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The Early Effects of Tendon Transfers and Open Capsulorrhaphy on Glenohumeral Deformity in Brachial Plexus Birth Palsy

By Peter M. Waters, MD, and Donald S. Bae, MD

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Background: Persistent muscle imbalance and soft-tissue contractures can lead to progressive glenohumeral joint dysplasia in patients with brachial plexus birth palsy. The objective of the present investigation was to determine the effects of tendon transfers and open glenohumeral reduction on shoulder function and dysplasia in patients with preexisting joint deformity secondary to brachial plexus birth palsy.

Methods: Twenty-three patients with preexisting glenohumeral deformity underwent latissimus dorsi and teres major tendon transfers to the rotator cuff with concomitant musculotendinous lengthening of the pectoralis major and/or subscapularis and open glenohumeral joint reduction for the treatment of internal rotation contracture and external rotation weakness. Shoulder function was assessed with use of the modified Mallet classification system and the Active Movement Scale. Glenoid version and humeral head subluxation were quantified radiographically, and glenohumeral deformity was appropriately graded. The mean duration of clinical and radiographic follow-up was thirty-one and twenty-five months, respectively.

Results: Clinically, all patients demonstrated improved global shoulder function, with the mean aggregate Mallet score improving from 10 points preoperatively to 18 points postoperatively (p < 0.01). The mean modified Mallet score for external rotation improved from 2 to 4 (p < 0.01). Similarly, the mean Active Movement Scale score for external rotation improved from 3 to 6 (p < 0.01). The mean Mallet hand-to-spine score improved from 1 to 2 (p < 0.01). The mean Active Movement Scale score for internal rotation remained constant at 6. Radiographically, the mean glenoid version improved from −39° preoperatively to −18° postoperatively (p < 0.01). The mean percentage of the humeral head anterior to the middle of the glenoid similarly improved from 13% to 38% (p < 0.01). The mean glenohumeral deformity score improved from 3 to 2 (p < 0.01). Nineteen (83%) of the twenty-three patients demonstrated glenohumeral remodeling; one patient had progressive worsening of glenohumeral deformity.

Conclusions: Tendon transfers to the rotator cuff, combined with musculotendinous lengthenings and open reduction of the glenohumeral joint, improve global shoulder function and lead to glenohumeral joint remodeling in the majority of selected patients with mild-to-moderate preexisting glenohumeral dysplasia secondary to brachial plexus birth palsy. Future study of the long-term outcomes of these procedures will help to clarify the ultimate effect on glenohumeral joint function.

Level of Evidence: Therapeutic Level IV. See Instructions to Authors for a complete description of levels of evidence.

Brachial plexus birth palsy refers to the paralysis of the upper extremity secondary to a traction or compression injury to the brachial plexus during birth1-2. Although the majority of infants demonstrate spontaneous recovery, some have persistent neurological deficits with upper limb impairment3-4. Microsurgical nerve reconstruction, soft-tissue releases, tendon transfers, and humeral osteotomy all have been proposed to improve upper extremity function in appropriately selected patients with brachial plexus birth palsy5-18.

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In addition to the physical impairments due to muscle weakness and soft-tissue contracture of the shoulder, recent studies have demonstrated that progressive glenoid dysplasia and/or joint instability may be seen in the setting of long-standing muscular imbalance about the shoulder\textsuperscript{19-25}. Previous studies have established that such glenohumeral deformity may appear early in life, progresses with age, and correlates with the magnitude of shoulder internal rotation contracture\textsuperscript{22,25}. Extra-articular procedures—including pectoralis major and/or subscapularis musculotendinous lengthening in combination with latissimus dorsi and/or teres major tendon transfers to the rotator cuff—have been reported to significantly improve global shoulder function in patients with brachial plexus birth palsy who have internal rotation contracture and external rotation and abduction weakness\textsuperscript{13,17,26-28}. However, despite amelioration of the extrinsic muscle imbalance across the growing shoulder, these extra-articular procedures have not reliably led to glenohumeral joint remodeling\textsuperscript{27,28}.

A recent study suggested that arthroscopic release of the glenohumeral joint capsule and subscapularis tendon, either in isolation or combined with latissimus dorsi and teres major tendon transfers to the rotator cuff, can result in improvements in passive shoulder external rotation and improved centering of the humeral head within the glenoid\textsuperscript{29}. Of the fifteen patients...
The purpose of the present study was to determine the effect of soft-tissue balancing and open glenohumeral joint reduction on shoulder function and preexisting glenohumeral dysplasia in patients with brachial plexus birth palsy.

Materials and Methods

Patients with brachial plexus birth palsy who have presented to the Hand and Upper Extremity Program in the Department of Orthopaedic Surgery at our institution have been prospectively evaluated since 1993. Throughout the study period, detailed medical histories and physical examinations were performed for all patients. Upper extremity function, and specifically active shoulder movement, was comprehensively categorized according to the modified Mallet classification system (Fig. 1). An aggregate Mallet score was calculated for each patient by summing each of the individual elements (maximum score, 25 points). In addition, upper extremity motion was assessed with use of the Toronto Test Score and Hospital for Sick Children Active Movement Scale (Table I). The intraobserver and interobserver reliability of these classification systems has been previously established.

In addition to these clinical assessments, radiographic evaluation of both glenohumeral joints was performed for all patients with use of magnetic resonance imaging or computed tomography with the patient under conscious sedation. Glenoid retroversion and humeral head subluxation were measured according to standardized techniques, and the overall radiographic appearance of the glenohumeral joints was classified according to a previously described grading system (Fig. 2, Table II). In the present study, by convention, glenoid retroversion is referred to with negative values. Furthermore, humeral head subluxation is described as the percentage of the humeral head, measured at its greatest diameter, lying anterior to the midline of the glenoid and the axis of the scapular spine on axial images. Previous reports have confirmed the validity and reliability of these measurement techniques; glenoid version measurements, in particular, have demonstrated a standard deviation of $5^\circ$ to $7^\circ$. For reference, the mean glenoid version in normal patients with an age of less than two years is $-6.3^\circ$ and mean glenoid version in normal patients with an age of more than two years is $-2.1^\circ$.

Patients with brachial plexus birth palsy associated with persistent impairment of shoulder function were managed according to an evolving surgical algorithm on the basis of three factors: muscle strength, soft-tissue contractures, and underlying glenohumeral deformity. All candidates for surgery had internal rotation contracture and concomitant external rotation weakness about the shoulder. Patients with rotator cuff muscle weakness and imbalance, minimal joint contractures, and minimal glenohumeral deformity were managed with latissimus dorsi and teres major tendon transfers to the rotator cuff, as previously described. Conversely, older patients with severe glenohumeral deformity, irreducible glenohumeral joint dislocation (defined as the absence of a glenoid and a flattened humeral head), and/or arthrosis were managed with derotational humeral osteotomy. Patients with mild-to-moderate glenohumeral deformity that was deemed reducible were managed with open reduction of the glenohumeral joint, latissimus dorsi and teres major tendon transfers to the rotator cuff, and musculotendinous lengthening of the pectoralis major and/or subscapularis (Fig. 3). Preoperative imaging studies (magnetic resonance imaging or computed tomography), examination with the patient under anesthesia, and open exposure of the joint were utilized to determine the reducibility of the joint. The results for this cohort of patients with mild-to-moderate glenohumeral deformity are the focus of the current investigation.

The indications for surgical intervention included progressive loss of passive shoulder external rotation and radiographic evidence of posterior humeral head subluxation and glenoid dysplasia. In addition, patients who lacked adequate active shoulder abduction and external rotation by the age of three years were considered to be candidates for surgery as the natural history was unlikely to lead to improvement.

Surgery was performed through an axillary incision with the patient in the lateral decubitus position. Musculotendinous lengthening of the pectoralis major and/or subscapularis was performed to improve passive shoulder external rotation to $>90^\circ$ with the arm abducted and to $>30^\circ$ with the arm adducted. Following these releases, the latissimus dorsi and teres major tendons were released from their humeral insertion. A gleno-
underwent physical or occupational therapy for range of motion as well as strengthening exercises. No postoperative bracing was utilized. Upper extremity motion was evaluated during serial postoperative visits. Glenohumeral joint morphology was assessed on the basis of magnetic resonance imaging or computed tomography scans that were made at one, two, and five years postoperatively.

Thirty-eight patients underwent tendon transfer and soft-tissue lengthening with concomitant open reduction of the glenohumeral joint at our institution between 1997 and the time of writing. Twenty-three of these patients had complete preoperative and postoperative clinical and radiographic evaluations and are the subject of this investigation. The study group included ten male and thirteen female patients. The mean age at the time of surgery was twenty-seven months (range, eight to fifty months). The mean duration of radiographic follow-up was twenty-five months (range, eleven to fifty-five months), and the mean duration of clinical follow-up was thirty-one months (range, eleven to fifty-five months) (Table III).

Comparisons of means for continuous variables were performed with use of the paired Student t test with Microsoft Excel 2000 software (Microsoft Corporation, Redmond, Washington). P values were two-tailed, and the level of significance was set at \( p < 0.05 \).

The present study was approved by the Committee on Clinical Investigation of our institution's internal review board.

### Results

All patients had significant improvement in global shoulder function following musculotendinous lengthenings, tendon transfers, and open joint reductions as measured on the basis of the aggregate score of the modified Mallet classification system. The mean aggregate Mallet score improved from 10 (range, 2 to 16) preoperatively to 18 (range, 13 to 22) postoperatively (\( p < 0.01 \)) (Table III). The mean modified Mallet score for global external rotation improved from 2 (range, 0 to 3) to 4 (range, 3 to 5) (\( p < 0.01 \)). Improvements in global shoulder function and global external rotation did not adversely affect shoulder internal rotation as the mean Mallet score for hand-to-spine motion increased from 1 (range, 0 to 3) preoperatively to 2 (range, 0 to 4) postoperatively (\( p < 0.01 \)). No patient had deterioration in global shoulder function as assessed on the basis of the aggregate Mallet score.

Evaluation of the Hospital for Sick Children Active Movement Scale scores demonstrated similar improvements in active shoulder motion. The mean Active Movement Scale score for external rotation improved from 3 (range, 0 to 6) to 6 (range, 6 to 7) (\( p < 0.01 \)). The mean Active Movement Scale score for internal rotation remained constant at 6 (range, 5 to 7) (\( p = 0.28 \)).

Glenohumeral joint morphology was characterized by the measurement of both glenoid version and the percentage of the humeral head anterior to the axis of the scapular spine and the middle of the glenoid. Preoperatively, the mean glenoid version of the affected shoulder was \(-39^\circ\) (range, \(-4^\circ\) to \(-58^\circ\)) and the mean percentage of the humeral head anterior to the axis of the scapular spine was \(-50\%\) (range, \(-27\%\) to \(-81\%\)). The mean difference between the versions at the time of surgery and preoperatively remained constant. The percentage of the humeral head anterior to the axis of the scapular spine and the middle of the humeral head increased but the differences were not statistically significant.

### Table II: Classification System for Glenohumeral Joint Deformity in Brachial Plexus Birth Palsy, Based on Measurements of Glenoid Version and Humeral Head Subluxation

<table>
<thead>
<tr>
<th>Classification</th>
<th>Radiographic Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(&lt;5^\circ) difference in glenoid version</td>
</tr>
<tr>
<td>2</td>
<td>(&gt;5^\circ) difference in glenoid version</td>
</tr>
<tr>
<td>3</td>
<td>Posterior humeral head subluxation, (&lt;35%) of humeral head anterior to axis of scapular spine</td>
</tr>
<tr>
<td>4</td>
<td>Presence of a false glenoid</td>
</tr>
<tr>
<td>5</td>
<td>Humeral head flattening, progressive/complete humeral head dislocation</td>
</tr>
<tr>
<td>6</td>
<td>Infantile posterior glenohumeral dislocation</td>
</tr>
<tr>
<td>7</td>
<td>Proximal humeral growth arrest</td>
</tr>
</tbody>
</table>
to the axis of the scapular spine was 13% (range, 0% to 40%). At a mean of twenty-five months of follow-up, the mean glenoid version in the affected shoulder was $-18^\circ$ (range, $-2^\circ$ to $-43^\circ$) and the mean percentage of the humeral head anterior to the axis of the scapular spine in the affected shoulder was 38% (range, 0% to 55%). The mean improvement in glenoid version in the affected shoulder was $21^\circ$ ($p < 0.01$), and the mean improvement in humeral head subluxation was 25% ($p < 0.01$).

Glenohumeral morphology of the affected extremity as determined with use of the classification system of Waters et al. improved in nineteen patients (83%), worsened in one, and remained static in three. The mean glenohumeral joint deformity score improved from 3 (range, 2 to 5) preoperatively to 2 (range, 1 to 5) postoperatively.

### TABLE III Summary of Mean Preoperative and Postoperative Data*

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mallet score</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>10 (range, 2 to 16)</td>
<td>18 (range, 13 to 22)</td>
</tr>
<tr>
<td>Global external rotation</td>
<td>2 (range, 0 to 3)</td>
<td>4 (range, 3 to 5)</td>
</tr>
<tr>
<td>Hand-to-spine</td>
<td>1 (range, 0 to 3)</td>
<td>2 (range, 0 to 4)</td>
</tr>
<tr>
<td><strong>Active Movement Scale</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External rotation</td>
<td>3 (range, 0 to 6)</td>
<td>6 (range, 6 to 7)</td>
</tr>
<tr>
<td>Internal rotation</td>
<td>6 (range, 5 to 7)</td>
<td>6 (range, 5 to 7)</td>
</tr>
<tr>
<td>Glenoid version (deg)</td>
<td>$-39^\circ$ (range, $-4^\circ$ to $-58^\circ$)</td>
<td>$-18^\circ$ (range, $-2^\circ$ to $-43^\circ$)</td>
</tr>
<tr>
<td>Percentage of humeral head anterior to axis of scapular spine</td>
<td>13% (range, 0% to 40%)</td>
<td>38% (range, 0% to 55%)</td>
</tr>
<tr>
<td>Deformity classification</td>
<td>3 (range, 2 to 5)</td>
<td>2 (range, 1 to 5)</td>
</tr>
</tbody>
</table>

*Clinical measurements of shoulder motion include the aggregate Mallet classification score as well as the Mallet scores for external rotation and hand-to-spine motion. The Hospital for Sick Children Active Movement Scale was also recorded for external rotation and internal rotation. Preoperative and postoperative values for glenoid version and the percentage of humeral head anterior to the axis of the scapular spine are also listed, with corresponding glenohumeral deformity classification according to the schema of Waters et al.
Figs. 4-A through 4-D Images demonstrating remodeling of the glenohumeral joint following musculotendinous lengthenings, latissimus dorsi and teres major tendon transfers to the rotator cuff, and open glenohumeral joint reduction with posterior capsulorrhaphy in a forty-four-month-old girl with left shoulder involvement. **Figs. 4-A and 4-B** Preoperative axial magnetic resonance imaging scan and corresponding outline. **Figs. 4-C and 4-D** Postoperative axial magnetic resonance imaging scan and corresponding outline demonstrating improvements in glenoid version and humeral head subluxation nineteen months after surgery. Reproduced with permission of COSF [Children’s Orthopaedic Surgery Foundation], Boston.
to 2 (range, 1 to 5) postoperatively (p < 0.01). An example of glenohumeral joint remodeling following soft-tissue balancing and open reduction is shown in Figures 4-A through 4-D.

**Discussion**

Although many infants demonstrate spontaneous recovery, some patients with brachial plexus birth palsy have persistent neurological deficits resulting in upper extremity weakness and functional compromise. In addition to limitations in upper extremity motion, persistent muscle weakness and imbalance affect osseous growth and joint development. Glenoid retroversion and hypoplasia, posterior subluxation and flattening of the humeral head, inferior hooking of the coracoid, and clavicular shortening all have been observed in patients with brachial plexus birth palsy.

It has been hypothesized that eccentric forces imparted across the developing glenohumeral joint result in abnormal joint morphology. These changes are progressive and may lead to secondary functional limitations. Ultimately, the severity of glenohumeral deformity influences the secondary reconstructive options as soft-tissue procedures alone may result in suboptimal outcomes in the setting of underlying osseous and joint deformity.

On the basis of these principles and the experience at our institution, we have adopted the treatment protocol outlined in Figure 3. For patients with no or minimal glenohumeral dysplasia, musculotendinous lengthenings and tendon transfers are performed to improve global shoulder function. At the other end of the spectrum, for patients with severe humeral head flattening, glenoid deformity, and glenohumeral dislocation, derotational humeral osteotomies are performed to position the distal part of the upper extremity in a more functional position. It has been our practice to perform tendon transfers with or without joint reduction and stabilization procedures in patients with mild-to-moderate glenohumeral dysplasia (type-II, III, and IV deformities). The effect of soft-tissue rebalancing procedures with concomitant open glenohumeral joint reduction on glenohumeral development is the focus of the current investigation.

Pearl et al. reported their experience with arthroscopic release of the subscapularis tendon and/or anterior glenohumeral joint capsule, performed either in isolation or combined with latissimus dorsi and teres major tendon transfers to the rotator cuff. Patients demonstrated improvement in terms of passive external rotation of the shoulder as well as in terms of centering of the humeral head within the glenoid. In addition, twelve of the fifteen patients for whom postoperative magnetic resonance imaging was available at a minimum of two years demonstrated improvement in terms of glenohumeral deformity, suggesting that intra-articular procedures combined with extra-articular soft-tissue rebalancing may lead to glenohumeral joint remodeling.

Hui and Torode similarly suggested that open reduction of the glenohumeral joint, accompanied by tendon lengthenings and transfers, may reduce abnormal glenoid retroversion in young patients with brachial plexus birth palsy. Indeed, in their series of twenty-three patients with an average duration of follow-up of forty-three months, glenoid retroversion improved by approximately 30% following open reduction of the glenohumeral joint.

Our results demonstrate that, in appropriately selected patients, latissimus dorsi and teres major tendon transfers to the rotator cuff combined with musculotendinous lengthenings and open glenohumeral joint reduction not only improve upper extremity function but also result in remodeling of glenohumeral dysplasia in the majority of patients. In the current investigation, the mean glenoid version improved from −39° to −18° following muscle rebalancing and soft-tissue releases. The percentage of the humeral head anterior to the middle of the glenoid improved from 13% to 38%. While the average duration of clinical and radiographic follow-up was thirty-one and twenty-five months, respectively, improvements in both shoulder motion and glenohumeral joint morphology were seen early and were maintained during the follow-up period.

Interestingly, improvements in shoulder external rotation were not seen at the expense of internal rotation in the patients described here. Indeed, the mean Mallet hand-to-spine score improved from 1 preoperatively to 2 postoperatively, and the mean Active Movement Scale score for internal rotation remained constant at 6. Preservation of internal rotation power is critical for midline activities of daily living and bimanual tasks, and the risk of losing internal rotation motion and strength may outweigh the benefits of improved external rotation. While some improvements in internal rotation and active shoulder motion might be attributable to improved compliance with rehabilitative care, several aspects of the surgical technique presented here, including fractional lengthening of the subscapularis at its musculotendinous junction as opposed to release of its scapular origins and selective release of the anteroinferior glenohumeral joint capsule through an open approach, may have contributed to the preservation of internal rotation strength.

It should be noted that the patients in the present study underwent surgery relatively early in life. Indeed, the average age at the time of surgery in this patient cohort was twenty-seven months, and the oldest patient was fifty months of age. Thus, the findings of the current investigation may not be applicable to brachial plexus birth palsy patients of all ages. However, early surgical intervention is warranted for younger patients with glenohumeral deformity and loss of passive shoulder external rotation despite extensive therapy aimed at maintaining glenohumeral motion. Previous analyses of older patients have demonstrated that glenohumeral dysplasia is progressive, and the opportunity to perform soft-tissue releases and musculotendinous lengthenings may be lost with advancing deformity. Only two patients in our series had type-V glenohumeral deformity; all others had less severe glenohumeral dysplasia. Patients with severe glenohumeral deformity—including humeral head flattening, glenoid absence, and complete posterior dislocation of the humeral head against the scapula—may still be best served by derotational humeral osteotomy to improve functional status.
Furthermore, patients in the present study demonstrated improvement in global shoulder function and improvement in glenohumeral dysplasia following combined joint reduction and muscle-rebalancing procedures. The relative effect of each of these procedures on joint remodeling and ultimate shoulder function is unknown to date, raising the question of whether joint reduction alone would lead to similar improvements in glenohumeral morphology and active shoulder motion. Future study will be directed at addressing this clinically important question.

It should be recognized that the long-term consequences of glenohumeral joint dysplasia in patients with brachial plexus birth palsy are still unknown. It is unclear whether long-standing glenohumeral dysplasia predisposes to shoulder pain or arthrosis in adulthood. Additional analysis and longer-term follow-up are needed to determine the clinical course of glenohumeral joint dysplasia in these patients.

With these caveats in mind, however, the current study demonstrates that surgical intervention in the form of tendon transfers, soft-tissue releases, and open glenohumeral joint reduction is effective for improving shoulder function and leads to glenohumeral remodeling in the majority of younger patients with mild-to-moderate dysplasia. Care providers—including pediatricians, neurologists, and physical and occupational therapists—must be aware of the risk of shoulder dysplasia and attuned to its potential sequelae. Appropriate radiographic evaluation and, when indicated, surgical treatment should be considered before glenohumeral dysplasia becomes too advanced.

Future efforts in this area should be directed toward the evaluation of a larger number of patients with longer follow-up. As greater numbers of patients are assessed, additional analysis may reveal specific risk factors for persistent or progressive glenohumeral joint deformity following tendon transfers, such as the pattern of brachial plexus involvement, the severity of involvement, the age of the patient at the time of treatment, or the degree of dysplasia. Given the inherent limitations of any case series, future randomized clinical trials should be considered to ascertain the efficacy of this procedure as compared with tendon transfers and musculotendinous lengthenings performed without glenohumeral joint reduction. Finally, long-term outcomes analysis is needed to determine if glenohumeral deformity, even when treated early and arrested, portends a worse prognosis in terms of upper extremity dysfunction, joint instability, or arthrosis. A multicenter prospective study is currently under way to address these important issues.

In summary, latissimus dorsi and teres major tendon transfers to the rotator cuff, combined with appropriate extra-articular musculotendinous lengthenings and open glenohumeral joint reduction, result in improved shoulder function and glenohumeral joint remodeling in the majority of patients with brachial plexus birth palsy with mild-to-moderate dysplasia.

References