit. In our experience, 1-stage grafting is performed when pulleys (A2 and A4) are intact and when the range of passive motion of the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joint is equivalent to the contralateral side. We report the retrospective results of 1-stage and 2-stage tendon grafting in secondary repair of the flexor tendons in a pediatric population based on this statement.

METHODS

A retrospective review was performed identifying 20 children treated for secondary rupture of the flexor digitorum profondus by means of a tendon graft. There were 17 boys and 3 girls with a mean age of 10.8 years (range: 3 to 15) at the time of surgery. Eight patients underwent 1-stage grafting and 12 patients underwent 2-stage grafting (Table 3). The mean follow-up was 2 years and 11 months (range: 5 months to 8 years and 4 months).

Clinical history was extracted from the files. The mechanism of injury was glass laceration in 6 cases, knife laceration in 5 cases, lawnmower complex laceration in 1 case, animal bite in 3 cases, and Jersey finger-type lesion in 5 cases. The fingers involved were the thumb in 5 cases, the index finger in 3 cases, the middle finger in 2 cases, the ring finger in 6 cases, and the little finger in 4 cases. Primary lesions were located in zone 1 in 10 cases, in zone 2 in 5 cases, in zone T2 in 3 cases, and zone T3 in 2 cases according to the International Federation for Societies for Surgery of the Hand classification (Fig. 1). Thirteen patients underwent primary repair of the FDP [or flexor

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Each author certifies that he or she has no commercial associations that might pose a conflict of interest in connection with the submitted article.

None of the authors received financial support for this study.

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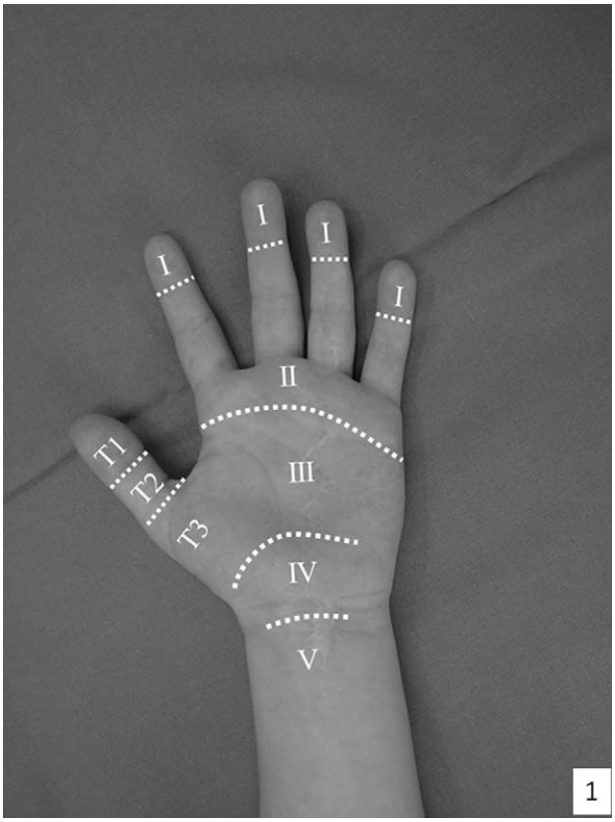

FIGURE 1. International Federation for Societies for Surgery of the Hand classification for flexor tendon injuries location.

pollicis longus (FPL) in 5 cases] with flexor digitorum superficialis sacrifice in 1 case. Five patients had neglected wounds and delayed repair. Two patients required tendon grafting during primary repair.

Functional status was obtained throughout follow-up using the Strickland classification (Table 1). The Strickland index was calculated using the following formula:

$$(\text{PIP} + \text{DIP active flexion} - \text{PIP}+$$

$$\text{DIP extension deficit} \times 100)/175$$

where PIP is proximal interphalangeal joint; DIP is distal interphalangeal joint.

TABLE 1. Strickland Classification of Functional Status

Strickland Classification		
Group	**ROM**	**Mobility (%)**
Excellent	> 150 degrees	85-100
Good	125-149 degrees	70-84
Fair	90-124 degrees	50-69
Poor	< 90 degrees	< 50

ROM indicates range of motion.

TABLE 2. Merle and Dautel Classification of Digital Damage

Grade 1	Moderate scared digit without neurovascular injury
Grade 2	Severe scared digit with or without Pulley injury Joint contracture One neurovascular bundle is intact
Grade 3	Severe scared digit with injury of both neurovascular bundles and/or a main vascular axis of the hand

Surgical Technique

Under general anesthesia and tourniquet control, a Brunner palmar incision was used to expose the tendon sheath. The condition of the local tissue was classified using the 3 stages of the Merle and Dautel classification[6] (Table 2), which takes into consideration the state of vascularity of the tissues. For Merle, incorporation of the tendon graft is dependent on the neurovascular status of the digit, which determines the quality of the recurrent scar formation. Evaluation of the integrity of pulleys A2 and A4 determined the indication for grafting.

One-stage grafting was carried out for grade 1 of Merle and Dautel classification when the pulley system is intact and the passive mobility of the PIP and DIP joints is complete. For both 1-stage and 2-stage procedures we used the palmaris longus tendon in 15 cases and the plantaris in 5 cases. The tendon was sutured proximally with a Pulvertaft knot to the proximal stump of the injured tendon after resection of its distal fibrous end. The graft was then sutured to a silicon rod, which was used as a guide in the digital canal. The graft distal end was externally fixed to the fingernail. Pretension of the graft was clinically appreciated. The clinical aspect of the hand should be harmonious in passive flexion and extension of the wrist.

Scarring within the flexor sheath was associated with excessive pulley system damage and PIP and DIP joint contractures mandated 2-stage tendon grafting. These situations corresponded to grades 2 and 3. The 2-stage grafting technique was similar to that described by Hunter and Salisbury[5,7] and later by Valenti and Gilbert.[2] In these severe cases reconstruction of the digital canal included the A2 and A4 pulleys as a minimum. However, pulleys A1 and A3 should also be reconstructed if the local environment is favorable. A2 and A4 pulleys were reconstructed using a strip from the tendon of the flexor digitorum superficialis passed through the edges of the remaining pulleys. No dilatation of the pulleys was attempted.

Once the digital canal reconstruction was achieved, a silicon rod was inserted into the digital canal from the most proximal pulley to the most distal pulleys, anchored distally between the palmar plate of the distal phalanx and the stump of the FDP with a U shape suture. We used the universal conformable tendon rod, Universal Tendon Spacer, developed by AREX (Palaiseau, France). The size of the pseudosheath developed during the first

TABLE 3. Clinical Assessment of Preoperative Injury Severity Using Merle and Dautel Classification

Case	Finger	Zone	Age at Surgery	Merle	Strickland Index	Strickland	Reconstruction
1	5	1	6	1	77	Good	One-stage
2	4	1	15	1	114	Excellent	One-stage
3	1	T2	15	1	97	Excellent	One-stage
4	4	2	8	2	49	Poor	One-stage
5	4	1	13	1	57	Fair	One-stage
6	3	1	15	1	63	Fair	One-stage
7	4	1	8	1	55	Fair	One-stage
8	1	T3	11	1	55	Fair	One-stage
9	3	1	4	2	80	Good	Two-stage
10	1	T3	3	1	86	Excellent	Two-stage
11	2	2	10	1	86	Excellent	Two-stage
12	4	1	11	2	103	Excellent	Two-stage
13	4	1	4	2	89	Excellent	Two-stage
14	5	2	3	2	0	Poor	Two-stage
15	1	T2	15	3	66	Fair	Two-stage
16	1	T2	14	2	51	Fair	Two-stage
17	5	2	5	3	51	Fair	Two-stage
18	2	2	13	1	69	Fair	Two-stage
19	5	1	2	3	63	Fair	Two-stage
20	2	1	12	2	51	Fair	Two-stage

Functional status obtained at last follow-up using Strickland classification.

stage depends on the size of the implant. The design of this device helps to restore the maximum anatomical space allowed by the digital canal.

The average time from the Hunter implant insertion to tendon grafting was 2 months (range: 1 to 2.5). During the second stage, only 2 small incisions were carried out—one proximally, to catch the proximal end of the silicon rod and one distally to remove its distal fixation. The tendon graft was sutured to the proximal end of the silicon rod, which was pulled out from the distal incision to bring the graft into its final position without opening the digital canal. The graft was sutured proximally to the distal stump of the injured flexor tendon with a Pulvertaft knot and distally anchored to the flexor distal stump or with a Brunelli-like fixation onto the nail.

Postoperative Care

An identical rehabilitation protocol was performed for both of the grafting procedures. Immobilization was performed with a dorsal above the elbow plaster splint for 1 month. The position of the wrist was 30 degrees of flexion and the interphalangeal joints 90 degrees of flexion. Protected passive motion exercises were started early.

Over 4 years, the rehabilitation modalities were based on protected active motion exercises described by Strickland,[8] which involves active rehabilitation of the graft of the profundus tendon, but which gives the patient a good perception of the forces he is applying to the graft.

With the elbow flexed and forearm in pronation, the sequence of exercises started with

1. Complete passive flexion of the fingers, then the position was held passively.
2. Progressive extension of the wrist up to a maximum of 30 degrees, then held for 5 seconds.
3. The wrist and the fingers were finally simultaneously relaxed using the tenodesis effect.

These exercises were repeated 10 times twice a day during the first 4 days after surgery and then 4 times a day.

Six weeks after surgery soft active flexion exercises were started. Resistance exercises were started 3 months after surgery.

A PIP extension splint with metacarpophalangeal joints with 90 degrees of flexion was necessary after the first month to avoid flexion contracture of the PIP joints.

Statistical Comparison

All statistical comparisons were performed using a Mann-Whitney test.

RESULTS

The secondary rupture location was classified as recommended by International Federation for Societies for Surgery of the Hand. Ruptures were located in zone 1 in 10 cases, in zone 2 in 5 cases, in zone T2 in 3 cases, and zone T3 in 2 cases. There were 10 children in grade 1, 6 grade 2, and 4 in grade 3 according to the Merle and Dautel classification.

The delay between the initial trauma or primary procedure and the secondary surgical procedure averaged 7.5 months for 1-stage grafting and 9 months for 2-stage grafting (range: 1 mo to 2 y), which is not statistically different ($P = 0.4$). The mean rehabilitation time (time between secondary repair and the end of rehabilitation) was 8 months (range: 4 to 24) for 1-stage grafting and 13 months (range: 6 to 36) for 2-stage grafting. No infections were encountered. Two patients needed a tenolysis (cases 4 and 17) and 1 patient needed a PIP joint arthrodesis (case 14). The functional status at last follow-up for each

patient is summarized in Table 3. The median Strickland index was 70 (range: 0 to 103) for 1-stage grafting and 66 (range: 55 to 114) for 2-stage grafting. Considering secondary repair of the flexor pollicis longus (FPL), the mean Strickland index was 71 (range: 51 to 97) and for secondary repair of FDP, the mean Strickland index was 67 (range: 0 to 114). No significant difference was observed between medians of age at surgery ($P=1$), Strickland index ($P=0.1$) of the groups treated with 1 or 2-stage grafting and Strickland index of the FDP and FPL group ($P=0.8$).

DISCUSSION

Our series is, at many points, comparable with the earlier published series in the literature. Ages of patients at surgery and injury circumstances are similar.[2,4,9,10] Despite the different systems of classification used in the literature, our findings are equivalent to the pediatric series reported earlier involving 1-stage or 2-stage grafting independently.[4,9,11]

A high rate of failure and complication is reported in the pediatric series either for 1-stage grafting[4,12] than for 2-stage grafting.[2,9] Two-stage grafting is the gold standard procedure for severely scarred digits, but in these circumstances there is no alternative option for reconstruction. Two-stage grafting is also likely to provide good results in moderate injuries. The main issue is to assess intraoperatively, whether a 1-stage graft would be indicated or whether 2-stage grafting is necessary.

Two-stage flexor tendon reconstruction is a complicated surgical procedure for severely scarred digits. It was therefore predictable to find poor results for 2-stage flexor tendon reconstruction in both the adult and pediatric series reported in the literature.[2,5,9,12] However, secondary flexor tendon surgery provides worse clinical results for an equivalent lesion in children than in adults.[9] Several investigators maintain that age under 6 years is associated with worse results than in older patients.[2,9] For these investigators, immaturity and lack of understanding may account for rehabilitation failure. In our series, the age of patients was very variable. Patients below 4 years of age obtained fair-to-good results, which does not support the previous statement. But the number of young patients is too small to be conclusive. In our opinion, the age was not a confounding factor in the overall results.

One-stage grafting was performed for grade 1 injuries when the primary suture was impossible because of delayed diagnosis and tendon retraction. The only poor result was obtained for a grade 2 patient with joint contracture but intact pulley system. In this case, a 2-stage grafting would have been a better option. Three cases of grade 1 underwent a 2-stage grafting procedure with 2 excellent and 1 fair result. In these cases a 1-stage procedure was indicated and would have probably achieved similar results. The influence of preoperative injury severity has been clearly shown.[2,6,13] Interestingly, the primary surgical procedure poorly influenced the type of secondary repair. Despite reconstructions of the digits achieved during the primary procedure, digits graded 2 or 3 initially underwent 2-stage grafting during the secondary procedure. Adhesions that are related to the initial severity led to contracture. A 2-stage procedure was therefore necessary, the first stage being tenolysis. This statement points out the essential place of postoperative passive mobilization.

Two-stage grafting may achieve fair-to-excellent results in grade 2 and even grade 3 injuries providing the objectives of the 2 stages are achieved. At the end of the first stage, the digital canal should be reconstructed over a silicon rod, which should glide freely in the entire range of motion of the digit.

Between the 2 patients who achieved poor results, one had a flexor tenolysis (case 4) and 1 a PIP joint arthrodesis (case 14). Birnie and Idler[14] have reported a significant improvement in active flexion after flexor tenolysis only in children more than 11 years old. A fair result was obtained after a flexor tenolysis in case 4 at the age of 10 years, 2 years after a secondary reconstruction with 1-stage grafting. The 2 tenolyses were performed when insufficient progression of active and passive motion was achieved.

In this series, the clinical outcome of 1-stage and 2-stage grafting was equivalent in terms of functional status to earlier reported series. Moreover, no statistical difference was observed between secondary repair of the FPL and FDP. The number of patients was, however, very small in the 2 groups. Some important points have, however, been raised. The severity grading of the initial injury seems to be the most determinant factor for functional outcome.[2,5,9] Age was not a detrimental parameter of clinical outcome in our study, which supports Hollwarth and Haberlik[4] findings.

In our opinion, 1-stage grafting is a relevant procedure when pulleys are intact and the range of motion is complete. In all other cases (grades 2 and 3), when neurovascular bundles are injured 1-stage grafting should not be tempted. In these conditions, satisfactory results are expected with 2-stage grafting provided that the principles of this procedure are carefully adhered to.

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