Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/jor

Original Article

Bipolar latissimus transfer for restoration of elbow flexion

Sonia Chaudhry*, Sevan Hopyan

Hospital for Sick Children, Department of Orthopaedic Surgery, Toronto M5G 1X8, Canada

ARTICLE INFO

Article history:

Received 21 March 2013

Accepted 1 June 2013

Available online 17 July 2013

Keywords:

Brachial plexus palsy

Elbow flexion

Flexorplasty

Muscle transfer

Latissimus

ABSTRACT

Background: Elbow flexion is often lacking in patients with brachial plexus palsy or anterior arm trauma. Restoring elbow flexion helps position the functioning hand for activity and nonfunctioning hand for stabilization. Bipolar latissimus transfer is one method of improving elbow flexion.

Methods: A clinical case of bipolar latissimus transfer is presented. Additionally, results of a literature search are incorporated.

Results: Bipolar latissimus can effectively improve elbow function, however residual deficits are to be expected. Additional transfers include unipolar latissimus, triceps, sternocleidomastoid, and pectoralis. Other methods include primary nerve transfer, Steindler flexorplasty, free muscle transfer, and elbow fusion.

Conclusion: Elbow flexion can be improved through various techniques. Each individual's clinical picture should be examined by an experienced clinician when choosing which technique to apply.

Copyright © 2013, Professor P K Surendran Memorial Education Foundation. Publishing Services by Reed Elsevier India Pvt. Ltd. All rights reserved.

1. Introduction

The goals of treating brachial plexus palsies or traumatic loss of upper extremity function include hand reanimation, protective hand sensation, shoulder stability, and elbow function. Elbow flexion is required for movements such as hand to mouth for feeding and hand to chest for dressing. Some believe elbow reanimation should be a first priority in the upper extremity reconstruction ladder.¹ In the setting of upper trunk lesions causing loss of elbow flexion, early strategies employ exploration and microsurgical reconstruction of the plexus. Free intercostal and spinal accessory nerve transfers to the musculocutaneous nerve can provide anti-gravity elbow flexion,² however six months after denervation the

biceps undergoes disuse atrophy, precluding this modality and necessitating reconstructive procedures.

The latissimus was initially transferred to achieve elbow extension in 1949 and modified for flexion in 1955.³ Bipolar transfer is advantageous in that proximal fixation near the coracoid stabilizes the anterior shoulder joint while concomitantly improving arm flexion in a direct line of pull.^{4,5} The latissimus was chosen for its long pedicle, easily contoured shape, and minimal donor morbidity. These favorable characteristics have led to its use for other reconstructions including triceps,⁶ trapezius,⁷ and deltoid,⁸ and most commonly irreparable rotator cuff tears.⁹

Numerous alternatives have been described to restore elbow flexion (Table 1). Prior to muscle transfers, Steindler

* Corresponding author. Tel.: +1 416 813 6686; fax: +1 416 813 6414.

E-mail address: Chaudhry85@gmail.com (S. Chaudhry).

0972-978X/\$ – see front matter Copyright © 2013, Professor P K Surendran Memorial Education Foundation. Publishing Services by Reed Elsevier India Pvt. Ltd. All rights reserved.
<http://dx.doi.org/10.1016/j.jor.2013.06.004>

Table 1 – Procedures for elbow flexion restoration.

Procedure	Indication	Pros	Cons
Primary transfers to musculocutaneous nerve (intercostals, spinal accessory)	Within 6 months of arm flexor deficit or before age 18 months in brachial plexus birth palsy	Reinnervate native arm flexors, donor nerves expendible	Incomplete reinnervation, limited window of opportunity for intervention, often need interposition grafts
Steindler flexorplasty	Strong forearm flexors preoperatively	Small incisions, no nerve/vascular anastomosis required	Elbow flexion-pronation contractures, wrist flexion contractures, weak elbow flexion, ²⁶ short lever arm gives weaker and less flexion range compared to latissimus ¹¹
Unipolar latissimus transfer	Strong preoperative latissimus function with well maintained passive elbow range of motion	Postoperative function similar to bipolar transfer, ²⁴ good cosmesis	Indirect line of flexion pull, unable to improve supination, ²² distal fixation to biceps tendon through thin muscular tissue
Bipolar latissimus transfer	Strong preoperative latissimus function with well maintained passive elbow range of motion	Direct line of pull, maintains original innervation and perfusion with preserved mobilized pedicle, elbow flexion weak gains, allows myocutaneous transfer good cosmesis	Difficult to assess preoperative latissimus strength, long incision from donor site, distal fixation to biceps tendon through thin muscular tissue
Triceps transfer	Strong preoperative elbow extension in patients with weak latissimus	Minimal dissection, does not require dissection of neurovascular pedicles, gravity augments weakened elbow extension	Imbalance from weak extension weakens elbow and shoulder function, ¹ Indirect line of pull
Sternocleidomastoid transfer	Uncommonly used	–	Asymmetric neck contour gives poor cosmesis, requires fascia lata harvest for supplementation
Pectoralis transfer	Uncommonly used	–	Asymmetric axillary folds gives poor cosmesis, loss of adduction
Free muscle transfer (gracilis, rectus femoris)	Pedicled transfers precluded by preoperative weakness from extensive plexus involvement	Larger muscle bulk increases work capacity ¹	More denervation and less protective sensation than pedicled transfers, ¹⁸ blood loss from well-perfused donor muscles
Elbow fusion	Older low-demand patients	Durable	Limits mobility

described proximal advancement of the medial epicondylar origin of the flexor-pronator mass.¹⁰ Though effective in increasing the elbow flexion moment of wrist flexors, strength and active flexion gains have been inferior to latissimus transfer, and both the elbow and wrist can develop pronation and flexion contractures.¹¹ Pectoralis major and sternocleidomastoid, while described, are less commonly used due to poor cosmesis and need for fascia lata graft interposition, respectively.^{3,12–16} Unipolar transfer of the triceps insertion anteriorly is well-described, but is limited by an indirect line of pull by an antagonistic muscle and concomitant weakening of elbow extension.¹⁶ Free muscle transfer, such as gracilis or rectus femoris, is another modality with good success,¹⁷ however they are not first line choices given the lack of protective sensation and increased atrophy compared with pedicled transfers.¹⁸

2. Anatomy

The latissimus dorsi acts to adduct, internally rotate, and extend or retropulse the arm. The muscle is broad and flat, with muscle fibers shorter posteriorly than anteriorly.¹ Triangular in shape, its base originates off the T7 through T12 vertebrae and iliac crest while the apex is in the axilla. The tendinous insertion onto the medial bicipital ridge of the humerus averages 3.3 cm wide by 7.3 cm long¹⁹ and is best

identified by positioning the shoulder in internal rotation. The tendon is easily mobilized over six inches.²⁰ The adjacent teres major tendon is most often separate, but is occasionally loosely bound or completely joined to the latissimus tendon.¹⁹

The neurovascular pedicle to the latissimus is a free-lying trunk. Prior to terminally dividing into axillary and radial nerves, the posterior cord gives off the thoracodorsal nerve that singularly innervates the latissimus via a pedicle 9–12 cm long and 2–3 mm wide.^{1,21} Perfusion is largely from the thoracodorsal artery, which, along with the circumflex scapular artery, branches off the subscapular artery arising from the distal axillary artery. The thoracodorsal artery also perfuses the overlying skin and part of the serratus anterior via 1–3 branches given off prior to entering the proximal third of the latissimus 10 cm from the humeral insertion.^{20,22} The latissimus is secondarily perfused by small perforators from its spinous origin.²¹

Proximity of the insertion to several neurovascular structures is worth mention. The upper portion of the radial nerve lies covered by fat anterior and distal to the latissimus tendon, while the ulnar nerve and axillary vessels are slightly more anterior at the same level. The quadrilateral space contains the posterior circumflex humeral vessels running with the axillary nerve, and while it is more posterior and proximal to the latissimus insertion and covered by a fibrous band, it can be closer than expected with concomitant atrophy of the posterior deltoid.²⁰

The primary elbow flexors are the biceps and brachialis. Additional flexion moment is given by the extensor carpi radialis longus and brachioradialis.²³

3. Indications and assessment

Lesions of C7 can have three possible consequences. Total elbow flexion can be lost from biceps and brachioradialis paralysis. The deltoid can be variably affected, resulting in shoulder subluxation that worsens elbow function, but can be improved by the concomitant stabilization afforded by the proximal limb of the bipolar latissimus transfer. Lastly, the latissimus itself, being innervated by the ventral rami of the C5, C6, and C7 roots, can be paralyzed or weakened to the point of precluding its use in a transfer.¹¹

Candidates for bipolar latissimus transfer have an elbow lacking active flexion with preserved passive range and are willing and able to undergo postoperative rehabilitation. While lack of hand function was once thought to be a contraindication for attempting to improve more proximal motors, it is now well accepted that there is still benefit to reanimation, such as positioning the limb as a stabilizer. Patients should be counseled to have reasonable expectations that include some improvement of active elbow flexion, with the potential additional benefit of anterior shoulder stabilization. Return to preinjury or contralateral side level of function is unlikely.

Preoperative evaluation of latissimus strength is difficult, albeit necessary, as preoperative function correlates with postoperative results.²⁴ The muscle can be palpated or held between the thumb and forefinger during adduction and extension, as well as during a cough, and compared with the contralateral side. Differentiating the contribution of teres major from latissimus is a challenge when testing resisted arm adduction. Equivocal clinical exams can be supplemented with nerve conduction studies or intraoperative electrical stimulation to further evaluate contractility, though decision on transferability should be made on preoperative manual motor testing.⁵ Some employ functional latissimus training 2–3 months preoperatively to “re-educate” the muscle until resisted adduction is achieved.^{25,26} The idiom of donor muscles needing at least grade 4/5 power to withstand losing one grade after transfer is not applicable in this case, as the goal is to maintain Grade 4/5 power despite an expected loss of strength.¹¹

Transfer is most likely to be successful if there is full passive range of motion of the elbow and the shoulder is stable.²¹ Subsequent shoulder fusion after latissimus transfer has improved elbow function, however this option has obvious limitations, especially in the pediatric population.

Myocutaneous transfer is performed for cases with skin compromise from traumatic destruction or electrical burns, though some routinely include overlying skin to increase space for the transferred muscle and allow blood supply monitoring.²³ When skin and muscle defects extend over 8 cm distal to the olecranon or proximally on the ipsilateral shoulder, free transfer of the contralateral latissimus or rectus abdominus is needed for additional coverage.¹⁸

4. Surgical technique

Patient is positioned in the lateral decubitus position with a beanbag. The latissimus origin is approached through a longitudinal incision posterior to the midaxillary line, from the inferior axilla to a point between the ribs and iliac crest. A flap superficial to the thoracodorsal fascia is developed. Proximally, fascial connections between the latissimus and the posterior axillary skin require release.⁴ The deep latissimus surface is separated from the underlying serratus anterior. Over the rib cage, intercostal perforators to the muscle must be ligated. Mobilizing the insertion of the latissimus with the overlying thoracodorsal fascia, the neurovascular pedicle is located on the ventral surface of the muscle proximally near the lateral edge.

The pedicle is then traced up to its axillary origin. Anastomoses between the thoracodorsal artery and the lateral thoracic vessels may be present, and meticulous hemostasis here will decrease postoperative hematoma formation. The humeral insertion is then isolated between the tendons of the pectoralis major and teres major. Fig. 1 demonstrates the freed latissimus attached by its neurovascular pedicle. We harvest the entire muscle to maximize power, however transplantation of only the lateral half when the latissimus is bulky has been described.²⁶

Next, a deltopectoral approach is utilized for proximal reattachment of the insertion. Both superior and inferior borders of the pectoralis major are developed until the deep surface is cleared. The latissimus tendon is then taken under the pectoralis major muscle from distal to proximal, simultaneously palpating the pedicle to ensure it has not been rotated or tensioned. Fig. 2 shows the latissimus passed through the axillary skin bridge to exit the deltopectoral interval. Proximally, the coracoid with its conjoint tendon is exposed for later attachment of the latissimus tendon.

The elbow is then approached through an S-shaped Anterior incision with a horizontal limb across the flexor crease

Fig. 1 – Lateral thorax incision for latissimus harvesting. The edge of the freed origin and overlying thoracodorsal fascia are toward the left, while the tendinous insertion is located to the right. The neurovascular pedicle can be seen in the superior portion of the incision.

Fig. 2 – The latissimus has been tunneled under the axilla to exit the deltopectoral incision. The latissimus tendon has been brought out deep and proximal to the pectoralis major.

connecting proximal–medial and distal–lateral longitudinal limbs. The biceps insertion on the radial tuberosity is delineated. Fasciotomy of the arm maximizes room in the anterior compartment for the latissimus muscle. Additional volume is available after debulking the biceps muscle belly through the proximal extent of this incision and the distal aspect of the deltopectoral opening, taking care to preserve the biceps tendon. Once this recipient bed is made, the anterior and posterior edges of the latissimus are rolled to maximize cross sectional area,²⁷ and the origin is passed under the axillary skin bridge to exit distal to the pectoralis major, followed by an additional pass under the anterior skin bridge exiting the anterior elbow incision (Fig. 3).

The latissimus tendon is attached proximally with nonabsorbable braided sutures (Ethibond, Menlo Park, CA)

Fig. 3 – The latissimus origin has been sutured into a roll and tunneled under the fasciotomized anterior arm to exit the anterior elbow incision. The biceps has been debried, preserving the distal tendon for attachment.

Fig. 4 – The latissimus and biceps have been sewn together while holding the forearm in maximum supination and 100 degrees of flexion.

placed through the coracobrachialis and periosteum overlying the coracoid, taking care to avoid the musculocutaneous nerve medial to the coracoid. The acromion,²¹ clavicle,¹ and biceps tendon in the bicipital groove²² have also been used as proximal fixation points. Distal fixation through the thin muscle is less robust, making sutures prone to loosening.²⁴ Absorbable sutures (Ethibond, Menlo Park, CA) are placed in a Krackow fashion through the muscle and overlying thoracodorsal fascia for attachment to the biceps tendon (Fig. 4). Alternatively, distal fixation can be performed to the radial tuberosity¹ or proximal third of the ulnar diaphysis to increase the lever arm and improve strength, mimicking the ulnar insertion of the brachialis.⁵ The resting tension of the repair should be about 100 degrees of flexion and maximum supination to optimize muscle strength along its Blix curve. Repair is reinforced with sutures across the tendon junction or hardware in the case of bony fixation.²³

A layered closure of incisions is performed, and a drain is placed in the trunk wound to prevent seroma. The elbow is splinted in 100 degrees of flexion and maximum supination.

5. Postoperative protocol

Immobilization is discontinued at 6 weeks to commence gentle passive ranging with isometric contractions, progressing to resisted flexion by 8 weeks.²⁶ Instead of splinting, some utilize a custom-made brace to hold the shoulder and elbow in 45 and 90 degrees of flexion, respectively.²³ Early functional training at three weeks with EMG and audiovisual feedback systems, followed by resisted flexion and extension,^{25,27} is described to prevent disuse atrophy.

6. Results

EMG demonstrates rapid integration into normal elbow motion patterns with latissimus activity during present during

both active flexion and typical latissimus activities such as shoulder adduction/extension.²⁶ Latissimus transfers generally result in high patient satisfaction despite poor power, often worsened by concomitant instability of the shoulder in brachial plexus palsies.²⁸ Though a stable shoulder is not a prerequisite for transfer,²⁹ the synergistic effect of adjacent joint stability is consistent with the finding that after the shoulder and wrist are stabilized, flexion strength of the elbow increases.²⁶ Better results are achieved in the setting of traumatic arm destruction compared to brachial plexus palsy, especially high palsies where the latissimus can be weakened preoperatively.²¹ Functioning forearm musculature is another favorable factor as the brachioradialis and other wrist flexors cross the elbow and act as secondary elbow flexors.

An overall 75% rate of achieving elbow flexion against resistance is reported.⁵ Flexion power averages 2–3 kg through a 90–140 degrees arc.^{2,5,7,23,28,30} Modest 10–50 degree gains in supination are also reported.^{15,21,26} Loss of latissimus power is reported as 56%, compared to 83% loss of forearm flexor strength in Steindler flexorplasties.^{1,11} Patients have good endurance of elbow control with sustained 4 s contractions through 3 h of repetitive elbow movement. Most papers report Grade 3 or 4 out of 5 in almost all patients by 3 months, with unsatisfactory strengths only in patients with preoperative weakness^{1,24} or excessive tendon length.²⁵ Flexion contractures of 10–15 degrees occasionally occur,^{5,8,9,26} though some do not aim to straighten past 30 degrees for risk of stressing the transfer.¹¹ Neither flexion nor pronation contractures have been functionally limiting.^{16,27}

7. Complications

Complications are seldom and varied. Spontaneously resolving hematoma, fibrofatty latissimus degeneration, loss of muscle tension requiring shortening, progressive myelopathy compromising the thoracodorsal nerve,²⁵ antagonistic co-contraction of the triceps resolving with botox injection,⁵ and necrosis from a thrombosed pedicle,²⁸ and have each been described once. Skin necrosis and infection at the elbow site occurred in 2 of 21 various types of latissimus transfers, however both involved prior scarring and splinted in 150 degrees of flexion postoperatively.¹ Additionally, 2 cases of compartment syndrome are reported, with risks including too small of an axillary canal, excessive bulk of transferred muscle, and kinking of draining veins.³¹ Prompt hematoma evacuation and pedicle inspection should be followed by judicious debridement after this rare complication but should avoid total excision, as function is reportedly salvageable. Lastly, scoliosis is a historically referenced complication, however we are unaware of instances and some papers specifically point out its absence.²⁷

Donor site morbidity is minimal. Patient surveys of latissimus harvesting for breast reconstruction reveal a 39% rate of moderate weakness, 50% rate of back numbness or tightness, and 22% rate of unacceptable scarring.³² No functional impairment is reported after latissimus harvesting, perhaps due to compensatory teres major hypertrophy.³³

8. Future studies

Series of latissimus transfers in the literature are relatively small with heterogeneous indications and variable techniques. Studies report muscle power and joint range of motion achieved, but details concerning gain or loss in functional activities of daily living are lacking. Despite the era of electronic medical records making imaging and tests more easily accessible for retrospective studies, without documentation of clinical improvement and detailed physical examination, questions about prognosis and outcomes are likely to remain unanswered. Multicenter collaboration to optimize transfer techniques and perform well-designed prospective comparisons of muscle advancements versus unipolar, bipolar, and free muscle transfers is indicated to better counsel patients on management of insufficient elbow flexion.

9. Conclusion

Bipolar latissimus transfer is an effective procedure for restoring active elbow flexion. The long mobile pedicle and minimal donor site morbidity allow for safe transfer for a direct line of pull. While strength gains are modest, achieving anti-gravity elbow flexion seems to be a significant improvement for patients.

Conflicts of interest

All authors have none to declare.

REFERENCES

1. Vekris MD, Beris AE, Lykissas MG, Korompilias AV, Vekris AD, Soucacos PN. Restoration of elbow function in severe brachial plexus paralysis via muscle transfers. *Injury*. 2008 Sep;39:15–22.
2. Chuang D, Epstein MD, Yek M-C, Wei F-C. Functional restoration of elbow flexion in brachial plexus injuries: results in 167 patients (excluding obstetric brachial plexus injury). *The Journal of Hand Surgery*. 1993 Dec 21;18A:285–291.
3. Schottstaedt ER, Larsen LJ, Bost FC. Complete muscle transposition. *Journal of Bone & Joint Surgery American Volume*. 1955 Oct 23;37-A:897–919.
4. Waters PM, Bae DS. The early effects of tendon transfers and open capsulorrhaphy on glenohumeral deformity in brachial plexus birth palsy. *Journal of Bone & Joint Surgery American Volume*. 2008 Oct 31;90-A:2171–2179.
5. Cambon-Binder A, Belkheyar Z, Durand S, Rantissi M, Oberlin C. Elbow flexion restoration using pedicled latissimus dorsi transfer in seven cases. *Chirurgie de la Main*. 2012 Dec;31:324–330.
6. Jones BN, Manske PR, Schoenecker PL, Dailey L. Latissimus dorsi transfer to restore elbow extension in Obstetrical palsy. *Journal of Pediatric Orthopaedics*. 1985 Dec 23;5:287–293.
7. Ihara K, Katsube K, Misumi H, Kawai S. Successful restoration of the trapezius muscle using pedicle latissimus dorsi, a case report. *Clinical Orthopaedics and Related Research*. 2000 Feb 22;371:125–130.
8. De Smet L. Bipolar latissimus dorsi flap transfer for reconstruction of the deltoid. *Acta Orthopaedica Belgica*. 2009 Dec 22;75:32–36.

9. Moursy M, Cafaltzis K, Eisermann S, Lehmann LK. Latissimus dorsi transfer: L'Episcopo versus Herzberg technique. *Acta Orthopaedica Belgica*. 2012 Dec 22;78:296–303.
10. Steindler A. Tendon transplantation in the upper extremity. *The American Journal of Surgery*. 1939 Apr 30;XLIV:260–271.
11. Eggers IM, Mennen U, Matime AM. Elbow flexorplasty: a comparison between latissimus dorsi transfer and Steindler flexorplasty. *Journal of Hand Surgery, British Volume*. 1992 Oct 23;17B:522–525.
12. Brooks DM, Seddon HJ. Pectoral transplantation for paralysis of the flexors of the elbow, a new technique. *The Journal of Bone and Joint Surgery British*. 1959 Feb 18;41 B:36–43.
13. Kumar VP, Satku K, Pho WH. Modified technique of sternomastoid transfer for elbow flexion. *The Journal of Hand Surgery*. 1992 Sep 18;17A:812–813.
14. Clark JM. Reconstruction of biceps Brachii by Pectoral muscle transplantation. *The British Journal of Surgery*. 1946 Nov 21;XXXIV:180–181.
15. Nagano A, Ochiai N, Okinaga S. Restoration of elbow flexion in root lesions of brachial plexus injuries. *The Journal of Hand Surgery*. 1992 Sep 22;17A:1–7.
16. Bunnell S. Restoring flexion to the paralytic elbow. *Journal of Bone & Joint Surgery American Volume*. 1951 Jul;33-A:566–571 [passim].
17. Chuang D, Carver N, Wei F-C. Results of functioning free muscle transplantation for elbow flexion. *The Journal of Hand Surgery*. 1996 Nov 20;21A:1071–1077.
18. Stevanovic M, Sharpe F, Itamura JM. Treatment of soft tissue problems about the elbow. *Clinical Orthopaedics and Related Research*. 2000 Jan 23;370:127–137.
19. Goldberg BA, Elhassan B, Marciniak S, Dunn JH. Surgical anatomy of latissimus dorsi muscle in transfers about the shoulder. *The American Journal of Orthopedics*. 2009 Mar 20;38:E64–E67.
20. Harmon PH. Muscle transplantation for triceps palsy, the technique of utilizing the latissimus dorsi. *Journal of Bone & Joint Surgery American Volume*. 1949 Apr 22;31-A:409–412.
21. Stern PJ, Carey JP. The latissimus dorsi flap for reconstruction of the brachium and shoulder. *Journal of Bone & Joint Surgery American Volume*. 1988 Apr 24;70-A:526–535.
22. O'Ceallaigh S, Mehboob Ali KSA, O'Connor TPF. Functional latissimus dorsi muscle transfer to restore elbow flexion in extensive electrical burns. *Burns*. 2005 Feb;31:113–115.
23. Terzis JK, Kokkalis ZT. Secondary procedures for elbow flexion restoration in late obstetric brachial plexus palsy. *HAND*. 2009 May 9;5:125–134.
24. Kawamura K, Yajima H, Tomita Y, Kobata Y, Shigematsu K, Takakura Y. Restoration of elbow function with pedicled latissimus dorsi myocutaneous flap transfer. *Journal of Shoulder and Elbow Surgery*. 2007 Jan;16:84–90.
25. Hirayama T, Tada H, Katsuki M, Yoshida E. The pedicle latissimus dorsi transfer for treconstruction of the plexus brachialis and brachium. *Clinical Orthopaedics and Related Research*. 1994 Dec 22;309:201–207.
26. Zancolli E, Mitre H. Latissimus dorsi transfer to restore elbow flexion. an appraisal of eight cases. *Journal of Bone & Joint Surgery American Volume*. 1973 Sep 18;55-A:1265–1275.
27. Hirayama T, Taremitsu Y, Atsuta Y, Ozawa K. Restoration of elbow flexion by complete latissimus dorsi muscle transposition. *The Journal of Hand Surgery*. 1987 Jun 28;12-B:194–198.
28. Marshall RW, Williams DH, Birch R, Bonney G. Operations to restore elbow flexion after brachial plexus injuries. *Journal of Bone & Joint Surgery American Volume*. 1988 Aug 21;70-B:577–582.
29. Schoeller T, Wechselberger G, Hussl H, Huemer GM. Functional transposition of the latissimus dorsi muscle for biceps reconstruction after upper arm replantation. *Journal of Plastic, Reconstructive & Aesthetic Surgery*. 2007 Jul;60:755–759.
30. Takami H, Takahashi S, Ando M. Latissimus dorsi transplantation to restore elbow flexion to the Paralysed limb. *The Journal of Hand Surgery*. 1984 Feb 28;9-B:61–63.
31. Rajoo R, Mennen U, Stevanovic M. Compartment syndrome in transferred muscle: an Unusual complication. *The Journal of Hand Surgery British Volume*. 1991 Feb 23;16B:75–77.
32. Adams Jr WP, Lipschitz AH, Ansari M, Kenkel JM, Rohrich RJ. Functional donor site morbidity following latissimus dorsi muscle flap transfer. *Annals of Plastic Surgery*. 2004 Jul;53:6–11.
33. Brumback RJ, McBride MS, Ortolani NC. Functional evaluation of the shoulder after transfer of the vascularized latissimus dorsi muscle. *Journal of Bone & Joint Surgery American Volume*. 1992 Mar 23;74-A:377–382.