Axillary nerve repair in 99 patients with 101 stretch injuries

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Object. The purpose of this paper was to analyze outcomes in patients at the Louisiana State University Health Sciences Center (LSUHSC) who presented with contusion–stretch injuries to the axillary nerve. These injuries resulted from shoulder injury either with or without fracture/dislocation. Although recovery of deltoid function can occur spontaneously, this was not always the case.

Methods. Severe deficits persisting for several months led the patients to undergo surgery. Operative categories included isolated axillary palsy (56 procedures), combined axillary and suprascapular palsies (11 procedures), axillary and radial palsies (14 procedures), and axillary palsy with another deficit, usually infraclavicular plexus loss (20 procedures). Deltoid function was evaluated pre- and postoperatively by applying the LSUHSC grading system. An anterior infraclavicular approach was usually followed during surgery, but in three patients an additional posterior approach was used.

Axillary lesions usually began in the proximal portion of the posterior cord. Although several patients had distraction of the nerve, lesions in continuity were found in more than 90% of cases. Intraoperative nerve action potential (NAP) recordings were performed to determine the need for resection. Most repairs were made using grafts, although in three patients with relatively focal lesions suture was used.

When an NAP was recorded across the lesion and neurolysis was performed, recovery was judged to be a mean Grade 4 according to the LSUHSC in 30 cases. Recovery following suture repairs was a mean Grade 3.8, whereas recovery after 66 graft repairs was a mean Grade 3.7. In cases in which suprascapular palsies were associated with axillary injuries, the former recovered but the latter did not necessarily do so without surgery. If the radial nerve was also injured, recovery of the triceps and brachioradialis muscles and wrist extension was usually obtained, but it was far more difficult to reverse the loss of finger and thumb extension. Although few in number, complications did occur and they are important.

Conclusions. Operative exploration of axillary contusion–stretch lesions is worthwhile in carefully selected cases. If indicated by inspection and intraoperative electrical studies, nerve repair can lead to useful function.

Key Words • axillary nerve • brachial plexus • suprascapular nerve • nerve action potential • suture • graft • outcome

A VARIETY of injuries such as contusion–stretch, gunshot wound, laceration, and iatrogenic injury can lead to axillary palsy and deltoid paralysis.5,11,15,17,20 Patients in whom this has occurred experience difficulty or the inability to abduct the arm laterally higher than 30 to 40˚.

Injury to the C-5 nerve root or spinal nerve, upper trunk, posterior division, or posterior cord can result in the loss of deltoid function.5,22 The largest category of injury, however, is blunt contusion and stretch to the axillary nerve itself either with or without injury to an associated plexus element.1–3,24 The purpose of this paper is to analyze operative outcomes in patients with solitary axillary palsy and also in those with associated neural injuries.

Clinical Material and Methods

Patient Population

This series includes 101 operations on the axillary nerve, which were performed in 99 patients with contusion–stretch injuries. Two of these patients had bilateral axillary nerve palsies. There were four categories of injuries: solitary axillary palsy (56 procedures), axillary palsy associated with suprascapular palsy (11 procedures), axillary and posterior cord palsies, which included loss of radial function (14 procedures), and axillary palsy with other plexus lesions (20 procedures). The patients’ ages ranged from 12 to 62 years with a mean of 37 years. Most (90%) of them were male.

Electromyography was performed in all patients and sometimes was repeated after an interval of several months.
Axillary nerve repair

TABLE 1
The LSUHSC grading scale for axillary palsy

<table>
<thead>
<tr>
<th>Grade</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no deltoid contraction</td>
</tr>
<tr>
<td>1</td>
<td>trace or twitch of deltoid contraction</td>
</tr>
<tr>
<td>2</td>
<td>some abduction of shoulder beyond 30° with gravity eliminated</td>
</tr>
<tr>
<td>3</td>
<td>abduction of shoulder against gravity &amp; mild pressure; lat abduction is usually 60–90°</td>
</tr>
<tr>
<td>4</td>
<td>abduction against gravity &amp; moderate pressure; lat abduction is usually &gt; 90°</td>
</tr>
<tr>
<td>5</td>
<td>abduction against gravity &amp; great amount of pressure; abduction is usually &gt; 110°</td>
</tr>
</tbody>
</table>

Because even early evidence of spontaneous recovery can take longer to be evident in the deltoid than in some other muscles, such as the biceps or triceps, patients were observed for 4 to 6 months. Surgery was performed because there was poor recovery of deltoid function, as assessed by clinical and electromyographic examination. Some patients were referred long after injury and thus the preoperative interval varied between 3 and 10 months with a mean of 6.5 months. Patients selected for surgery had undergone x-ray studies and sometimes magnetic resonance imaging of the shoulder, had often been evaluated by orthopedists for rotator cuff injury, and had a passive range of motion to at least 90° laterally. Deltoid function was graded again postoperatively according to the same criteria used preoperatively. All patients were seen at least once during the follow-up period. Most attended clinic several times, whereas in some others subsequent follow up after the initial postoperative visit was made through other physicians or by phone. The last follow-up visit occurred between 2 and 12 years postoperatively. This final visit occurred at a mean interval of 4.2 years.

Surgical Procedure and Related Anatomy

The operative approach used in these cases was an anterior infraclavicular one; because of very distal extension of the lesion, in some cases a posterior approach was added.

The anterior infraclavicular exposure was made while the patient lay supine at a 20° reversed Trendelenburg tilt. The patient’s arm was at the side and only abducted approximately 10 to 20°. The incision extended from the clavicular level to the axilla. The pectoralis major muscle was split away from the deltoid muscle in the deltopectoral groove, leaving some bundles of the pectoralis muscle laterally on which to suture back the medial pectoralis. The deltopectoral vein and associated vascular branches were ligated at the superior aspect of the wound and the pectoralis minor muscle was then divided.

After the lateral cord was identified and dissected free from fat and scar we traced the lateral cord not only down to and through its contribution to the median nerve, but also past the coracobrachialis branches and on to the musculocutaneous nerve. The latter was freed up several inches distal to the coracobrachialis branches by splitting the overlying biceps/brachialis muscle. The axillary artery was dissected out and traced distally along with the overlying median nerve. A large venous branch-crossing median nerve was usually isolated and divided. The posterior cord was then isolated by retracting the lateral cord and, sometimes, a more proximal portion of the axillary artery and even the medial cord medially. The thoracodorsal branch extended from the posterior aspect of the posterior cord and was usually found at right angles to it and heading toward the latissimus dorsi muscle (Fig. 1). More distally, subscapularis branches were usually found leaving the posterior cord close to where it bifurcates into the axillary and radial nerves (Fig. 2). By retracting the more distal axillary artery medially by applying a Penrose drain, and the musculocutaneous nerve superiorly and either medially or laterally, an approach to the deep axillary nerve, including that in the quadrilateral space, could be gained. Lateral pectoral vessels usually had to be ligated and divided. At this level, the nerve passes lateral to the profundus branch of the axillary artery, whereas the radial nerve is located on its medial side (Fig. 2). The axillary nerve follows a slightly oblique course laterally and posteriorly to reach the quadrilateral space.

Exposure of the nerve down to the level of the quadrilateral space was sometimes helped by deep placement of one or two Alm retractors. The quadrilateral space is composed of the long head of the triceps muscle medially, the humerus laterally, the subscapularis and teres minor muscles above, and the teres major and latissimus dorsi muscles below.24

The axillary nerve branches are close to the quadrilateral region.16 An anterior branch innervates the anterior delto-self muscle and a larger posterior branch innervates the teres minor muscle and, more posteriorly, the deltoid muscle. A cutaneous branch destined for skin over the cap of the shoulder pierces the deep fascia at the posterior border of the deltoid muscle.24 Initially, these branches curl around the humerus to the underside of the deltoid muscle itself (Fig. 3). The branches further divide to innervate this muscle, which has three bundles. These bundles contract in concert to raise the arm laterally; however, the anterior bundles contract more for anterior or forward abduction, which is aided by the pectoralis major muscle and sometimes by the long head of the biceps, depending on its relationship to the

FIG. 1. Drawing showing the anterior view of the posterior cord and its major branches, the radial nerve and the axillary nerve. Note the relationships of these nerves to adjacent muscles and the quadrilateral space. n. = nerve.
glenohumeral joint. Posterior abduction is primarily provided by more posteriorly located deltoid muscle bundles.

In this series of cases, the thoracodorsal and subscapularis branches responded to stimulation. The axillary nerve usually had a lesion in continuity and both stimulation and recording studies were needed to see whether there was NAP conduction downward and beyond the lesion (Fig. 4). Often this lesion began or extended into the axillary portion of the posterior cord regardless of whether thoracodorsal, subscapularis, or radial outflows were involved. If an NAP was recorded through and distal to the contusion–stretch injury, the epineurial scar was removed, but the lesion in continuity was not resected. If the lesion was irregular with a portion of the nerve cross-section appearing worse than the rest, however, that portion was resected, leaving the rest behind. The resected portion was replaced usually by grafts. If there was no NAP conduction, the lesion was resected and the gap was usually repaired by grafts either sural or antebrachial cutaneous nerves using a technique similar to that described by Millesi. With more focal lesions, end-to-end nerve repair could sometimes be performed.

Whenever the results of the preoperative examination and electrical studies demonstrated involvement of other plexus elements or proximal nerves, these were operatively evaluated and treated in a similar fashion.

Whenever a posterior approach was also deemed necessary, the incision was usually begun between proximal triceps muscle bundles. This exposure was then extended proximally to undermine the deltoid muscle so that the axillary branches could be identified on its undersurface. A posterior exposure, which has been described but was not used by us, creates a split between the middle and posterior thirds of the deltoid muscle and peels back this musculature in a fashion similar to opening a book. The muscle can be detached from the scapular spine and the acromion, and can later be attached using a heavy suture through drill holes in these bundles.

Results

Results were sorted by the extent of the injury to the nerve itself and thus by the operative repair that was performed, as well as by the nature of the associated neural injuries. See Table 2 for a summary of the results for each of these categories of injury.

Solitary Axillary Palsy

Four patients with a partial nerve loss (LSUHSC Grade 1 or 2) preoperatively underwent exploratory surgery. In these cases we only used neurolysis on the axillary nerves. The nerves recovered well, but they most likely would have done well without an operation because an NAP was recorded as it conducted past relatively mild stretches in continuity. On the other hand, six patients with stretch injuries in continuity were found to have complete nerve loss preoperatively, but they still had conducted NAPs. We treated these nerves with neurolysis alone and eventually a mean grade of 3.8 was attained (Table 2). In three patients suture...
repairs were made for relatively focal lesions without conduction and the mean outcome grade in these cases was 3.8. In 43 patients in whom graft repairs were made for lengthier lesions in continuity that required resection, the mean outcome grade once again was 3.8. Two of the graft repairs were split repairs and the outcomes for both of these were, as expected, quite good.

Axillary Palsy Associated With Suprascapular Palsy

This was an interesting group of patients because preoperatively they were able to attain very little abduction or external shoulder rotation because of associated suprascapular nerve loss as well as axillary nerve loss. In patients treated early in this series, the suprascapular nerve was explored as well as the axillary nerve; the former always exhibited a recordable NAP and, sometimes, muscle contraction in response to nerve stimulation. For this reason, later in the series we no longer explored the suprascapular nerve in cases of axillary palsy with associated suprascapular palsy. Follow-up examinations showed good recovery of the supraspinatus muscle and, in most cases, the infraspinatus muscle. The mean recovery grade for the three axillary nerves that displayed complete paralysis but received neurolysis based on a positive NAP was 4.3, whereas the mean outcome grade in the seven patients who received graft repairs was 3.2.

**TABLE 2**

*Outcomes of axillary nerve repair in 99 patients*

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No. of Nerves/Mean Postop LSUHSC Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Partial Loss &amp; Positive NAP/Neurolysis*</td>
</tr>
<tr>
<td>solitary axillary palsy (56 cases)</td>
<td>4/4.3</td>
</tr>
<tr>
<td>axillary palsy w/ suprascapular palsy (11 cases)</td>
<td>1/4.5</td>
</tr>
<tr>
<td>axillary palsy w/ radial loss (14 cases)</td>
<td>3/4.3</td>
</tr>
<tr>
<td>axillary palsy w/ other plexus loss (18 cases)</td>
<td>7/4.0</td>
</tr>
<tr>
<td>totals**</td>
<td>15/4.1 ± 0.4</td>
</tr>
</tbody>
</table>

* The mean preoperative grade was 2.2 (range 1–4).
† Preoperative grade in each case was 0.
‡ Preoperative grade in most cases was 0, except in three in which it was 1 (trace only).
§ Includes two split repairs with a mean outcome grade of 4.
∥ Two additional axillary nerves were exposed, but irreparable due not only to lengthy involvement, but also to distal avulsion.
** The mean values are expressed as means ± SDs.

![Diagram of Axillary nerve repair](image)
Axillary Palsy Associated With Radial Palsy

These 14 cases included eight complete and six incomplete radial palsies. Six cases of radial palsy required repair by grafts, whereas the remainder displayed NAP conduction and were treated only with neurolysis. The need for radial nerve repair did not always correlate with the need for resection and repair of the axillary nerve. Results achieved by repair of the radial nerve were better for the triceps, brachioradialis, supinator, and extensor carpi radialis muscles than for the extensor capri ulnaris, extensor communis, and pollicus longus muscles. The mean outcome grade for these axillary nerves that had partial loss (three cases) preoperatively was 4.3, whereas the mean outcome grade for those with complete loss that were treated with neurolysis based on positive NAPs (two cases) were 4.5. The mean outcome grade in nine patients who received axillary graft repairs in this subset of patients was 3.

Axillary Palsy Associated With Other Plexus Loss

This was a relatively large category of 20 patients. Associated palsies included those of the lateral cord, musculocutaneous nerve, proximal median nerve, and medial cord and ulnar with or without antebrachial cutaneous loss. Eight of these associated injuries required repair and again the need for this did not always relate to whether the axillary nerve needed to be repaired. Results included a mean grade of 4.2 for four axillary lesions with conduction of NAPs and a mean grade of 3.1 for seven nerves that required graft repair. Two additional patients in this category with associated plexus lesions not only had lengthy axillary nerve lesions, but also distal avulsion from the deltoid muscle. These lesions could not be repaired. None of the other nerves in this category with associated plexus loss had lesions that were focal enough to receive end-to-end suture repair after resection.

The overall results are provided in Table 2 for each major injury category. As might be expected, the mean recovery grade for the 15 patients who only had partial loss of axillary nerve function was 4.1 ± 0.4 (mean ± SD). Fifteen patients who arrived at the operating room with complete loss of function but in whom a recordable NAP was found intraoperatively had a mean grade of 4 ± 1. The few suture repairs (three cases) made in patients with complete loss and no detectable NAP resulted in a mean outcome grade of 3.8 ± 0.6 and the 66 graft repairs for lesions with complete loss and no detectable NAP resulted in a mean outcome grade of 3.7 ± 1.1.

Fortunately, in this series, the complications were relatively minor and recovery from them was good (Table 3). In one case, however, the patient sustained an intraoperative injury to the axillary artery involving a previous graft repair, which required an additional repair by our vascular service on an emergency basis. Fortunately, this second repair was successful, with restoration of adequate distal limb circulation.

Discussion

Clinical Features

Loss of deltoid function was not always so obvious or localized in the early weeks to months after closed injury, especially if there were associated injuries involving the glenohumeral joint, rotator cuff, or suprascapular nerve.12,13,23 Careful clinical and imaging studies were needed to identify repairable humeral fractures and/or rotator cuff tears.4,5,7,25 In several cases, such an injury was totally responsible for the patient’s inability to abduct the shoulder, rather than the axillary nerve injury. In these cases, the electromyogram did not reveal any denervational charge in the deltoid muscle. When there were associated injuries to other plexus elements, the loss of deltoid function was sometimes attributed to a plexus level more proximal than the axillary nerve itself. Repetitive clinical and electromyographic sampling, however, usually identified the deltoid paralysis as secondary to a more distal axillary nerve involvement.

Preoperatively, the apparent recovery of axillary distribution sensation over the cap of the shoulder and deltoid area can be misleading. This is because sensory input in the distribution of C-3 and C-4 overlaps this area and/or can branch into it, simulating axillary nerve sensory recovery.

Operative Observations

Reports of operations on smaller series of axillary palsies than this have been published in the last three decades.6,17–19,21,26 Usually an anterior approach has been used for operative exposure, but several reports have advocated the posterior approach because distal exposure at the level of the quadrilateral space can be difficult.17 In almost all cases in this series adequate exposure down to the quadrilateral space could be attained, but in three cases the anterior approach was supplemented by a posterior one, which has been described by Friedman and Nunley and their associates.8,9 It should be noted, however, that often the stretch lesion had extended well into the posterior cord or had begun there and extended distally (Fig. 5). This occurred, despite the fact that the thoracodorsal branch input to the latissimus dorsi muscle and the subscapular branch input to the subscapularis muscle, as well as the proximal innervation of the triceps muscle, was usually spared, at least in cases of solitary axillary palsy or cases of axillary palsy that were only associated with suprascapular palsy. Thus, the anterior approach has the advantage of providing good proximal exposure and, most of the time, sufficient distal exposure. When it does not, exposure of distal axillary branches through a separate posterior incision can be added.

Of interest was the fact that, in this series, each of the patients with suprascapular palsies associated with an axillary palsy recovered acceptable function in the suprascapular muscle spontaneously and without the need for repair. These outcomes differed from some others in the literature.13,15,23 The suprascapular nerve takes a somewhat oblique course as it arises from the upper trunk and passes

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**TABLE 3**

Complications that occurred in 101 surgeries performed to repair the axillary nerve

<table>
<thead>
<tr>
<th>Complication</th>
<th>No. of Ops</th>
</tr>
</thead>
<tbody>
<tr>
<td>wound infection or seroma</td>
<td>2</td>
</tr>
<tr>
<td>biceps paresis but not paralysis</td>
<td>2</td>
</tr>
<tr>
<td>vascular repair needed</td>
<td>1</td>
</tr>
<tr>
<td>atelectasis</td>
<td>1</td>
</tr>
<tr>
<td>repair not believed feasible</td>
<td>2</td>
</tr>
</tbody>
</table>

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posteriorly to reach the suprascapular notch and scapula where it is relatively tethered, as is the axillary nerve as it takes its somewhat oblique course and eventually traverses the quadrilateral space. Thus, the same forces that stretch the axillary nerve may also stretch the suprascapular nerve. The suprascapular nerve, at least in this series, frequently recovers spontaneously from a contusion-stretch injury, whereas the axillary nerve does not recover without repair in many cases. Axillary nerve lesions associated with loss of radial function had acceptable outcomes, although it was difficult to restore distal radial function, especially finger and thumb extension.

Other Operative Points

A thorough dissection of most of the infraclavicular plexus was usually necessary. Dissection and some medial retraction of the axillary artery and the overlying median nerve, as well as lateral or medial retraction of the musculocutaneous nerve was of help. Dissection and neurolysis of the axillary nerve as it branches from the posterior cord down to the quadrilateral space was performed by splitting away smaller subscapularis, teres, and occasional proximal triceps branches. It was rare to find the nerve pulled apart, although in several cases there was distraction just proximal to the quadrilateral space as well as lengthy proximal lesions in continuity. Because most lesions were in continuity, it was important to attempt to record an NAP, especially because these operations were almost always performed in a delayed fashion (mean 6.2 months postinjury). Thus, a number of lesions, in which there was preoperative clinical verification of complete loss and severe denervation on needle sampling of various portions of the deltoid muscle, transmitted an NAP and thus only required neurolysis. On the other hand, in cases in which resections were performed, we had the assurance that the NAP traces through the lesion were flat.

Very few axillary nerves had lesions that were focal enough to merit end-to-end repair after resection. All such repairs were in patients with solitary axillary lesions, from which we can infer that when there were associated plexus or other more peripheral nerve lesions, the forces might have been greater than those responsible for a solitary axillary lesion. The mean recovery grade for the three end-to-end sutured nerves was 3.8. The vast majority of nonconducting nerves needed replacement by grafts composed of either sural or antebrachial cutaneous nerves because the gaps resulting from the resection were greater than 2.5 cm. Antebrachial cutaneous nerves were used for grafts if they were of good caliber and were not injured. Otherwise the sural nerve was harvested for graft repair. There was no advantage to using one nerve rather than the other as far as outcomes were concerned. The mean grade for graft-repaired axillary nerves was 3.7. Two patients received split repairs because one portion of the nerve was more severely injured than the rest. Most split repairs of nerves recover well and those of the axillary nerve were no exception, because the mean recovery grades in these cases was 4.

Electromyograms and Axillary Palsy

Two observations referable to the electromyograms pre- and postoperatively are important. Over time, a relatively small number of regenerating fibers can penetrate some lesions in continuity, reach the deltoid muscle, and provide a few nascent potentials during needle examination. Nevertheless, further clinical follow-up review over a period of many months may show no muscle contraction or, if the nerve is surgically treated, it will sometimes not transmit an NAP and will require resection, despite the presence of some nascent potentials recorded in muscle. Conversely, in cases of significant spontaneous recovery with or without surgery, perceptible and palpable contraction of the deltoid muscle can be recorded and still a needle assay of the muscle will show a severe denervational pattern. Areas of reinnervation are not always sampled. Muscle can sometimes contract despite what appears to be severe denervational change. Thus, although the electromyogram remains a valuable tool for studying axillary palsies, it must be correlated with other clinical findings as well as the interval between injury and the time of the study.

Conclusions

Judging from outcomes obtained in this series of patients, operative exploration of axillary contusion-stretch lesions is worthwhile in carefully selected cases. If indicated by in-

Fig. 5. Drawing of variable injury patterns seen in this series of contusion-stretch lesions of the axillary nerve. a: Lesion usually found, which originates from the posterior cord and extends distally just short of the nerve branches. b: Lesion involving the axillary nerve as well as its branches. c: Lesion that begins distal to the thoracodorsal branch. d: Distractive stretch injury that has pulled apart the axillary nerve and sometimes has damaged distal branches to the extent that useful direct repair is impossible.
spection and intraoperative electrical studies, nerve repair can lead to useful function.

References


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