Radial to axillary nerve neurotization for brachial plexus injury in children: a combined case series

Clinical article

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Object. Axillary nerve palsy, isolated or as part of a more complex brachial plexus injury, can have profound effects on upper-extremity function. Radial to axillary nerve neurotization is a useful technique for regaining shoulder abduction with little compromise of other neurological function. A combined experience of this procedure used in children is reviewed.

Methods. A retrospective review of the authors’ experience across 3 tertiary care centers with brachial plexus and peripheral nerve injury in children (younger than 18 years) revealed 7 cases involving patients with axillary nerve injury as part of an overall brachial plexus injury with persistent shoulder abduction deficits. Two surgical approaches to the region were used.

Results. Four infants (ages 0.6, 0.8, 0.8, and 0.6 years) and 3 older children (ages 8, 15, and 17 years) underwent surgical intervention. No patient had significant shoulder abduction past 15° preoperatively. In 3 cases, additional neurotization was performed in conjunction with the procedure of interest. Two surgical approaches were used: posterior and transaxillary. All patients displayed improvement in shoulder abduction. All were able to activate their deltoid muscle to raise their arm against gravity and 4 of 7 were able to abduct against resistance. The median duration of follow-up was 15 months (range 8 months to 5.9 years).

Conclusions. Radial to axillary nerve neurotization improved shoulder abduction in this series of patients treated at 3 institutions. While rarely used in children, this neurotization procedure is an excellent option to restore deltoid function in children with brachial plexus injury due to birth or accidental trauma.

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Key Words • axillary nerve injury • brachial plexus • neurotization • peripheral nerve

Abbreviation used in this paper: OBPP = obstetric brachial plexus palsy.
Radial to axillary nerve neurotization

population, the injury mechanism is most often traumatic secondary to motor vehicle collisions or sporting activities. In neonates, axillary nerve injury is seen as a part of obstetric brachial plexus palsy (OBPP). In cases of upper trunk lesions involving C5–6 nerve roots, commonly referred to as Erb’s palsy, neonates are unable to abduct the shoulder and remain internally rotated.

Following brachial plexus injuries, restoration of shoulder abduction is a functional necessity, second only to elbow flexion. Neurotization, or nerve transfer, and nerve grafting are options for repairing axillary nerve lesions. Many options for donor nerves and surgical approaches exist. Possible donor nerves that have been described include the radial, thoracodorsal, intercostal, medial pectoral, and long thoracic nerves. The approach may be anterior axillary, posterior, deltopectoral, or through a sabre-cut incision, an incision from the deltopectoral groove over the clavicle posteriorly to the quadrangular space. The axillary nerve lies deep to the axillary artery from an anterior approach and can be challenging to access for repair; therefore, alternative approaches are critical. As experience has grown with axillary nerve injuries, transfer of triceps motor branches of the radial nerve to the axillary nerve has emerged as a safe, effective, and expedient means of restoring shoulder abduction. However, its use in children is less clear. This 3-institution series is the first detailing radial to axillary nerve neurotization in various brachial plexus injuries of childhood.

Methods

An institutional review board–approved retrospective review of all cases involving children undergoing radial to axillary nerve neurotization across 3 institutions was performed from 2000 to 2013 at Children’s Hospital of Alabama, St. Louis Children’s Hospital, and Monroe Carell Jr. Children’s Hospital at Vanderbilt. Seven children were identified: 4 infants, an 8-year-old, a 15-year-old, and a 17-year-old. Patients 18 years and older but operated on by the authors were excluded to highlight the utility of the repair in pediatric patients. All infants (Cases 1–4) presented after shoulder dystocia during birth. The infants’ ages at surgery were 0.6, 0.8, 0.8, and 0.6 years. The radial to axillary neurotization was the first surgical intervention in all patients; there was no previous surgical intervention. The median infant age at time of surgery was 0.7 years. Of the older children, one child presented after an explosion injury (previously reported case), one after a motor vehicle collision, and one after a football injury (ages 8, 15, and 17 years). Time to surgery was 6, 8, and 11 months in the older group. All patients were followed for a minimum of 8 months after surgery (median 15 months, range 8–59 months).

Muscle strength was graded in children and infants with 2 separate grading scales. For noninfant children, strength was graded on a 0–5 scale, according to the Medical Research Council motor grading scale: 0, no contraction; 1, flicker of contraction; 2, active motion with gravity eliminated; 3, active motion against gravity; 4, active motion against resistance; and 5, normal strength. In several other reports, shoulder abduction was graded based on a scale described by Narakas and others with minimal modifications: M0, no contractility; M1, muscle contraction but no active motion; M2, abduction less than 60°; M3, abduction to 60° for 10 seconds; M4, abduction to 60° against resistance applied to the elbow; M5, abduction to 60 against resistance applied to the forearm. For infants, an alternative 4-grade scale was used, as infants cannot follow commands, thus making it difficult to distinguish between 4 and 5 strength. For pre- and postoperative examinations, it was important to distinguish between deltoid and supraspinatus function in assessing shoulder abduction. The first 15°–20° of shoulder abduction was generally attributed to supraspinatus action, and the remaining abduction to 90° was attributed to deltoid function. In terms of surgical decision making, it was felt that neurotization provided the best chance for muscle recovery (rather than nerve grafting) in all 7 patients. An exact common surgical algorithm for all 3 primary surgeons (C.M.S., T.S.P., and J.C.W.) was not evident, and these patients had neurologic findings suggestive of potential success (deltoid weakness with excellent triceps function in the older age group) or in the cases of the infants who had previously failed primary surgery. For the older age group, the senior author (J.C.W.) combined the procedure with an Oberlin procedure for noted elbow flexion weakness. In treating infants, one common approach among all 3 surgeons was that the initial operation centered on direct exposure of the neuroma with either neurolysis, neurotization, or grafting performed, and in the case of C.M.S., often combined with an orthopedic adjunctive operation in the same sitting. At all institutions, multiple pediatric patients who were not candidates for radial to axillary nerve neurotization underwent traditional brachial plexus repair. Most of these cases have been reported in a previous paper or will be in one currently in progress (Allen LA, Safiano N, Falola M, et al., presented at the 40th Annual Meeting of the AANS/CNS Section on Pediatric Neurological Surgery, 2011).

Operative Procedures

All 3 surgeons (C.M.S., T.S.P., and J.C.W.) used either a transaxillary or posterior approach for radial to axillary nerve neurotization. In terms of surgical decision making, it was felt that neurotization provided a better chance for muscle recovery than nerve grafting. Direct nerve stimulation was used in all cases, so paralytic agents were not used after initial intubation. For a posterior approach, the patient was placed in prone position with the involved upper limb placed over his or her thorax. An incision was made along the posterior arm, beginning at the lateral border of the scapula and running down the posterior deltoid muscle and lateral border of the long head of the triceps. After dissection down to the fascia overlying the triceps, the lateral cutaneous brachial nerve was traced down to the axillary nerve. The quadrangular space was located by following the axillary nerve down. The long and lateral heads of the triceps were separated to visualize the radial nerve and subsequent motor branches to each head. The axillary nerve was then sectioned proximally to the teres minor branch. The long or lateral head motor branch was flipped...
upward to be connected to the previously sectioned axillary nerve using microsutures. Direct neurotization was performed using 8-0 nylon sutures affixed directly to the epineurium of the sectioned radial nerve fascicle and the anterior fascicle of the axillary nerve responsible for innervation of the deltoid muscle. The cutaneous branch was removed from the axillary nerve stump.

When a transaxillary approach was used, the involved arm, axilla, chest, and flank were prepared and draped in a sterile fashion. An incision was made through the axilla and carried down to the split between the biceps and triceps as initially described by Bertelli et al.⁵ The branch of the long head of the triceps was stimulated and identified. The radial nerve was followed back to the tendon of the latissimus dorsi muscle, where the axillary nerve was identified medially. The 2 divisions of the axillary nerve were identified and stimulated for confirmation, specifically looking for the anterior branch. The nerve to the long head of the triceps was cut as distally as possible. The anterior branch of the axillary nerve was then severed as proximally as possible. Under the microscope, three 8-0 nylon sutures were used to connect each nerve.

After neurotization was complete with each approach, elbow and shoulder extension and/or flexion were performed without rupture of the neurotization site. The extremity was moved through its range of motion, ensuring that there was no significant pressure on the neurotization and good alignment was maintained. The wound was irrigated copiously. The incision was closed in layers followed by a subcuticular suture for skin closure. Following closure, the patient’s arm was wrapped in an elastic bandage and placed in a sling to limit tension on the repair site for approximately 2 weeks, after which all patients underwent aggressive occupational therapy.

**Results**

All 7 cases are reviewed in further detail in Table 1. All infants presented at birth and the median age of surgical intervention was 0.7 years. Of the 7 children, 3 were female. No patient had significant shoulder abduction past 15° preoperatively. Three patients had additional neurotization performed in conjunction with the procedure of interest: in all 3 cases the additional procedure was an ulnar nerve to musculocutaneous neurotization procedures, also termed the Oberlin procedure.⁸ Two surgical approaches were used: posterior and transaxillary. The median duration of postoperative follow-up was 15 months (range 8–59 months). All patients displayed improvement in shoulder abduction. All were able to activate their deltoid muscle to abduct against gravity and 4 of 7 were able to abduct against resistance. The median duration of follow-up was 15 months. Of note, after transfer of the radial nerve branch to the long head of the triceps, arm extension remained full strength in all 7 patients.

**Illustrative Cases**

**Case 3 (infant)**

Persistent inability to abduct the shoulder at 8–10 months is a relative indication to proceed with surgical treatment. This male infant was delivered at full term and presented with evidence of right OBPP secondary to shoulder dystocia thought to be due to macrosomia. On examination, he displayed shoulder abduction of less than 15°, 0/4 strength in deltoid, 4/4 in biceps, 2/4 in triceps, and 3/4 in grip. He underwent an axillary to radial nerve coaptation procedure at 1 year of age through a posterior approach. At 59 months’ follow-up, evaluation of his right upper-extremity revealed shoulder abduction to more than 90°, 4/4 deltoid strength, 4/4 biceps strength, 4/4 triceps, and 4/4 grip. He had full range of motion in elbow extension, wrist extension, and finger extension as well as shoulder abduction. In addition, there was more than 50% range of motion in shoulder abduction and a good range of motion in elbow flexion. A photograph obtained during a postoperative examination at 59 months is shown in Fig. 1.

**Case 6 (child)**

General tenets of peripheral nerve recovery are followed in this age group as well. After allowing 4–6 months to assess native recovery, rarely less than 3 months, surgery is pursued when the patient still lacks meaningful shoulder abduction. This 15-year-old female adolescent presented with a left-sided brachial plexus injury following an all-terrain vehicle (ATV) accident. On examination, deficits incurred included total loss of shoulder abduction, shoulder flexion, and elbow flexion, which did not recover by 8 months after injury. Neurotization of the branch to the long head of the triceps from the radial nerve to the axillary nerve was performed via a transaxillary approach. Due to absence of meaningful elbow flexion recovery, the patient also underwent neurotization of a fascicle of the ulnar nerve to the biceps branch of the musculocutaneous nerve as initially described by Oberlin et al.⁹ At 12-month follow-up, she demonstrated intact hand-to-mouth function, shoulder abduction to 90°, and 4 to 4+/5 strength in her biceps, deltoid, triceps, wrist, and grip.

**Discussion**

A significant proportion of axillary nerve injuries occur during obstetrical brachial plexus injuries. Incidences of OBPP range from 0.1% to 0.4% of live births, with rates climbing in recent years due to increasing birth weights.¹⁷ Risk factors for OBPP include shoulder dystocia, vacuum delivery, macrosomia, prolonged second stage of delivery, and breech delivery.⁸ Injuries occur when the abducted arm is placed in traction, which leads to stretching of the upper or lower plexus.¹²,¹⁵,¹⁷ Clavicle fractures are seen in 10%–15% of cases.¹⁷ OBPPs are classified according to location. Upper root level injuries occur most frequently, in 90% of patients, and result in Erb’s palsy—paresis of the supraspinatus, infraspinatus, and deltoid muscles. Thirty percent of OBPPs involve multiple nerves (axillary, suprascapular, and biceps). However, our group of neonatal patients had isolated axillary nerve injuries;
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age at Presentation, Sex</th>
<th>Mechanism</th>
<th>Preop Diagnosis</th>
<th>Time to Surgery (yrs)</th>
<th>Preop Exam</th>
<th>Approach, Additional Procedures</th>
<th>Follow-Up Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>birth, M</td>
<td>large for gestational age</td>
<td>shoulder dystocia</td>
<td>0.6</td>
<td>shoulder abduction 40°, 2/4 deltoid, 3/4 biceps, 4/4 triceps, 3/4 grip</td>
<td>posterior</td>
<td>18 mos: shoulder abduction &gt;90°, 3/4 deltoid, 4/4 biceps, 4/4 triceps, 4/4 grip</td>
</tr>
<tr>
<td>2</td>
<td>birth, F</td>
<td>difficult delivery</td>
<td>shoulder dystocia</td>
<td>0.8</td>
<td>shoulder abduction &lt;15°, 0/4 deltoid, 0/4 biceps, 2/4 triceps, 4/4 grip</td>
<td>posterior</td>
<td>48 mos: shoulder abduction &gt;90°, 4/4 deltoid, 3/4 biceps, 4/4 triceps, 4/4 grip</td>
</tr>
<tr>
<td>3</td>
<td>birth, M</td>
<td>difficult delivery</td>
<td>shoulder dystocia</td>
<td>0.8</td>
<td>shoulder abduction &lt;15°, deltoid 0/4, biceps 4/4, triceps 2/4, 3/4 grip</td>
<td>posterior</td>
<td>59 mos: shoulder abduction &gt;90°, 4/4 deltoid, 4/4 biceps, 4/4 triceps, 4/4 grip</td>
</tr>
<tr>
<td>4</td>
<td>birth, F</td>
<td>difficult delivery</td>
<td>shoulder dystocia</td>
<td>0.6</td>
<td>shoulder abduction &lt;15°, 1/4 deltoid, 1/4 biceps, 4/4 triceps, 4/4 grip</td>
<td>posterior, Oberlin</td>
<td>15 mos: shoulder abduction &gt;15°, 3/4 deltoid, 4/4 biceps, 4/4 triceps, 4/4 grip</td>
</tr>
<tr>
<td>5</td>
<td>8 yrs, M</td>
<td>explosion</td>
<td>upper trunk brachial plexus injury</td>
<td>0.5</td>
<td>shoulder abduction &lt;15°, 1/5 deltoid, 1/5 biceps, 4/5 triceps, 4/5 grip</td>
<td>transaxillary, Oberlin</td>
<td>8 mos: shoulder abduction 90°, 4/5 deltoid, 4/5 biceps, 4/5 triceps, 4/5 grip</td>
</tr>
<tr>
<td>6</td>
<td>15 yrs, F</td>
<td>ATV accident</td>
<td>brachial plexus injury</td>
<td>0.7</td>
<td>shoulder abduction &lt;15°, 0/5 deltoid, 0/5 biceps, 0/5 triceps, 5/5 grip</td>
<td>transaxillary, Oberlin</td>
<td>12 mos: shoulder abduction 90°, 4/5 deltoid, 4/5 biceps, 4/5 triceps, 5/5 grip</td>
</tr>
<tr>
<td>7</td>
<td>17 yrs, M</td>
<td>football</td>
<td>axillary nerve palsy</td>
<td>0.9</td>
<td>shoulder abduction &lt;15°, 0/5 deltoid, 5/5 biceps, 5/5 triceps, 5/5 grip</td>
<td>posterior</td>
<td>13 mos: shoulder abduction 90°, 3/5 deltoid, 5/5 biceps, 5/5 triceps, 5/5 grip</td>
</tr>
</tbody>
</table>

*All infant motor scores are on a scale of 0–4, as infants cannot follow commands and one cannot distinguish between 4 and 5 strength (Cases 1–4). All other cases are scored on a strength scale of 0–5 (Cases 5–7). ATV = all-terrain vehicle.
thus, only axillary nerve neurotization was required. The data on isolated axillary nerve injury in OBPP are limited to one case series reported by Terzis and Kokkalis,49 who demonstrated good and excellent results, defined by deltoid strength of M3 or better in 49 (87.5%) of 56 plexuses. Postoperatively, the average shoulder abduction increased from 35° to 109°. The authors concluded that the best results were seen in early cases (in which surgery was performed at the age of 3 months or younger) and when intraplexus donors were used to reconstruct the posterior cord. The following methods of axillary nerve reconstruction were used: posterior cord grafting (in 37 cases), intraplexus donors (in 12), intercostal nerve donor (in 5), and contralateral C-7 nerve graft (in 2). For the intraplexus donors, the article makes no mention of radial to axillary nerve neurotization and states that C-5, C-6, and T-1 stumps were used for intraplexus neurotization. Thus, despite the large, impressive case series, radial to axillary nerve neurotization was not performed in this cohort.

Non-OBPP axillary nerve injury most often occurs secondary to blunt trauma, but can be due to athletic injuries or iatrogenic causes.5,7,11,21,29,38,51 Patients are most often young and male. Kline and Kim19 described 4 distinct types of axillary nerve injuries: 1) isolated axillary palsy, 2) axillary with suprascapular palsy, 3) axillary and posterior cord palsies, and 4) axillary palsy with other plexus lesions.16,19 Our case series represents a combination of isolated axillary nerve injuries and upper brachial plexus injuries, and when necessary, musculocutaneous nerve repair was performed in the same setting. All 3 patients with upper trunk lesions had excellent results after their Oberlin procedures.

In 1948, Lurje25 was the first to describe radial to axillary nerve neurotization, reporting a case involving a 20-year-old woman who had been injured in a bomb explosion. The author completed neurotization of the long thoracic nerve to suprascapular nerve and motor branches of the radial nerve to the axillary nerve to restore shoulder function. Since this initial experience, several case series in adults have been reported. In one of the largest series of isolated axillary nerve injuries, Lee et al.21 reported on 21 patients, ages 13–79 years, who underwent triceps motor branch transfer. Mechanisms of injury included motor vehicle accidents (in 15 cases), falls or athletic injuries (in 5 cases), and proximal humerus fracture surgery (in 1 case).21 The patients’ average postoperative deltoid strength was 3.5 ± 1.1. Of the 5 patients who did not achieve greater than M3 function, 4 were older than 50 years and 1 was treated 14 months postinjury.21 The authors’ regression model revealed that “delay from injury to surgery” (treatment delay), age of patient, and BMI affected outcome of the procedure, although it is difficult to find robust predictors in a study of 21 cases.

Most axillary nerve repairs are not isolated procedures, as they are usually performed in patients with upper cord lesions that necessitate concomitant suprascapular and/or biceps nerve transfers. When conducting dual transfers to the suprascapular and axillary nerve in patients with upper cord palsies, Chuang et al.7 reported an average of 55° increase in shoulder abduction as comp-

Fig. 1. Case 3. Image obtained during follow-up examination 59 months after surgery.
Radial to axillary nerve neurotization

pared with 45° when only suprascapular nerve transfer was performed. Similarly, Nagano40 showed that following dual nerve transfer to axillary and suprascapular nerve, 88% of patients achieved greater than 50° of shoulder abduction and 30° of external rotation. Bertelli and Ghizoni4 transferred the triceps motor branches to shoulder abduction and 30° of external rotation. Kawai and Akita18 performed radial nerve transfer to the axillary nerve, accessory nerve transfer to the suprascapular nerve, and a partial median nerve transfer to the musculocutaneous nerve in a 15-year-old patient, although no preoperative or postoperative details were provided. Dahlin et al.12 evaluated 6 pediatric patients with axillary nerve injuries. One 9-year-old boy and two 13-year-old boys underwent radial to axillary nerve transfer after blunt shoulder trauma. At 11–14 months after surgery (11 and 12 months for the two 13-year-olds and 14 months for the 9-year-old), each of the patients had positive electromyography findings and had recovered 4/5 deltoid muscle function. In the same cohort, a 10-year-old boy and 16-year-old boy suffered shoulder dislocations and underwent sural nerve grafting to the axillary nerve with 4/5 and 2/5 deltoid strength, respectively. Two patients were treated conservatively (without surgery)—a 10-year-old and an 11-year-old, who sustained axillary nerve injury due to blunt trauma and shoulder dislocation, respectively—and both achieved 4/5 deltoid function. Lastly, Lee et al.22 evaluated two 16-year-old patients who had both suffered isolated axillary nerve injuries in motorcycle accidents. They both underwent triceps motor branch transfer to the axillary nerve, and at 41 months in 1 case and 12 months in the other, achieved 4.5/5 deltoid strength with 170° of shoulder abduction.

Timing between the inciting trauma and operative intervention is an important factor for full recovery and remains controversial.31,41,50 Alnot and Valenti suggested waiting 12 months postinjury until surgical repair is explored. Leechavengvongs et al.23 reported satisfactory results with an average of 6 months from injury to operation. In their anatomical study and report of 3 cases, Bertelli et al.5 recommended surgery in patients with paralysis lasting more than 8 but less than 12 months. In cases in which the injury was not discovered until after 1 year, Dahlin et al.11 reported promising outcomes with radial nerve transfer at 14–22 months after injury, with all 3 patients achieving 4/5 deltoid strength. As previously mentioned, Lee et al.21 reported a delay to surgery as a predictor for poor recovery of shoulder abduction. In our series, all patients underwent surgery within 10 months of their initial injury.

Several donor nerve options exist. Samardzic et al.41 reported on 11 cases in which the median pectoral nerve,22 sometimes combined with the first intercostal nerve, was used for axillary nerve neurotization; 82% of the patients achieved a functional recovery. Several years earlier, the same authors observed that 74% of their patients recovered shoulder abduction over 45° when the thoracodorsal or subscapular nerve was used as donor to the axillary nerve.42 Intercostal nerves were some of the earliest options available for nerve transfer in avulsed brachial plexus injuries.31,46 Limitations included increased distance between site of anastomosis, denervated muscles, use of nerve grafts, and mixing motor and sensory axons.44 Results with intercostal donor nerves vary widely, depending on how many intercostal nerves are used, with one
<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Cases</th>
<th>Avg Pt Age in Yrs (range)</th>
<th>Common Injury Mechanism</th>
<th>Avg Time to Op in Mos (range)</th>
<th>Avg Preop Deltoid Abduction</th>
<th>Concomitant Nerve Transfers</th>
<th>Donor Nerve</th>
<th>Avg FU (mos)</th>
<th>Median Postop Deltoid Strength</th>
<th>Mean Postop Shoulder Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leechavengvongs et al., 2003</td>
<td>7</td>
<td>25 (13–35)</td>
<td>MVA</td>
<td>6.3 (3–10)</td>
<td>0/5</td>
<td>CN XI to suprascapular nerve, Oberlin</td>
<td>long HTB</td>
<td>20</td>
<td>4/5</td>
<td>124°</td>
</tr>
<tr>
<td>Bertelli &amp; Ghizoni, 2004</td>
<td>10</td>
<td>28 (19–32)</td>
<td>—</td>
<td>6.0 (5–7)</td>
<td>0/5</td>
<td>CN XI to suprascapular nerve, Oberlin</td>
<td>7 long HTB, 3 lateral HTB</td>
<td>24</td>
<td>4/5</td>
<td>92°</td>
</tr>
<tr>
<td>Kawai &amp; Akita, 2004</td>
<td>6</td>
<td>20 (15–27)</td>
<td>—</td>
<td>2.3 (1.3–3)</td>
<td>0/5</td>
<td>5/6 cases: CN XI to suprascapular nerve, Oberlin</td>
<td>radial</td>
<td>39</td>
<td>—</td>
<td>90° elevation in 5/6; 45° in 1/6</td>
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<tr>
<td>Leechavengvongs et al., 2006</td>
<td>15</td>
<td>27 (13–62)</td>
<td>MVA</td>
<td>6.0 (3–10)</td>
<td>0/5</td>
<td>CN XI to suprascapular nerve, Oberlin</td>
<td>long HTB</td>
<td>32</td>
<td>4/5</td>
<td>115°</td>
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<td>3</td>
<td>23 (19–27)</td>
<td>—</td>
<td>9.0 (8–10)</td>
<td>0/5</td>
<td>none</td>
<td>2 long HTB, 1 medial HTB</td>
<td>18</td>
<td>4/5</td>
<td>abduction, improved strength by 50%</td>
</tr>
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<td>Jerome, 2011</td>
<td>5</td>
<td>27 (—)</td>
<td>—</td>
<td>— (1–6)</td>
<td>—</td>
<td>CN XI to suprascapular nerve</td>
<td>long HTB</td>
<td>26</td>
<td>5/5</td>
<td>120°</td>
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<td>12 (9–24)</td>
<td>MVA</td>
<td>18.3 (14–22)</td>
<td>3/5</td>
<td>none</td>
<td>radial</td>
<td>12</td>
<td>4/5</td>
<td>—</td>
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<td>Jerome, 2012</td>
<td>6</td>
<td>28 (20–52)</td>
<td>MVA</td>
<td>4.2 (3–5)</td>
<td>0/5</td>
<td>CN XI to suprascapular nerve</td>
<td>long HTB</td>
<td>26</td>
<td>5/5</td>
<td>133°</td>
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<tr>
<td>Jerome &amp; Rajmohan, 2012</td>
<td>9</td>
<td>26 (20–52)</td>
<td>MVA</td>
<td>3.8 (3–5)</td>
<td>0/5</td>
<td>none</td>
<td>long HTB</td>
<td>35</td>
<td>5/5</td>
<td>134°</td>
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<tr>
<td>Lee et al., 2012</td>
<td>21</td>
<td>38 (16–79)</td>
<td>MVA, sports, iatrogenic</td>
<td>7.6 (4–14)</td>
<td>0/5</td>
<td>none</td>
<td>long HTB</td>
<td>21</td>
<td>4/5</td>
<td>119°</td>
</tr>
<tr>
<td>Lu et al., 2012</td>
<td>9</td>
<td>27 (21–39)</td>
<td>—</td>
<td>7.0 (3–11)</td>
<td>0/5</td>
<td>CN XI to suprascapular nerve, Oberlin</td>
<td>long HTB &amp; medial HTB</td>
<td>33</td>
<td>3/5–4/5</td>
<td>full abduction in 6/9, 50–130° in 3/9</td>
</tr>
<tr>
<td>Kostas-Agnantis et al., 2013</td>
<td>9</td>
<td>27 (21–35)</td>
<td>MVA &amp; falls</td>
<td>7.2 (4–11)</td>
<td>0/5</td>
<td>CN XI to suprascapular nerve</td>
<td>long HTB &amp; medial HTB</td>
<td>18</td>
<td>4/5</td>
<td>112°</td>
</tr>
</tbody>
</table>

* Avg = average; CN = cranial nerve; FU = follow-up; HTB = head of triceps brachii; MVA = motor vehicle accident; pt = patient.
Radial to axillary nerve neurotization

case series achieving 63.2% recovery of axillary nerve function. Reports suggest that taking 3 or 4 intercostal nerves is an accepted practice with good results. If the spinal accessory nerve is used for axillary nerve neurotization, although the trapezius is synergistic to deltoid function, an interposition graft is required due to distance. The thoracodorsal nerve, responsible for shoulder abduction, has also been used, but deltoid contraction was seen during shoulder abduction, which defeats the purpose of restoring shoulder abduction.

Numerous options exist for recovery of shoulder abduction. A major strength of this particular neurotization is that the radial nerve is adjacent to the axillary nerve, thus no graft is needed. Superior results have been shown in transfer compared with grafting. Furthermore, the radial nerve is mostly a motor nerve with minor sensory input; thus, sensory deficit after surgery is rare. Moreover, the radial nerve is a similar size to the axillary nerve. In terms of function, the optimal candidate for donor nerve is one that innervates a muscle synergistic to the target muscle. The triceps works in tandem with the deltoid, making reinnervation and retraining of the muscle natural. The long head of the triceps is one of 3 heads and thus relatively redundant. Losing it appears to have negligible effect on triceps function. The long head of the triceps is also used in musculocutaneous flaps and muscle transfers. No patient in any series, including the current study, was found to have elbow extension deficits after this procedure.

Conclusions

We have reviewed our experience with axillary nerve injuries across 3 institutions. Excellent results were impaled after radial to axillary nerve neurotization, with all patients achieving shoulder abduction against gravity and most against resistance, with a negligible effect on arm extension via triceps function. Radial to axillary nerve neurotization appears to be a safe, effective, and expedient operation to restore shoulder abduction in children. Our series highlights its role in pediatric patients representing a broad range of ages, from neonates to young adults.

Disclosure

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