Single-stage Reconstruction of Elbow Flexion Associated with Massive Soft-Tissue Defect Using the Latissimus Dorsi Muscle Bipolar Rotational Transfer

Milan V. Stevanovic, MD*
Vanessa G. Cuéllar, MD*
Alidad Ghiassi, MD*
Frances Sharpe, MD*†

Introduction: In the upper extremity, the latissimus dorsi muscle can be used as an ipsilateral rotational muscle flap for soft-tissue coverage or functional reconstruction of arm and elbow. Patients who have both major soft-tissue loss and functional deficits can be successfully treated with a single-stage functional latissimus dorsi rotational muscle transfer that provides simultaneous soft-tissue coverage and functional reconstruction.

Methods: Our data base was queried for all patients undergoing a rotational latissimus dorsi muscle transfer for simultaneous soft-tissue coverage and functional reconstruction of elbow flexion. Four patients were identified. A chart review documented the mechanism of injury, associated injuries, soft-tissue defect size, number of surgical procedures, length of follow-up, last elbow range of motion, and flexion strength.

Results: Four patients with loss of elbow flexion due to traumatic loss of the anterior compartment muscles and the overlying soft tissue underwent simultaneous soft-tissue coverage and elbow flexorplasty using the ipsilateral latissimus dorsi as a bipolar muscle rotational tissue transfer. All flaps survived and had a recovery of Medical Research Council Grade 4/5 elbow flexion strength. No additional procedures were required for elbow flexion. The surgical technique is described and supplemented with surgical technique video and patient outcome.

Conclusions: This patient series augments the data provided in other series supporting the safety and efficacy of this procedure which provides both soft-tissue coverage and functional restoration of elbow flexion as a single-stage procedure in the setting of massive traumatic soft-tissue loss of the arm. *(Plast Reconstr Surg Glob Open 2016;4:e1066; doi: 10.1097/GOX.0000000000001066; Published online 28 September 2016.)*

L oss of elbow flexion reduces one's ability to position the hand in space affecting activities of daily living such as feeding, dressing, and perineal hygiene. With normal shoulder function, approximately 120 degrees of elbow flexion is required for placing the hand to the mouth and approximately 75 degrees for placing the hand to the perineum.[1,2] Several options exist for reconstruction of elbow flexion, which include nerve transfer, Steindler flexorplasty, triceps tendon transfer, pectoralis major transfer, latissimus dorsi muscle transfer, and functional free-muscle transfer. In the setting of soft-tissue loss in combination with loss of elbow flexion, the bipolar latissimus dorsi rotational transfer provides a single-stage option to address both deficits.

The versatility of the latissimus dorsi muscle for soft-tissue and functional reconstruction is well described. As a free-tissue transfer for soft-tissue coverage, it has numerous applications throughout the upper and lower extremities, chest wall, and abdomen. As a rotational transfer for soft-tissue coverage, it can be used for soft-tissue coverage of the arm and elbow, spine, neck, and chest wall.[3–7] Functional reconstruction in the upper extremity using the latissimus dorsi has been reported as both rotational and

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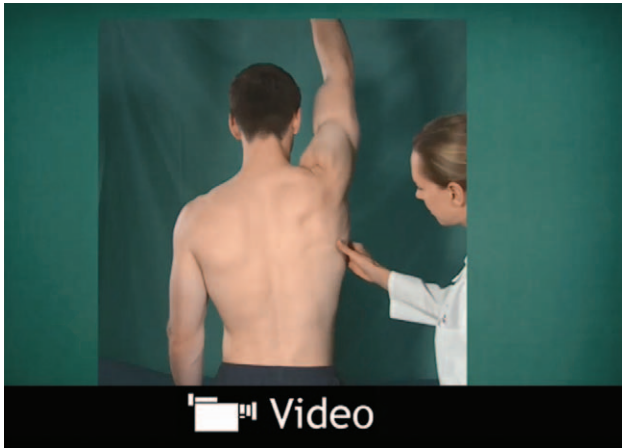
Video Graphic 1. See video, Supplemental Digital Content 1, which displays the physical examination of latissimus dorsi muscle. This video is available in the related videos section of the full text article on PRSGlobalOpen.com or available at ***http://links.lww.com/PRSGO/A267***.

functional free-muscle transfer. Both techniques provide the added benefit of supplying functional reconstruction in combination with soft-tissue coverage.

The application of the latissimus dorsi as a bipolar muscle transfer to restore elbow flexion was first described by Schottstaedt et al[8] in 1955 for a patient with poliomyelitis. Subsequent clinical reports have documented the use of the latissimus dorsi muscle transfer in patients with loss of elbow flexion due to poliomyelitis, brachial plexus injuries, congenital absence of elbow flexors, and traumatic or posttraumatic loss of the anterior compartment of the arm. Most studies include patients with a mixture of diagnoses for which the transfer is being performed and only a few of which include a combined functional and soft-tissue defect.[9–20]

Preoperative assessment of the latissimus dorsi muscle function is emphasized by several authors.[11,21,22] Preoperative evaluation is more important when the latissimus may have been affected by the same condition that has caused the loss of upper extremity function, such as brachial plexus injury or shoulder girdle trauma, or congenital weakness

or deficiency as may occur in arthrogryposis. Isolated testing of latissimus dorsi function is not routinely performed during clinical examination and the technique of evaluating this muscle may not be familiar to many clinicians. (**See video**, **Supplemental Digital Content 1**, which demonstrates the physical examination of the latissimus dorsi muscle. This video is available in the related videos section of the full text article on PRSGlobalOpen.com or available at ***http://links.lww.com/PRSGO/A267***.)

The unique use of the latissimus dorsi muscle transfer—both to address a soft-tissue defect and to restore elbow flexion or extension simultaneously—has been described only in small case reports of patients.[15,23–26] This article adds to the literature on combined biceps reconstruction in combination with soft-tissue coverage and supplements the literature with video technique of the clinical examination of the latissimus dorsi, the critical portions of the surgical procedure, and illustrative case outcome.

METHODS

Approval for this study was obtained from our institutional review board. Our database was queried from 2010 to 2015 for all patients undergoing a rotational latissimus dorsi muscle transfer for simultaneous soft-tissue coverage and functional reconstruction of elbow flexion. Four patients were identified. A chart review documented the mechanism of injury, associated injuries, soft-tissue defect size, number of surgical procedures, length of follow-up, last elbow range of motion, and flexion strength. Preoperative examination of the latissimus was conducted using one or several of the techniques described in Table 1, Figure 1, and the video supplement. (**See video**, **Supplemental Digital Content 1**, which demonstrates the physical examination of the latissimus dorsi muscle. This video is available in the related videos section of the full text article on PRSGlobalOpen.com or available at ***http://links.lww.com/PRSGO/A267***.)

Surgical Technique

All surgical sites had at least one prior surgery to debride devitalized tissue and to treat associated injuries. At the time of muscle transfer, a repeat debridement was

Table 1. Examination Techniques for Latissimus Dorsi Function

Patient Position	Examination
Standing	Arm is held at the side in internal rotation
	Elbow is in extension (limits the contribution of the triceps)
	Patient attempts to adduct the shoulder against the examiner's resistance
Standing	Arm is at the side in neutral rotation
	Elbow is in extension
	Patient is asked to extend the shoulder against the examiner's resistance
Seated or standing	Patient is asked to cough as the examiner palpates for latissimus contraction
Seated or standing "body-builder pose" (Fig. 1)	Bilateral hands are placed on the iliac crests
	Elbows are brought in line with the body bringing shoulders into internal rotation
	Hands are pushed against the body toward midline
Seated	Patient is asked to push him/herself up off of the table
Seated	Arm is in neutral rotation
	Elbow flexed to 90 degrees
	Patient pushes the elbow down against the examiner's hand (shoulder depression)
Lying (contralateral decubitus)	Arm is placed in maximum shoulder forward flexion and abduction.
	The latissimus muscle can be palpated along the chest wall.

Most tests require examiner's hand on latissimus dorsi muscle to palpate for contraction. Muscle contraction may also be visible depending on the patient's habitus and overlying soft tissue. It is useful to use the contralateral side for comparison.

Fig. 1. Body-builder position for physical exam evaluating latissimus dorsi muscle function.
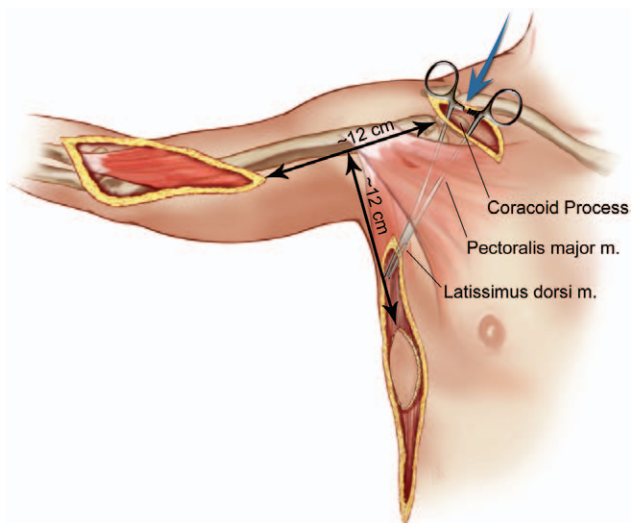

Fig. 2. The apex of the skin paddle for the latissimus harvest is placed approximately equidistant from the arc of rotation of the flap to the apex of the soft tissue defect on the anterior arm.

performed and any additional soft-tissue reconstruction, including nerve grafting was completed. The recipient defect site was extended distally as needed to expose the distal stump of the biceps, into which 2 parallel Krackow nonabsorbable sutures were placed.

The technique for harvesting and transferring the latissimus dorsi has been well described. The following text summarizes our technique with emphasis on specific details critical to this procedure. Surgery was performed with the patient in the lateral decubitus position. The entire lateral side from the ilium to the shoulder girdle and including the affected arm was included in the preparation site. The defect size on the anterior arm and the distance from the

proximal aspect of the wound to the approximate axis of rotation of the flap (roughly the level of the coracoid process) were measured. The skin paddle was planned equidistant of this measurement on the chest wall relative to the flap axis of rotation and was designed to approximately match the area of the anterior soft-tissue defect (Fig. 2).

The skin incision for harvesting the latissimus began in the posterior axillary fold after the course of the latissimus along its midline axis to four-finger-breadths cephalad to the posterior iliac crest, incorporating a skin paddle at the appropriately marked position. The dissection of the latissimus was carried out in the suprafascial plane. The muscle resting length was marked with the arm placed in full forward flexion and abduction. Marking sutures were placed at 5 cm intervals. The muscle was then fully mobilized. The pedicle was dissected and mobilized, dividing the branch to the serratus anterior to gain additional pedicle length and mobility and releasing any fascial bands adjacent to the artery. The tendinous insertion was released from the humerus and two parallel Krackow nonabsorbable sutures were placed in the tendon.

A transverse incision was made over the coracoid, and a subcutaneous tunnel was developed above the axillary fascia connecting the posterior and anterior incisions. Blunt dissection below the pectoralis major tendon was carried out to the coracoid and the tendinous insertion was passed to the coracoid and secured to its neo origin using the preplaced Krackow sutures. The latissimus was then tubularized and passed through the subcutaneous tunnel to the anterior arm, avoiding any kinking of the pedicle.

Muscle resting length was restored with the elbow in full extension, and excess muscle length was trimmed from the caudad origin of the latissimus. The tubularized latissimus was then wrapped around the remaining stump of the biceps tendon and any remaining portion of the musculotendinous junction. It was then secured using the preplaced Krackow sutures. Although resting length was restored with the elbow in extension, the repair was completed with the elbow flexed. Muscle tension was assessed by checking both the restoration of the preplaced marking sutures for muscle resting length and the ability of the transferred muscle to maintain the elbow at 90 degrees of flexion. If the transfer did not maintain the elbow at 90 degrees, then sutures were removed and the muscle was further advanced. The pedicle was checked for any signs of compression or tension as the arm was moved from adduction to abduction. The wounds were closed over drains at the donor and recipient sites.

Postoperatively, patients were kept immobilized in a sling with an abduction pillow for 8–9 weeks. At 4 weeks, the patients were asked to start isometric contraction of the biceps when they are at 90 degrees of elbow flexion. After 9 weeks, the patient began working on regaining extension at a rate of 10–20 degrees per week. Light and progressive strengthening began at 3 months, progressing to unrestricted activity by 6 months. (**See video**, **Supplemental Digital Content 2**, which describes the surgical technique and functional outcome of latissimus dorsi muscle transfer. This video is available in the Related Videos section of the Full Text article on

Video Graphic 2. See video, Supplemental Digital Content 2, which displays the surgical technique and functional outcome of bipolar latissimus dorsi functional muscle transfer to restore elbow flexion. This video is available in the Related Videos section of the Full Text article on PRSGlobalOpen.com or available at ***http://links.lww.com/PRSGO/A268***.

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RESULTS

Four patients were identified who had undergone early simultaneous reconstruction of elbow flexion in combination with soft-tissue reconstruction. The rotational latissimus transfer was performed at an average of 12 days after the initial injury (range: 8–21 days). There were 3 humerus fractures, and 2 were open. There were 2 brachial artery injuries requiring emergent reconstruction. Three patients had nerve contusions. The median nerve was most commonly affected. One patient required median and radial nerve reconstruction (Tables 2 and 3). There were no complications at the recipient site. No patient required additional surgery to advance the latissimus muscle. One patient developed an infected hematoma at the donor site (patient # 3) and required three additional surgeries for irrigation and debridement with later delayed primary wound closure. Case summaries are detailed below.

Patient #1

The patient was a 19-year-old female passenger involved in a motor vehicle accident (MVA). She sustained an open right-humerus fracture with a large anterior soft-tissue defect, consisting of skin, subcutaneous tissue, and the anterior muscle compartment of the arm. Associated injuries included traction neuropraxias to median, radial, and ulnar nerves and a compartment syndrome of the forearm. She was initially treated at an outside hospital with forearm fasciotomy and repeated irrigation and debridement. Upon transfer, she underwent initial debridement and external fixation of the humerus. Three weeks after her injury, a bipolar latissimus dorsi muscle with a skin paddle was used for biceps reconstruction and soft-tissue coverage of the arm. The forearm fasciotomy wound

Table 2. Demographic Details of Patients Included in the Study

Patient Age/Sex	Mechanism of Injury	Diagnosis	Associated Injuries	Defect Size (Final Debridement), cm	No. of Surgeries	Last F/U, mo	Final ROM (F/E)	Final ROM Supination	Flexion Strength (lbs/kg)	Supination Strength
19/F	Passenger MVA	Open humerus biceps + brachialis defect	Forearm compartment syndrome traction neuropraxia median, radial, and ulnar nerves	10×18	4	12	10–130	60	8/3.6	NR
26/F	Dog bite	Soft-tissue loss including biceps/brachialis	Ulna fracture + soft-tissue defect proximal forearm	11×25	2	14	0–137	75	10/4.5	NR
6/M	Passenger MVA	Closed humerus fracture with internal amputation from crush injury of biceps and brachialis	9-cm brachial artery 6-cm median nerve defect 7-cm radial nerve defect	8×7	7	10	0–125	40	0.75/3.6	NR
22/M	GSW	Humerus fracture with anterior compartment loss	6-cm brachial artery defect Median nerve contusion Posterior arm soft-tissue defect	9×15	4	7	20–145	75	10/4.5	NR

F/E, flexion/extension; F/U, follow-up; GSW, gunshot wound; MVA, motor vehicle accident; NR, not reported; ROM, range of motion.

Table 3. Cumulative Comparisons of Similar Patients

	Defect Size, cm²	Elbow Extension, Degrees	Elbow Flexion, Degrees	Supination, Degrees	Flexion Strength, kg
This study (4 patients)	161 (56–275)	7.5 (0–20)	134 (120–145)	62.5 (40–75)	3.4 (0.34–4.5)
Combined series (8 patients)	NR	12 (−5–20)	112 (75–140)	80 (reported in 2 patients)	4 (3.6–4.5) (reported in 4 patients)

NR, not reported.

was partially closed, and the split-thickness skin graft was required at the distal arm and proximal forearm.

Patient #2

A 26-year-old female sustained a dog bite to the left arm and forearm. Her biceps and brachialis muscles were absent over the distal 2/3 of the humerus. She had an associated median nerve contusion and an open ulna fracture. She underwent 2 debridements. Ten days after the initial injury, she underwent a rotational latissimus dorsi muscle transfer for biceps reconstruction. A large skin paddle was harvested to provide soft-tissue coverage over the arm and proximal forearm. Her ulna fracture was stabilized with plate fixation and split thickness skin graft was applied to the forearm wounds.

Patient #3

A 6-year-old boy was a seat-belted passenger in an MVA. He had a closed fracture of the humerus associated with a subtotal internal amputation of the biceps, brachialis, brachial artery, median nerve, and radial nerve, and a contusion of the ulnar nerve. He underwent emergent debridement and vascular reconstruction. The humerus was stabilized with an anterior plate. Two additional debridements were performed. One week after the injury, he underwent a latissimus dorsi rotational transfer for biceps reconstruction and soft-tissue coverage. He had a simultaneous median and radial nerve reconstruction with sural nerve grafts. Ten days after surgery, he developed an infected hematoma at the recipient site requiring 3 debridements with subsequent delayed primary wound closure (Figs. 3–12).

Patient #4

A 22-year-old man sustained a close-range gunshot wound to the right arm. His treatment course is summarized in the video (**See video, Supplemental Digital Content 2**, which describes the surgical technique and functional outcome of latissimus dorsi muscle transfer. This video is available in the Related Videos section of the Full Text article on PRSGlobalOpen.com or available at *http://links.lww.com/PRSGO/A268*.).

DISCUSSION

The use of the latissimus dorsi as local tendon transfer was first described in 1949 to restore elbow extension.[27] The tendinous insertion of the latissimus dorsi was detached from the humerus, mobilized proximally, and reinserted into the triceps. Transposition of the whole muscle as a functional transfer was described by Schottenstaedt et al[8] in 1955. The entire latissimus dorsi muscle was mobilized and new origins and insertions were established to restore elbow flexion in one patient and elbow exten-
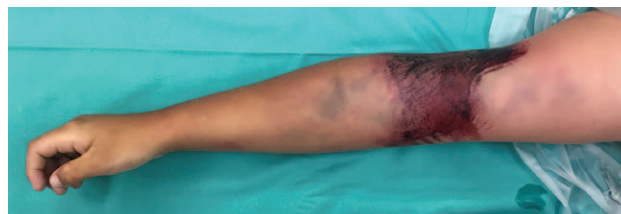

Fig. 3. Appearance of the arm at initial presentation, volar.

Fig. 4. Radiographs of injury and after 6 months.

sion in another. Hovnanian[28] described a similar case as a monopolar transfer in 1956. Since that initial description, the technique received little attention until Zancolli and Mitre[20] reported on a series of 7 patients who underwent a bipolar latissimus dorsi transfer to restore elbow flexion. There have been only few studies that have described the simultaneous use of the latissimus to address soft-tissue loss in combination with restoring flexion.[15,23–25,29]
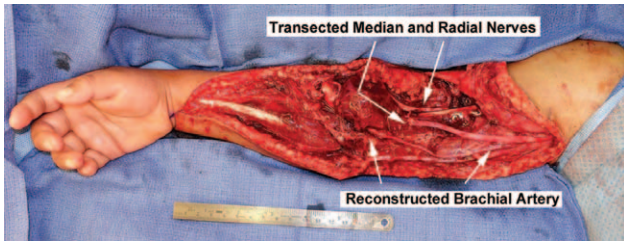
Fig. 5. Appearance of the arm and forearm after revascularization, debridement of nonviable tissue, and forearm fasciotomy. The transected median and radial nerves are evident in the wound. Also noted is the absence of anterior muscle compartment.

Fig. 6. Latissimus dorsi fully mobilized on its pedicle. Pedicle length has been increased by ligation of the branch to the serratus anterior.
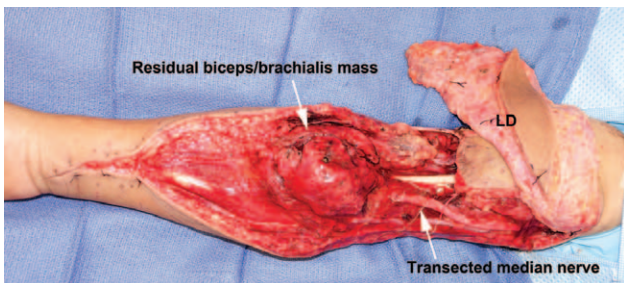

Fig. 7. The latissimus has been transposed into the anterior compartment of the arm. The tendinous insertion has been secured into its new position at the neo origin on the coracoid. Further debridement of the biceps/brachialis mass and nerve reconstruction will be done before insetting the latissimus.

This study reports results in 4 patients who underwent early simultaneous reconstruction of elbow flexion with soft-tissue coverage. Although this is a small series, it represents the largest to date for this dual indication performed acutely as a one-stage procedure. Similar to other studies, our patients achieved comparable range of motion in flexion, extension, and supination (Tables 3 and 4). Our average flexion strength is slightly lower than other case reports, likely due to our 6-year-old patient who was only able to lift 0.75 pounds at his last visit. Table 4 summarizes previous papers reporting outcomes of patients undergoing early simultaneous soft-tissue coverage and biceps reconstruction.
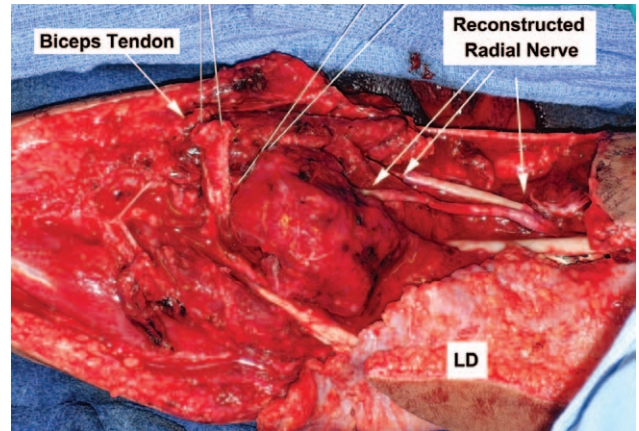

Fig. 8. The nonviable biceps and brachialis have been debrided, leaving only the stump of the biceps tendon. The radial nerve has been reconstructed with sural nerve grafts.
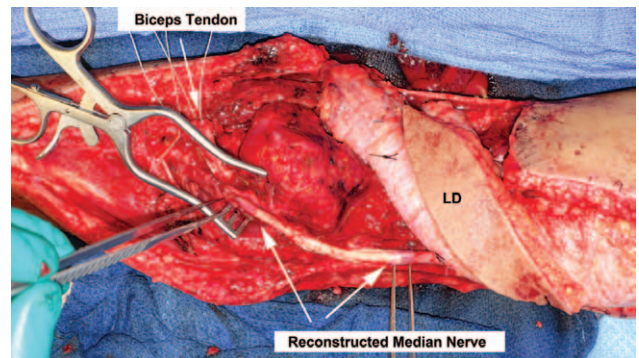

Fig. 9. The median nerve has also been reconstructed with sural nerve graft.

Several authors emphasize the importance of preoperative evaluation of the latissimus dorsi muscle before using this as a transfer as the functional outcome is correlated to the preoperative strength of the latissimus.[11,21,22] It is difficult to isolate the latissimus for strength testing, especially separating latissimus dorsi function from the teres major, which functions in concert with the latissimus dorsi to internally rotate and adduct the humerus. We describe several techniques to examine the latissimus dorsi. In the setting of acute trauma, many of these tests cannot be performed; however, the use of palpation for muscle bulk and contour and having the patient cough when the examiner palpates for muscle contraction are the most useful tools in this setting. The other techniques described provide a more detailed assessment of the muscle which can be conducted in the setting of late trauma, congenital anomalies, and brachial plexus injuries.

There are several points to the surgical technique that we have found important in improving functional outcomes. The inclusion of a skin paddle improves cosmesis, allows for monitoring of the flap, and improves muscle and tendon gliding of the transferred latissimus muscle. Next, the establishment of appropriately placed and secure fixation at the neo origin and neo insertion is important in the biomechanics of the transfer and reducing muscle stretching that

Fig. 10. After insetting, the tension in the transferred latissimus maintains the elbow at 90 degrees of flexion.

Fig. 11. Six-month follow-up demonstrating full elbow extension.

may occur at the sites of attachment. Moving the latissimus insertion from the humerus to the coracoid improves the mechanical advantage of the muscle transfer and may also help stabilize the anterior shoulder when there is weakness about the shoulder girdle.[21] The tensioning of any muscle transfer remains a surgical art rather than an exact science. Both overtensioning and undertensioning of a transferred muscle lead to disturbance of the length–tension curve for muscle force generation.[30] Marking and restoring the muscle resting length helps maintain the appropriate actin–myosin overlap, so as to retain muscle strength in transfer. Slight overtightening of the transfer may help compensate for the anticipated stretching that may occur at the coaptation sites. To this end, the transferred muscle is expected to be able to maintain the elbow at a minimum of 90 degrees of flexion at the completion of the transfer. Finally, our postoperative protocol is slower than that described in other series. It is thought that this may contribute to the patients not requiring additional surgeries to tighten the muscle transfer. The muscular origin of the latissimus dorsi at the thoracodorsal fascia and the frequent need to trim the transferred muscle result in coaptation of latissimus to the stump of the biceps through muscle fibers that do not hold sutures well. For this reason, the repair site is protected for a longer period of time and the rehabilitation is progressed slowly.[21,22,29]

One of the patients developed an infected hematoma at the donor site. In the long term, no patients in this study reported complaints at the donor site. Any deficits

Fig. 12. Six-month follow-up demonstrating elbow flexion. Patient is still wearing a brace for his radial nerve injury.

Table 4. Comparison of Outcomes of Selected Patients with Similar Reconstructive Requirements from Previously Published Studies

Authors	Year	No. of PTS	Mechanism	ROM, Degrees	FL ST	SUP	Comments
Hochberg and Fortes da Silva[24]	1982	1	Electrical burn	"Full" (0–130)	NR	NR	Case report with reported full flexion, but no strength and no discussion of supination
Hirayama[29]	1987	2	Trauma	"Excellent" (criteria of Segal)	ND MRC 4	NR	2 of 6 were reported for trauma. 4/6 BPI 1 revision surgery Reported as "excellent" = FROM with contraction against resistance
Stern and Carey[25]	1988	1	ST avulsion	15–140	4 kg	80	3 patients with ST coverage and functional restoration (combined) 2 of these patients were reported on in 1982 article
Germann and Steinau[23]	1995	2	Avulsion-degloving Crush-avulsion	20–135 20–75	MRC 4+ at 6 months 4.5 kg MRC 4 at 10 months	NR	No additional procedures
Mordick et al[12]	1997	1	Crush/rollover MVA	−5–110	8 lbs	80	
O'Ceallaigh et al[13]	2005	1	Electrical burn	20–80	MRC 4 at 9 months 4 kg bimanual lift	NR	Wide area of injury and deficits, not confined to biceps only

BPI, brachial plexus injury; FL ST, flexion strength; FROM, full range of motion; MRC, Medical Research Council; NR, not reported; PTS, number of patients in the study who had LD for simultaneous biceps reconstruction and soft-tissue coverage; SUP ST, supination strength.

in upper extremity function related to latissimus harvest were obscured by the traumatic injury. Early complications that can be seen at the latissimus dorsi harvest site include hematoma and seroma formation. We employ a quilting technique for donor site closure and maintain drains at the donor site until output is <5 mL over 24 hours.[31,32] Shoulder girdle weakness has been measured after the harvest of the latissimus dorsi, particularly the loss of extension strength. Despite isolated weakness in muscle testing, global shoulder function scores remain high due to compensation for latissimus dorsi function by synergistic muscle groups (predominantly teres major, pectoralis major, and subscapularis).[33–35]

This study is limited by a small patient cohort and limited long-term follow-up. This is not uncommon for trauma patients, particularly those treated at an urban referral center.[36] Nevertheless, final available data are comparable to previous reports in the literature. Although several options exist for reconstruction of elbow flexion, none except a functional free muscle transfer provides simultaneous reconstruction of a soft-tissue defect. This article adds to the available data on a procedure that is not commonly performed, and provides supplemental videos to help physicians refresh their technique and surgical pearls critical to achieving good functional outcomes.

Milan V. Stevanovic, MD
Division of Hand and Microsurgery
Department of Orthopaedics
1520 San Pablo St, Suite 200
Los Angeles, CA 90033
E-mail: stevanov@usc.edu

PATIENT CONSENT

Parents or guardians provided written consent for the use of the patient's image.

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