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Surgical Technique and Anatomical Considerations for the Modified L'Episcopo Tendon Transfer

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Abstract

Background: Birth brachial plexus injury usually affects the upper trunks of the brachial plexus and can cause substantial loss of active shoulder external rotation and abduction. Due to the unbalanced rotational forces acting at the glenohumeral joint, the natural history of the condition involves progressive glenohumeral joint dysplasia with associated upper limb dysfunction. Surgical reconstruction methods have been described previously by Sever and L'Episcopo, and modified by Hoffer and Roper to release the adduction contracture and to restore external rotation and shoulder abduction. **Methods:** The authors describe their preferred technique for contracture release and tendon transfer to improve external rotation and shoulder abduction. Pertinent anatomy and highlights of surgical exposure are reviewed. **Results:** The senior author has utilized this technique with consistent clinical outcomes to improve shoulder function for patients with persisting nerve palsy associated with birth brachial plexus injury. A review of the literature supports utilization of this technique. **Conclusions:** Transfer of the latissimus dorsi and teres major to the posterior rotator cuff for reanimation of shoulder abduction and external rotation deficits associated with birth brachial plexus injury is a safe and reliable technique. Careful patient selection and attention to surgical detail are critical for optimal outcomes.

Keywords: brachial plexus birth palsy, L'episcopo, latissimus dorsi tendon transfer, surgical technique, Erb palsy

Introduction

Birth brachial plexus injury (BBPI) involves a spectrum of injury, ranging from transient neurapraxia to catastrophic nerve root avulsions. Incidence has been reported to range from 0.4 to 4 per 1000 births.[1] The etiology of BBPI involves traction across the affected brachial plexus, often involving contradictory forces acting at the head and shoulder. The greatest risk factor associated with BBPI is increased newborn weight, or macrosomia; there is a 3 times increased risk in infants with shoulder dystocia weighing greater than 4500 g.[2] Other risk factors include maternal diabetes, higher maternal weight gain and higher maternal body mass index, breech delivery, increased maternal age (>35 years), parous women, and alterations in the maternal birthing canal.[3,4] The prognosis for infants born with signs of BBPI is generally good; the majority of BBPIs will resolve or recover such that surgical intervention is not warranted,[5-7] particularly when recovery of biceps function occurs within the first 3 months of life.[8] Several findings may be associated with a worse prognosis and should be considered carefully, including increasing nerve root involvement,[4] associated orthopedic injuries such as clavicle or humerus fracture, and a Horner sign. Careful observation and serial examinations are essential for maximizing potential outcomes, particularly as treatment is time-sensitive.

Motor nerve deficit, particularly involving the upper trunk, may cause an imbalance in motor function, compromising coordinated muscular activity and imparting asymmetric forces within the affected limb, notably involving the shoulder. An upper trunk injury typically is associated with weak shoulder abduction and external rotation.[9] This is due to weakness of the denervated external rotators (infraspinatus and teres minor) and relative preservation of internal rotation strength of the subscapularis, latissimus dorsi, and pectoralis major muscles.[10] If untreated, this imbalance causes a progressive glenohumeral dysplasia,[11] manifesting as glenoid retroversion and progressive posterior sublux-

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ation of the humeral head accentuating the loss of external rotation.[12]

Although the precise timing of nerve reconstruction has been debated, many authors opine that surgical intervention by 3 to 6 months of age is appropriate in the absence of active, antigravity elbow flexion.[1,13,14] In the absence of complete motor recovery, with or without surgical nerve reconstruction, secondary procedures designed to improve upper extremity function and to reduce the effects of muscular imbalance on joint development should be considered for patients with a compliant patient-family-guardian unit. While early nerve reconstruction (such as nerve grafting or nerve transfer) remains a priority, delayed or secondary interventions include musculotendinous transfers.

In 1934, L'Episcopo[15] described use of an anterior and posterior incision to transfer the latissimus dorsi and teres major laterally to enhance external rotation. This transfer has subsequently been modified to insert on the posterior and superior rotator cuff by Hoffer et al[16] to address Erb palsy and, similarly, by Pearle et al to treat shoulder weakness associated with massive rotator cuff tears.[17] Based on its potential to enhance both external rotation and shoulder abduction, we have used a modified Hoffer procedure for selected BBPI patients associated with absent or weak active shoulder external rotation and abduction and with acceptable internal rotation strength. This transfer may be performed in conjunction with other procedures such as contracture release (open or arthroscopic). Surgical technique and awareness of critical anatomic relationships and surgical dissection planes make this a reliable and safe transfer for shoulder reanimation.

Indications

Transfer of the latissimus dorsi, with or without the teres major, to the posterior and superior rotator cuff is considered for patients ideally 2 to 4 years of age, although there may be indications for earlier intervention or salvage for later presentation. These patients have sustained at least an upper trunk injury and typically present with persisting shoulder abduction and external rotation weakness without clinical evidence of progressive motor recovery, with or without previous brachial plexus reconstruction.

The natural history of persisting upper trunk motor weakness typically involves progressive glenohumeral internal rotation contracture and/or glenohumeral dysplasia.[12] A comprehensive clinical evaluation is imperative to assess for confounding factors that might contribute to a loss of functional shoulder motion including:

1. Motor weakness;
2. Musculotendinous contracture, often involving the pectoralis major and/or subscapularis muscles;
3. Shoulder capsular contracture; and
4. Dysplastic changes or anklyosis of the glenohumeral joint.

The examiner should discriminate carefully between glenohumeral and scapulothoracic joint motion. Tendon transfers can be performed in older children with a delayed presentation; however, it is our general practice to emphasize earlier intervention which may improve potential cortical reintegration and may minimize the adverse effects of motor imbalance at the shoulder contributing to joint dysplasia, as well as the patient's functional and psychological development. An association between age and more severe glenoid retroversion has been demonstrated; children greater than 5 years of age tend to demonstrate greater deformity of the posterior glenoid.[11]

Contraindications

A functioning latissimus dorsi is required for the procedure, so patients with a pan-plexus injury or injury involving the thoracodorsal nerve are not candidates for this musculotendinous transfer. Prior surgery or substantial scarring around the latissimus donor site or the intended recipient site may be relative contraindications, also. We strongly believe that the patient's social environment should be optimized as the patient/family/guardian unit compliance with perioperative care is critical.

Patient Evaluation

At the senior author's institution, a multidisciplinary clinic has been established to care for children with BBPI. Patients are evaluated by a pediatric neurologist, the surgical team (orthopedic and plastic surgery), and dedicated occupational/physical therapists to facilitate the formation of a comprehensive care plan. When indicated, patients may undergo early exploration, possible neurolysis, and/or reconstruction of the injured brachial plexus within the first 3 to 12 months of life.

Several anatomic structures contribute to an internal rotation contracture of the shoulder. Patients with a contracted subscapularis or pectoralis major will demonstrate an internal rotation contracture of the arm. Differentiating the primary and secondary influences on the development of an internal contracture can be difficult as the cause is often multifactorial. Both glenohumeral dysplasia and capsular contracture can restrict global motion; evaluating the patient's passive external rotation with the arm at the side and at 90° abduction will assess the relative influence of the subscapularis and pectoralis muscles, respectively. Contracture of the anterior capsule can restrict external rotation, particularly with the arm in abduction due to accentuated tightening of the anterior capsule caused by the cam effect of the proximal humerus.[18] Reduced glenohumeral joint motion will occur also with increasing glenohumeral joint dysplasia, for which preoperative magnetic resonance imaging (MRI) can be useful in quantifying alterations in joint morphology. Waters et al[11] described the natural history of glenohumeral dysplasia in a case series of 42 patients with brachial plexus birth injury and cross-sectional imaging of the bilateral shoulders. Persistent palsy led to increased glenoid retroversion and posterior subluxation of the humeral head with eventual morphologic changes to the glenoid. These abnormal shoulders were assigned to 1 of 7 described types, with increasing progressive deformity.

Surgical Management

Children with medical comorbidities undergo preoperative evaluation by their pediatrician and/or the perioperative anesthesia clinic. Our preference is to place the patient on a regular operating room table in a well-padded "sloppy lateral" position, using a pediatric beanbag. The surgical field extends from the midline of the anterior chest to the mid-scapular line posteriorly and includes the entire upper limb and the supraclavicular region.

Pertinent Anatomy

The anatomy of the axilla may be considered as a triangle with 3 muscular boundaries: pectoralis major (anterior), serratus anterior (medial), and latissimus dorsi (posterior)[19] (Figure 1). The lateral border of the axilla is formed by the axillary fascia, a continuation of the fascia overlying the pectoralis major muscle that terminates into the investing fascia of the latissimus dorsi muscle. Medial to this fascia is the intermuscular septum, and behind the septum lies the insertion of the latissimus and teres major. The intermuscular septum provides a plane for dissection when isolating the latissimus dorsi muscle and is a landmark that assists in protecting the radial nerve during latissimus tenotomy. In adults, on average, the radial nerve lies 2.5 cm medial to the humerus at this level[17]; however, in children, this distance can be substantially less.

Anteriorly, the interval between the deltoid and pectoralis major muscles is marked typically by the course of the cephalic vein. The biceps tendon runs in the bicipital groove, deep to the pectoralis major tendon but superficial to the insertion of the latissimus dorsi. This insertion is anterior to the musculotendinous footprint of the teres major; the latissimus insertion has an average width of 3.1 cm in an adult[17] compared with an average width of 4.0 cm of the teres major that extends distal to the insertion of the latissimus dorsi.[17]

The radial nerve courses from proximal-medial to distal-lateral, penetrating the axillary fascia at the inferior margin of the teres major. It courses anterior to the latissimus dorsi tendon insertion, and passes posteriorly through the triangular interval (formed by the long head of the triceps medially, the teres major superiorly and the humerus laterally) to continue distally in the posterior brachium. It can be found within 1.6 to 2.4 cm of the posterior deltoid insertion as it traverses the posterior humerus.[20] The axillary nerve arises from the posterior cord and courses posteriorly, traversing the quadrangular, or quadrilateral space, from anterior to posterior; the space is defined by the subscapularis (±teres minor) superiorly, the long head of the triceps, the humerus laterally, and the teres major inferiorly. Prior to entering the quadrangular space, the axillary nerve lies 1.4 cm proximal to the superior border of the insertion of the teres major tendon[17] and 4.5 cm proximal to the deltoid insertion in adults,[20] but is age- and size-dependent in children. The axillary nerve is at risk in the interval between the long head of the triceps and the deltoid and, therefore, care is required when extending this surgical interval inferiorly and laterally.[17]

Figure 1. The surface landmarks of the axilla and general dissection planes are highlighted anteriorly by the palpable inferior margin of the pectoralis major muscle and the definition of the latissimus muscle posteriorly. The axillary incision utilizes the skin creases and courses anteriorly from just posterior to the inferior pectoralis margin to the posterior axillary fold. If an open contracture release and/or pectoralis lengthening is indicated, the anterior incision may extend within the deltopectoral interval.

Inferiorly, the thoracodorsal pedicle to the latissimus dorsi and the teres major branch of the lower subscapular nerve should be protected with dissection of these muscles. In adults, the former enters the latissimus at an average of 13.1 cm from the humeral insertion of the tendon, and the latter enters teres major 7.4 cm from its insertion[17]; however, in young children, these distances are substantially diminished.

Appreciation of anatomic relationships is critical, highlighted by the semi-lateral position of the patient and the changing position of the arm during surgery, and, therefore, the changing perspectives of the surgeon for the surgical field.

Surgical Management—Superficial Exposure

An incision is marked on the abducted arm along midsagittal aspect of the contour of the axillary crease from the inferior margin of the pectoralis major to the posterior axillary fold. In the presence of an internal rotation contracture of the shoulder where open contracture release is indicated, increased anterior exposure may be achieved using the deltopectoral interval. For children younger than the age of 4 years, an incision superior to the inferior margin of the pectoralis major tendon is avoided often, thereby improving the cosmetic appearance of the surgical incision. Similarly, the posterior extent of the incision typically may reside within the axilla, avoiding extension superior to the inferior margin of the triceps-deltoid interval.

The skin incision is carried out to the subdermal level, avoiding sharp incision into the subcutaneous tissue due to the proximity of the traversing sensory nerves and the deeper vital structures. Superficial dissection highlights the longitudinally oriented sensory nerves (intercostobrachial cutaneous nerve and posterior brachial cutaneous nerve branches) that are preserved throughout the procedure (Figure 2).

Important to the success and efficiency of the procedure is the recognition and the preservation of the fascial planes that distinguish the key anatomic structures. Blunt dissection immediately inferior to the distinct inferior margin of the pectoralis major muscle and tendon will facilitate the development of a defined soft tissue plane, protective of the brachial vessels and branches of the brachial plexus inferiorly (Figure 3). If a shoulder contracture release is indicated, pectoralis major z-lengthening, subscapularis partial tenotomy and/or advancement, and/or anterior capsulotomy (open or arthroscopic) may be performed at the same time as tendon transfer to maximize shoulder mobility. Alternatively, we may consider staged arthroscopic contracture release and have performed this both prior to or following musculotendinous transfer based on an individual patient's requirements.

Figure 2. Curved tenotomy scissors are used to develop and to maintain the fascial planes. Posterior brachial cutaneous nerve and intercostobrachial nerve branches running superficially in the center of the operative field from anterior to posterior.

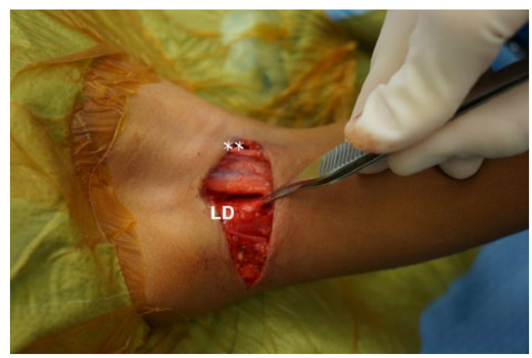


Figure 3. Development of fascial planes that highlight the inferior margin of the pectoralis major (**) anteriorly and the latissimus dorsi (LD) held by the forceps here posteriorly. The critical neurovascular structures course between these structures.

Surgical Management—Contracture Release

If pectoralis major lengthening is indicated, the axillary incision may be extended proximally along the deltopectoral interval with care as to protect the cephalic vein that is retracted laterally. The conjoined tendon is traced to its insertion into the anteromedial humerus; the insertion is deep to the overlying biceps tendon that is retracted laterally to expose the pectoralis insertion. The inserting tendons of the sternal head (deep) and clavicular head (superficial) of the pectoralis major can be separated. When a z-lengthening of the pectoralis tendon is warranted, we prefer to divide the superficial tendon at its humeral insertion and transect the deep tendon approximately 2 to 4 cm from its insertion, repairing it with a nonabsorbable, braided suture once the latissimus dorsi and/or teres major tendon transfer is complete. The authors find the pectoralis to be a less common cause of internal rotation contracture compared with the adverse influence of subscapularis and joint capsule contractures, and the influence of glenohumeral dysplasia.

Several methods of subscapularis release have been described, including coracoid osteotomy and step-cut lengthening of the subscapularis,[21] subscapularis slide,[22] and arthroscopic release of both the anterior capsule and upper subscapularis.[12] In our practice, we have utilized early arthroscopic contracture release (including at the time of nerve reconstruction prior to a year of age), and open or arthroscopic release at the time of tendon transfers for shoulder reanimation, as indicated. Staged arthroscopic contracture release is also a part of our treatment algorithm for certain cases.

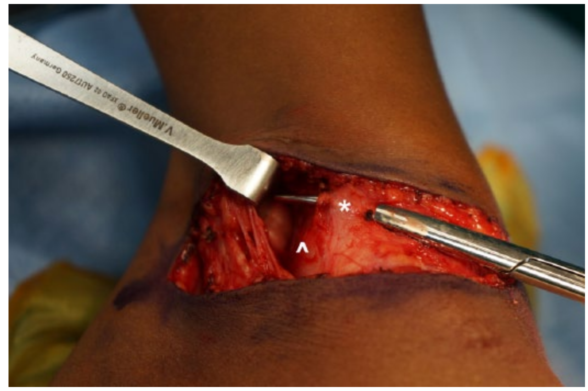


Figure 4. Identification of the plane of the latissimus dorsi (^) can be misguided by the out-of-plane orientation of the superficial fascia (*) that is directed toward the posterior dermis. Isolation and division of the superficial fascia (*) can improve exposure of the deeper latissimus dorsi muscle.

Surgical Management—Tendon Transfers

Attention is directed to the posterior axilla and the contour of the latissimus dorsi is palpated. Superficially, the interval between the latissimus dorsi and the long head of the triceps is identified. This can be difficult due to the orientation of the superficial fascia that originates with the investing fascia of the latissimus inferiorly, but ultimately runs laterally to the skin, out of the plane of the latissimus muscle, potentially misguiding superficial surgical dissection (Figure 4). This fascial extension is divided to facilitate both the exposure of the latissimus and the musculotendinous transfer.

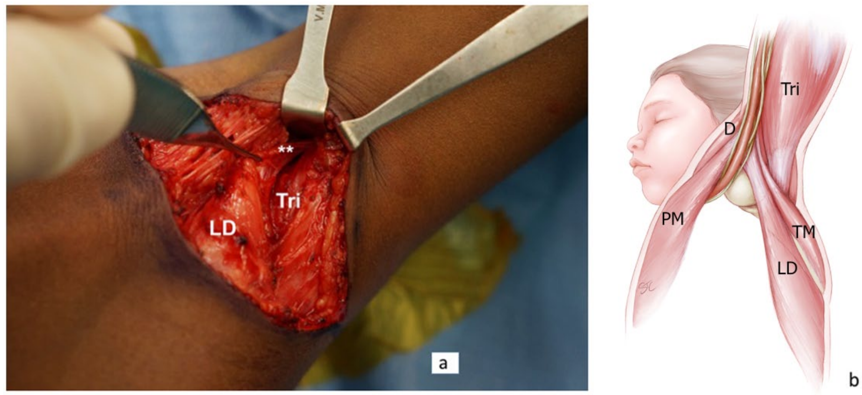
Defining the superior and inferior margins of the latissimus tendon (Figure 5) is critical as the muscle is exposed anteriorly; defining and preserving the investing fascia will facilitate safe and efficient dissection to isolate the muscle from the surrounding tissues. The neurovascular structures are retracted carefully away from the anterior surface of the latissimus as the dissection continues to the tendinous insertion into the humerus. The anterior humerus may be palpated at the latissimus-teres major insertions.

Anteriorly, the inserting tendinous fibers of the latissimus are visualized and direct access to both the superior and the inferior margins of the tendon is confirmed before the insertion is divided from the periosteum of the humerus. Recognition of the regional neurovascular anatomy is critical before performing a tenotomy of the latissimus and teres major insertions. The axillary nerve traverses the quadrangular immediately superior to the teres major insertion. The radial nerve and profunda brachii artery course from anterior and proximal to the latissimus-teres major insertion, anterior to the latissimus tendon.

Tenotomy of the latissimus dorsi and/or teres major insertion from the periosteum of the humerus is completed under direct visualization. Their combined insertion can be distinguished as 2 layers with the broader and more muscular teres major insertion extending distal to the latissimus insertion.[17] Mobilization of the latissimus and teres major is facilitated by release of the superficial fascial bands from the tendons. Forceful or blind dissection during proximal mobilization is avoided to prevent injury to the thoracodorsal neurovascular pedicle or the lower subscapular nerve (Figure 6). The decision to transfer both latissimus dorsi and teres major instead of an isolated teres major transfer is controversial. Transfer of both tendons resulted in a modest improvement in external rotation in a matched cohort group of dual and isolated teres major tendon transfers. Despite a slight improvement in external rotation with the combined transfer, patients in this cohort also suffered an increased loss of midline function.[23]

The subtle interval between the long head of the triceps and the deltoid muscles is highlighted often by a faint fat stripe. This intermuscular plane is developed in the direction of the posterior and superior humeral head to define the interval between the deltoid and the rotator cuff (Figure 7). The proximity of the axillary nerve to this interval must be appreciated. The greater tuberosity of the humerus is palpated, emphasized with arm abduction and external rotation, and the interval is appropriately enlarged to accommodate the transfer.

Uninhibited gliding of the redirected muscle-tendon unit is essential for successful transfer. Superficial fascial bands are divided, particularly overlying the triceps-deltoid interval, to improve gliding characteristics of the transferred muscle-tendon unit. The arm is placed in maximal abduction and external rotation (not greater than 90°) and the prominence and the accessibility of the greater tuberosity are palpated. The latissimus dorsi-teres major tendon is transferred and sutured to the posterior and superior aspect of the rotator cuff, although several variations of the repair



Figures 5. (a) The inferior margin (**) of the latissimus insertion is identified and elevated under direct visualization to facilitate tenotomy. The long head of the triceps muscle (Tri) is seen posterior to the latissimus insertion. (b) Diagram demonstrating the anatomic relations of the shoulder girdle musculature in the axilla (LD = latissimus dorsi muscle; TM = teres major; PM = pectoralis major; D = deltoid).

method have been described. Typically, we use a nonabsorbable, braided suture, creating a locking suture configuration into the rotator cuff.

Postoperative Care and Rehabilitation

The surgical wound is irrigated thoroughly by using normal saline, and hemostasis is maintained using bipolar electrocautery; a "dry" wound is confirmed prior to closure or a small drain is used rarely overnight. The skin is closed with simple, interrupted absorbable suture such as plain or chromic gut with a light dressing of Xeroform (DeRoyal, Powell, Tennessee), gauze, and a Tegaderm dressing (3M, St. Paul, Minnesota).

Under anesthesia, the patient is moved to a sitting position and a well-padded, shoulder-spica cast is applied. Arm positioning during cast placement may vary depending on any persisting shoulder contracture; however, in general, the arm is placed in approximately 70° to 80° abduction, 10° to 15° forward flexion, and 70° external rotation.

Patients return to clinic approximately 2 weeks postoperatively for a cast change. At approximately 6 weeks, the cast is removed and the patient is transitioned into a sling for support and is allowed to begin actively moving the shoulder. Postoperative immobilization and rehabilitation protocols vary widely between surgeons and may be patient-dependent. We delay formal physical therapy for approximately 2 weeks following cast removal to minimize patient anxiety associated with postoperative mobilization that might adversely influence therapeutic outcomes.

Pearls and Pitfalls

- *Careful patient selection*: perioperative compliance will correlate with improved outcomes and family education and involvement is essential for optimal outcomes
- *Preoperative evaluation*: consider influences of musculotendinous, capsular, and articular structures on limitations to both active and passive motion
- *Surgery*: recognize and preserve cutaneous nerves during superficial dissection
- *Surgery*: recognize and preserve fascial and intermuscular planes to maximize surgical efficiency and to minimize complications
- *Surgery*: direct visualization of the latissimus-teres major insertion will help to avoid inadvertent neurovascular injury
- *Surgery*: avoid distal dissection in the deltoid-triceps interval to reduce risk of axillary nerve injury

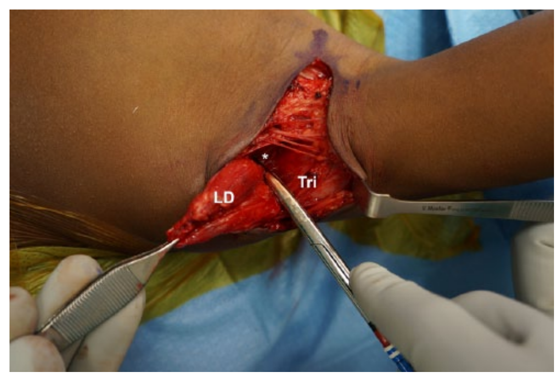


Figure 6. The latissimus dorsi/teres major muscle (LD) isolated for transfer is carefully freed from adherent fascial connections, particularly noted posteriorly, while avoiding injury to the thoracodorsal neurovascular pedicle (*) or the lower subscapular nerve (Tri = long head of the triceps muscle).

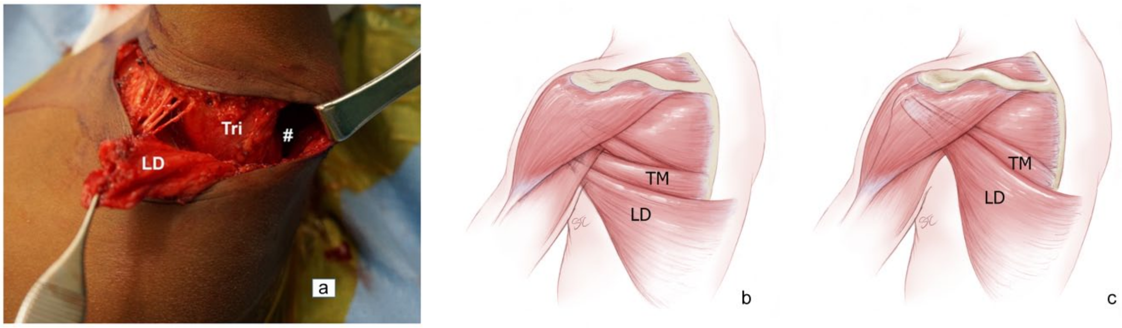


Figure 7. (a) The interval between the deltoid and the deep head of the triceps (Tri) superficially and, subsequently, between the deltoid and the rotator cuff is developed. A retractor facilitates exposure of this interval (#) for careful blunt dissection and hemostasis. Demonstration of shoulder girdle musculature with latissimus dorsi (LD) and teres major muscle (TM) before (b) and after (c) transfer.

Complications

Excessive retraction during exposure anterior to the latissimus dorsi may cause a neurapraxic injury to the brachial plexus. Similarly, blind or indirect dissection of the latissimus/teres insertion from the humerus may increase the risk of injury to any of the axillary or radial nerves or posterior brachial artery, given their close proximity to the tendon. Also, excessive mobilization of the latissimus muscle and tendon can increase the injury risk to the thoracodorsal nerve.

Discussion

Birth brachial plexus injury manifests as a spectrum of injury, but severe consequences include the devastating effects on shoulder function, particularly external rotation and abduction. The latissimus dorsi and teres major to posterior rotator cuff tendon transfer provides a reliable and reproducible method of improving shoulder function. Waters et al[11] reported on a series of 42 patients with advanced cross-sectional imaging evaluated for BBPI. Fifteen of the patients underwent latissimus dorsi and teres major tendon transfer to the greater tuberosity. Mallet scores were reported as outcomes measures, with average improvement rated as abduction from 2.9 to 3.9, external rotation from 2.0 to 3.9, and in ability to bring hand to mouth from 2.2 to 4.0.

A recent meta-analysis by Louden et al[24] found that soft tissue shoulder procedures including tendon transfer and releases can substantially improve shoulder function after neonatal brachial plexus palsy. A total of 17 studies including 405 patients were reviewed: three studies used arthroscopic techniques with subscapularis release and the remaining 14 studies included open techniques of tendon transfer and releases of pectoralis major or subscapularis. All studies transferred the latissimus dorsi and teres major tendons to the posterior humerus or the posterior rotator cuff. The overall success rates were 56% for Mallet scoring, 58% for global abduction, and 72% for external rotation. The authors concluded that secondary soft tissue procedures provide an effective solution for reconstruction of shoulder function.

The current literature and our clinical experiences have demonstrated that transfer of the latissimus dorsi and teres major to the rotator cuff insertion for shoulder abduction and external rotation deficits can be done safely and reliably in appropriately screened patients. Recognition of the pertinent surgical and functional anatomy improves surgical efficiency and reduces the risk of surgical complications, thereby improving patient outcomes.

Ethical Approval

This study is exempt from institutional review board approval.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

No identifying details of any patient were included in this manuscript.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: DMB was a medical education consultant and received research support from Arthrex. He was a board or committee member of American Society for Surgery of the Hand. He received other financial or material support from Axogen. FJL received royalties from Wolters Kluwer / Lippincott Williams & Wilkins and Orthohelix Surgical Designs / Wright Medical. He was a consultant at Stryker Orthopaedics, AxoGen, and Bioventus. He received research support from AxoGen and Bioventus. He was a board or committee member of American Society for Surgery of

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