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Research Article

Anatomical Variations of the Axillary Nerve and Their Impact on Proximal Humerus Fracture Surgery

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ABSTRACT

Background: The axillary nerve is associated with the surgical neck of the humerus and is especially susceptible on operative treatment of the proximal humerus fracture. Changes in its location, branching configuration and relation to adjacent structures can increase the risk of intra-operative injury and negatively impact post-operative shoulder function. This study was conducted to find the incidence of specific anatomical variations of the axillary nerve and to assess their relevance to the surgical and functional results in patients who have had surgery for the proximal humerus.

Methodology: This is a prospective observational study that took place between January 2025 and June 2025 at Rawal Institute of Health Sciences, Islamabad. Patients with patients of displaced proximal humerus fractures who were managed by surgery were all included consecutively, total 85 patients. Demographic data, fracture-related and operative data were recorded. The course, branching pattern and relationships of the axillary nerve was determined intraoperatively. Patients were grouped into either a normal or variant axillary nerve anatomy. The neurological status, duration of the operation, blood loss, range of the shoulder, Constant–Murley shoulder score, and complications were assessed postoperatively. Data were analyzed statistically by appropriate comparative tests and multivariable logistic regression and p value < 0.05 was considered statistically significant.

Results: The mean age of the patients was 52.8 ± 13.6 years, and 49 (57.6%) were male. Anatomical variations of the axillary nerve were identified in 26 (30.6%) patients. Multiple branching was the most frequent variation, observed in 10 (11.8%) patients, followed by a low-positioned nerve in 7 (8.2%), a high-positioned nerve in 5 (5.9%) and accessory or communicating branches in 4 (4.7%). The mean nerve-to-acromion distance was significantly shorter in patients with anatomical variations than in those with normal anatomy. Postoperative axillary nerve dysfunction occurred in 11 (12.9%) patients and was significantly more frequent in the variation group than in the normal-anatomy group, 30.8% versus 5.1% (p=0.002). Patients with anatomical variations also had longer operative duration, greater blood loss, more frequent modification of the surgical approach, lower Constant-Murley scores and reduced shoulder abduction. Anatomical nerve variation independently increased the likelihood of postoperative nerve dysfunction.

Conclusion: Anatomical variations of the axillary nerve are common and may significantly influence the complexity and outcome of proximal humerus fracture surgery. Awareness of these variations, careful intraoperative identification and individualized surgical planning may reduce the risk of nerve injury and improve postoperative shoulder function.

Keywords: Axillary Nerve, Anatomical Variation, Proximal Humerus Fracture, Nerve Injury, Shoulder Surgery, Deltoid-Splitting Approach, Functional Outcome.

INTRODUCTION

Proximal humerus fractures are frequently encountered injuries of the humeral head, surgical neck, anatomical neck and greater/lesser tuberosities. Their severity ranges from fractures with minimal displacement, which will respond to conservative treatment, to fractures that are completely displaced or comminuted, and must be surgically fixed or arthroplasty. The operative treatment is generally indicated when the fracture is severely displaced, the dislocation, instability, involvement of the joint or failure to maintain acceptable alignment. Common surgical options include open reduction and internal fixation with a locking plate, intramedullary nailing, hemiarthroplasty and reverse shoulder arthroplasty [1-3].

Restoring fracture alignment and preserving the humeral-head blood supply and protecting the surrounding soft tissues and neurovascular structures are important aspects of successful surgical management of proximal humerus fractures. The axillary nerve is especially significant as it passes close to the proximal humerus and is critical for the function of the shoulder amongst these structures. Damage to the axillary nerve may result in deltoid and teres minor weakness or paralysis, sensory loss over the lateral shoulder and marked limitation of active shoulder abduction [4-6].

The axillary nerve is normally derived from the posterior cord of the brachial plexus and is mainly composed of fibres from the fifth and sixth cervical nerve roots. It travels posteriorly through the quadrilateral space with the posterior circumflex humeral vessels, and then loops around the surgical neck of the humerus. The nerve is usually split into anterior and posterior divisions. The anterior branch innervates the anterior and middle parts of the deltoid while the posterior branch supplies the posterior part of the deltoid, the teres minor and extends as the superior lateral cutaneous nerve of the arm [7-9].

Although the general course of the axillary nerve is well described, its exact position and branching pattern can differ considerably between individuals. Modifications may be a relatively high or low position of the nerve, division too early, several motor branches, accessory motor branches and twining with adjacent nerves. The axillary nerve may also be at a greater distance from the lateral border of the acromion. Such differences have clinical significance due to the potential for the nerve to become injured during deltoid splitting, plate insertion, screw placement, fracture reduction or soft tissue retraction, depending on its proximity to the acromion or the surgical neck.

Proximal humerus fracture surgery is often performed by the deltopectoral approach and anterolateral deltoid-splitting approach. The deltopectoral approach offers excellent exposure of the lateral aspect of the proximal humerus; however, a large amount of retraction may be necessary to achieve this access without splitting the deltoid. The anterolateral approach is more direct to the greater tuberosity and lateral proximal humerus, but exposes the axillary nerve more, as it passes under the deltoid at the level of the surgical field. If the deltoid split is extended too far, the nerve may get injured or its motor branches [10, 11].

Surgeons traditionally have relied on a safe corridor at a fixed distance from the lateral edge of the acromion for safe deltoid splitting. However, a standard measurement may not be reliable to ensure protection in all patients due to individual anatomy and arm length, body size, fracture displacement and positioning of the arm during surgery. Furthermore, complex fractures could alter the normal anatomical relationships and nerve identification may be more difficult. Therefore, knowledge of anatomical variation is critical to the safe exposure and implant placement [11].

Axillary nerve dysfunction after surgery for a fractured proximal humerus can be caused by direct nerve trauma, entrapment, traction, compression from retractors or from swelling or other trauma associated with fracture fragments. Many injuries are neuropraxias which heal with observation and rehab, but there are cases in which axonal injury is severe, resulting in chronic weakness and loss of function. Even partial nerve injury can adversely affect the rehabilitation and patient satisfaction since the deltoid function is crucial for the elevation and abduction of the shoulder [12].

Although the axillary nerve is important in the clinical setting, there is little evidence showing how variation of the nerve affects the difficulty of surgery, surgical modification, neurological complications, and functional outcome in patients undergoing surgery for proximal humerus fractures. Previous anatomical investigations have been conducted using cadaveric dissections, which may not completely apply in the changed relationships found in surgery for fractures. These variations in the spine may therefore be of clinical value to surgeons and enhance the safety of surgery.

The present study was conducted to determine the frequency and types of anatomical variations of the axillary nerve in patients undergoing surgery for proximal humerus fractures. It also aimed to evaluate the association of these variations with operative duration, blood loss, difficulty in nerve identification, modification of the surgical approach, postoperative nerve dysfunction, shoulder range of motion and functional outcome.

METHODOLOGY

This prospective observational study was conducted in the Department of Orthopaedic Surgery at Rawal Institute of Health Sciences, Islamabad from January 2025 to June 2025. The study was designed to determine the frequency and patterns of anatomical variations of the axillary nerve and to assess their influence on the surgical management and postoperative outcomes of patients undergoing surgery for proximal humerus fractures. A total of 85 patients fulfilling the eligibility criteria were enrolled through consecutive non-probability sampling.

Included were patients between 18 years old and older with the proximal humerus fracture that was displaced and treated operatively. Fractures were included if they were two-part, three-part, or four-part fractures (classified by Neer), or greater tuberosity or surgical neck fractures. Patients with a low-grade open fracture (2nd and 3rd degree) who were either closed or selected for open fracture surgery were considered eligible for inclusion. Patients with a previous fracture or surgery of the affected shoulder, congenital deformity of the shoulder girdle, pathological fracture, a pre-existing axillary nerve palsy unrelated to the current injury, severe brachial plexus injury, advanced neuromuscular disease, incomplete operative records or who could not be followed up for the required period were excluded.

Demographic and clinical data was collected in a structured data collection form, before the surgery. The variables considered were age, sex, BMI, dominant arm involvement, mechanism of injury, interval between injury and surgery as well as associated comorbidities. A comprehensive neurological examination of the affected upper limb was performed, which involved sensory exam over the lateral shoulder, motor exam of the deltoid muscle. The Medical Research Council scale was used to grade deltoid power. In all patients standard anteroposterior, scapular-Y and axillary radiographs were taken. If needed, a 3D computed tomography (CT) and computed tomography reconstruction was performed to assess fracture displacement, comminution, tuberosity involvement and fracture-dislocation. The fractures were classified according to Neer classification and AO/OTA classification, if applicable.

The surgery was conducted by an experienced Orthopaedics surgical team under general anaesthetic and/or regional nerve block. Deltopectoral and anterolateral deltoid-splitting approaches were decided depending on the fracture configuration, soft-tissue condition and the fixation method planned. Surgical treatment comprised open reduction and internal fixation with a proximal humeral locking plate, intramedullary nailing, hemiarthroplasty or reverse shoulder arthroplasty depending on the fracture pattern and patient characteristics. The axillary nerve was carefully identified during exposure in the course of the exposure, by direct visualization or palpation, when clinically indicated. It was found to be related to the lateral border of acromion, the surgical neck of humerus, greater tuberosity, deltoid muscle and greater tuberosity posterior humeral circumflex vessels. The intra-operative axillary nerve to lateral acromion distance was measured in a standardized neutral arm using a sterile ruler or digital calliper. The surgical neck of the humerus to the nerve distance was also measured. The number of branches visible, the division of branches into anterior and posterior branches, the presence of accessory branches, communicating branches and high or low positioning of nerve courses were recorded. The classification of the axillary nerve was made as normal or variant. The high, low, multiple branching pattern and accessory branch or communicating branch were additional classifications for variations. Care was taken to avoid excessive traction, compression or thermal injury to the nerve. Any nerve difficulty encountered, change of placement of the retrator, length of nerve splitting or change in the approach to the nerve was noted.

Operative variables were surgical approach, surgical procedure, implant used, operative time, estimated blood loss, intraoperative identification of the axillary nerve, difficulty protecting the axillary nerve, modification of the surgical technique and occurrence of intraoperative injury to the axillary nerve. Operative time was defined as the time taken from the incision of the skin to the closure of the wound. Analgesia, antibiotic prophylaxis and immobilization in an arm sling were given to all patients, as well as a standardized rehabilitation programme, in postoperative treatment. Passive shoulder exercises were started based on the fracture stability and quality of the fixation, followed by active assisted and active range of motion exercises. Strengthening exercises started after radiological evidence of fracture healing.

Patients were assessed postoperatively before discharge, and at the follow-up visits at 2 weeks, 6 weeks, 3 months and 6 months. Sensory function over the regimental-badge area, power of deltoid muscles, shoulder pain and range of motion and wound condition were evaluated at each visit. When sensory loss was persistent or there was weakness in the deltoid, electrophysiological testing was performed (nerve-conduction studies and electromyography - as indicated). The axillary nerve injuries were classified based on clinical and electrophysiological features as neuropraxia, axonotmesis or neurotmesis. Neurological recovery was assessed as normal sensation and/or improvement to grade 4 or 5 in deltoid power on the Modified Medical Research Council scale.

Functional outcomes were evaluated at the last follow-up with the Constant–Murley Shoulder Score. Measurements of shoulder abduction, forward flexion and external rotation were taken using a goniometer. The radiographs are evaluated for fracture union, maintenance of reduction, position of the implant, delayed union, non-union, malunion and avascular necrosis of the humeral head. Other postoperative complications such as infection, stiff shoulder, implant failure, postoperative neurological deficit and need reoperation were documented. The primary outcome was development of postoperative axillary nerve dysfunction. Secondary outcomes were the incidence of occurrence and type of anatomical variations, operating time, blood loss, neurological recovery and functional outcome of the shoulder.

Data were input and analyzed in SPSS version 26 (IBM corp., USA). For continuous variables (age, anatomical distance, operative time, blood loss, ROM, and Constant–Murley score) the mean and standard deviation or the median and interquartile range were used, depending on the distribution of the data. Categorical variables were represented in frequencies and percentages. A series of patients with normal axillary nerve anatomy were compared to those with anatomical variations. Continuous variables were analysed either by independent-samples t-test or Mann–Whitney U test, and categorical variables were analysed by chi-square test or Fisher's exact test. Multivariable binary logistic regression was used to determine independent risk factors for postoperative axillary nerve dysfunction. Factors that had clinical significance or a p value of 0.20 or less in the univariable analysis were included in the bivariable analysis. Odds ratios were reported with 95% CIs and p-values <0.05 were judged to be statistically significant.

RESULTS

A total of 85 patients who underwent surgical treatment for proximal humerus fractures were included in the study. The age of participants was (mean ± SD) 52.8 ± 13.6 years (range 21 to 78 years). The majority of the patients were males (49, 57.6%) and 36 (42.4%) were females. In 47 (55.3%) patients the right shoulder was involved and in 44 (51.8%) patients the dominant limb was involved. The most common mechanism of injury was falls in 48 (56.5%) patients, road traffic accidents in 29 (34.1%) and sports-related or other mechanisms in 8 (9.4%).

Table 1. Demographic and Clinical Characteristics of the Patients

Variable	Frequency (%) or Mean ± SD
Age, years	52.8 ± 13.6
Male	49 (57.6%)
Female	36 (42.4%)
Right shoulder involvement	47 (55.3%)
Left shoulder involvement	38 (44.7%)
Dominant limb affected	44 (51.8%)
Fall-related injury	48 (56.5%)
Road traffic accident	29 (34.1%)
Sports or other injury	8 (9.4%)
Diabetes mellitus	18 (21.2%)
Hypertension	25 (29.4%)
Osteoporosis	14 (16.5%)
Time from injury to surgery, days	4.7 ± 2.1

The Neer classification showed that two parts fractures were seen in 32 (37.6%) patients, three parts fractures in 35 (41.2%) patients and four parts fractures in 18 (21.2%) patients. Sixty-nine (81.2%) had involvement of the surgical neck and 43 (50.6%) had fractures of the greater tuberosity of the humerus. 13 (15.3%) patients had fracture-dislocation. The displacement and angulation at the fracture site were 12.4 mm ± 4.8 mm and 39.6° ± 14.2°, respectively.

Table 2. Fracture-Related Characteristics

Variable	Frequency (%) or Mean ± SD
Two-part fracture	32 (37.6%)
Three-part fracture	35 (41.2%)
Four-part fracture	18 (21.2%)
Surgical-neck involvement	69 (81.2%)
Greater tuberosity fracture	43 (50.6%)
Lesser tuberosity fracture	16 (18.8%)
Fracture-dislocation	13 (15.3%)
Open fracture	4 (4.7%)
Mean fracture displacement, mm	12.4 ± 4.8
Mean fracture angulation, degrees	39.6 ± 14.2

A normal anatomical course of the axillary nerve was found in 59 (69.4%) patients and the anatomical variations were found in 26 (30.6%) patients. The most frequent was a multiple-branching pattern; 10 (11.8%) patients had this pattern. A relatively low nerve was found in 7 (8.2%), a high nerve in 5 (5.9%) and accessory/communicating branches in 4 (4.7%). The mean distance between the axillary nerve and the lateral border of the acromion was 5.6 ± 0.8 cm. This distance was 5.8 ± 0.6 cm in normal patients and 5.1 ± 0.9 cm in patients with anatomical variations. There was a significant difference between the two groups ($p<0.001$). The gap between the nerve and the surgical neck of the humerus was 1.4 ± 0.4 cm on average.

Table 3. Anatomical Characteristics of the Axillary Nerve

Variable	Frequency (%) or Mean ± SD
Normal anatomical course	59 (69.4%)
Any anatomical variation	26 (30.6%)
Multiple-branching pattern	10 (11.8%)
Low-positioned nerve	7 (8.2%)
High-positioned nerve	5 (5.9%)
Accessory or communicating branch	4 (4.7%)
Nerve-to-acromion distance, cm	5.6 ± 0.8
Nerve-to-surgical-neck distance, cm	1.4 ± 0.4
Number of identifiable branches	2.3 ± 0.9
Division into anterior and posterior branches	73 (85.9%)

Open reduction and internal fixation with a proximal humeral locking plate was performed in 67 (78.8%) patients. Ten (11.8%) underwent intramedullary nailing, and eight (9.4%) patients had hemiarthroplasty or reverse shoulder arthroplasty. In 55 (64.7%) cases the deltopectoral approach and in 30 (35.3%) cases the anterolateral deltoid-splitting approach was performed. During the surgical procedure, the axillary nerve was clearly identified in 53 (62.4%) patients. Identification or protection of the nerve was difficult in 18 (21.2%) procedures. Surgical adjustment to the deltoid split and/or placement of retractors was necessary in 14 (16.5%) patients. Patients with anatomical variations were also more likely to have been modified, 10/26 (38.5%) versus 4/59 (6.8%) ($p<0.001$) in those with normal anatomy.

Table 4. Operative Characteristics

Variable	Frequency (%) or Mean ± SD

Locking-plate fixation	67 (78.8%)
Intramedullary nailing	10 (11.8%)
Hemiarthroplasty/reverse arthroplasty	8 (9.4%)
Deltopectoral approach	55 (64.7%)
Anterolateral approach	30 (35.3%)
Axillary nerve directly identified	53 (62.4%)
Difficulty identifying the nerve	18 (21.2%)
Modification of surgical approach	14 (16.5%)
Operative duration, minutes	94.7 ± 21.5
Estimated blood loss, mL	228.6 ± 91.4

Axillary nerve dysfunction after surgery was reported in 11 (12.9%) patients. Seven patients suffered transient sensory loss over the lateral aspect of the shoulder and six had reduced deltoid power. Two patients had both sensory and motor deficits. Twenty cases were consistent with neuropraxia and two with axonotmesis. There were no cases of total nerve section. Patients with an anatomical variation had much higher rates of neurological deficits than patients with normal nerve anatomy. Eight of the 26 (30.8%) patients had a variation while 3 of the 59 (5.1%) patients had a normal anatomy (p=0.002). The anterolateral approach was also more likely to result in a dysfunction of the axillary nerve than the deltopectoral approach (7/30 (23.3%) vs 4/55 (7.3%) (p=0.036)).

Table 5. Postoperative Axillary Nerve Outcomes

Outcome	**Frequency (%)**
Any postoperative axillary nerve dysfunction	11 (12.9%)
Sensory deficit	7 (8.2%)
Deltoid weakness	6 (7.1%)
Combined sensory and motor deficit	2 (2.4%)
Neuropraxia	9 (10.6%)
Axonotmesis	2 (2.4%)
Complete nerve injury	0 (0.0%)
Complete neurological recovery	9 (81.8% of injured patients)
Persistent neurological deficit	2 (18.2% of injured patients)
Mean recovery time, weeks	12.6 ± 5.4

The average Constant–Murley score at the last follow-up was 76.8 ± 11.9 and the mean shoulder abduction was 118.7 ± 24.6 degrees. Patients with normal axillary nerve anatomy had a significantly higher mean Constant–Murley score than patients with axillary nerve anatomy variations (79.4 ± 10.2 versus 70.9 ± 13.2, respectively; p=0.002). Likewise, the mean abduction was found to be larger for the normal-anatomy group than the variation group (p=0.005) (123.6 ± 21.8 degrees versus 107.5 ± 27.1 degrees). 79 (92.9%) patients had fracture union. Three patients suffered delayed union, two suffered malunion and one non-union. Ten (11.8%) patients had shoulder stiffness, 4 (4.7%) had a surgical-site infection and 5 (5.9%) had implant-related complications. The number of cases requiring reoperation was six (7.1%).

Table 6. Comparison of Outcomes According to Axillary Nerve Anatomy

Outcome	**Normal anatomy (n=59)**	**Anatomical variation (n=26)**	**p-value**
Operative duration, minutes	89.8 ± 18.7	105.8 ± 23.5	0.001
Blood loss, mL	207.4 ± 79.6	276.7 ± 99.8	0.001
Difficulty identifying nerve	6 (10.2%)	12 (46.2%)	<0.001
Modification of surgical approach	4 (6.8%)	10 (38.5%)	<0.001
Postoperative nerve dysfunction	3 (5.1%)	8 (30.8%)	0.002
Constant–Murley score	79.4 ± 10.2	70.9 ± 13.2	0.002
Shoulder abduction, degrees	123.6 ± 21.8	107.5 ± 27.1	0.005

Overall complications	9 (15.3%)	11 (42.3%)	0.007
Reoperation	2 (3.4%)	4 (15.4%)	0.061

Multivariable logistic regression analysis showed that the presence of an anatomical axillary nerve variation was independently associated with postoperative nerve dysfunction. Patients with anatomical variations had about 5 times greater chance of developing postoperative dysfunction than patients with normal anatomy. The anterolateral approach and intra-operative difficulty in identifying the nerve were also significant predictors and a nerve-acromion distance < 5 cm.

Table 7. Multivariable Logistic Regression Analysis of Postoperative Axillary Nerve Dysfunction

Predictor	**Adjusted odds ratio**	**95% confidence interval**	**p-value**
Anatomical nerve variation	5.21	1.28–21.17	0.021
Nerve-to-acromion distance <5 cm	4.36	1.09–17.42	0.038
Anterolateral surgical approach	3.48	1.01–11.97	0.048
Difficulty identifying the nerve	4.92	1.27–19.06	0.021
Three- or four-part fracture	2.16	0.57–8.18	0.256
Age >60 years	1.39	0.36–5.41	0.634

Overall, anatomical variations of the axillary nerve were found in nearly one-third of the patients. These variations were associated with longer operative duration, greater blood loss, increased difficulty in nerve identification, a higher frequency of postoperative neurological dysfunction, and poorer functional shoulder outcomes.

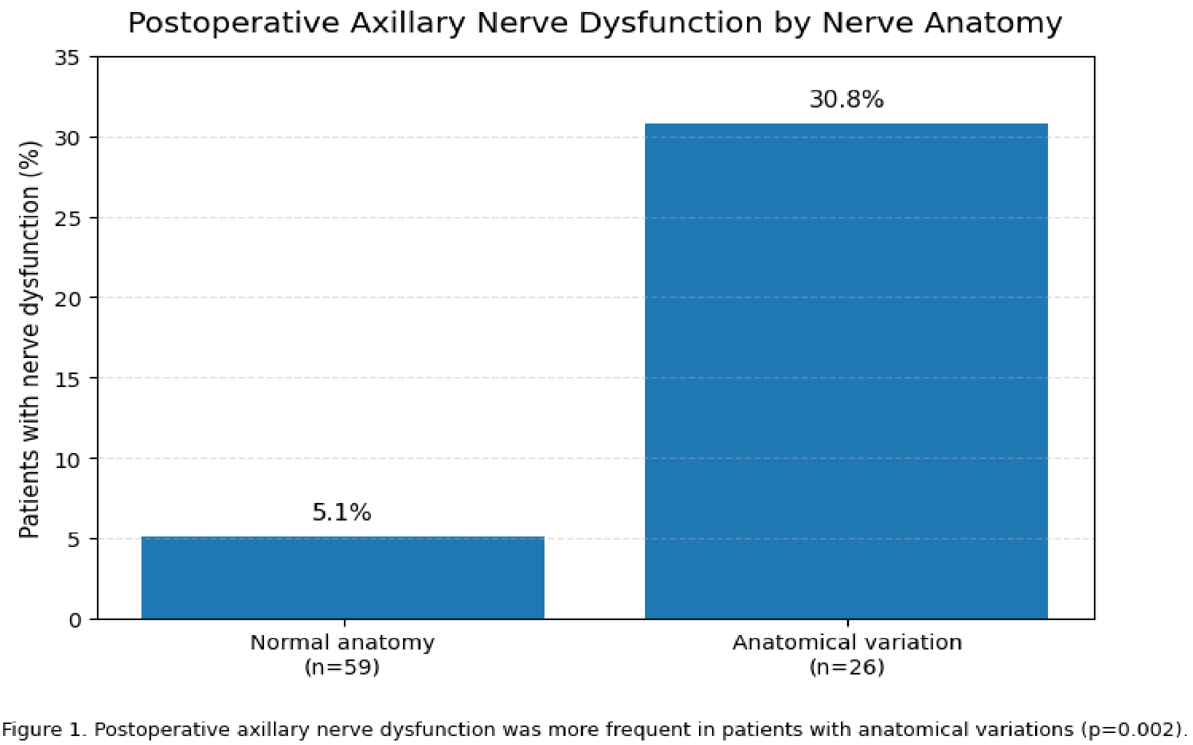

Figure 1. Comparison of Postoperative Axillary Nerve Dysfunction According to Axillary Nerve Anatomy. Dysfunction Occurred in 30.8% of Patients with Anatomical Variations Compared with 5.1% of those with Normal Anatomy (p = 0.002).

DISCUSSION

The present study evaluated anatomical variations of the axillary nerve and their influence on the surgical treatment of proximal humerus fractures. Anatomical variations were identified in 30.6% of patients, with multiple branching being the most frequent pattern, followed by low-positioned and high-positioned nerves and accessory or communicating branches. Patients with variant anatomy experienced longer operations, greater intraoperative blood loss, more difficulty in nerve identification and a higher requirement for modification of the surgical approach. Postoperative axillary nerve dysfunction occurred in 12.9% of the overall sample and was significantly more frequent among patients with anatomical variations than among those with a normal nerve course. These findings indicate that variations in the position and branching pattern of the axillary nerve may have clinically important consequences during proximal humerus fracture surgery [13].

The present study demonstrated that in normal individuals the acromion-lateral border distance of the axillary nerve was 5.6 ± 0.8 cm. This distance was much smaller in patients with anatomical variations, indicating that the anatomical safe zone described is not applicable to all patients. Anatomical studies have been conducted in the past, with reports of significant differences in the distance between the acromion and the axillary nerve. A clinical study by Patra et al. on proximal humerus fracture patients undergoing plate fixation showed that the distance of the nerve from the acromion was correlated with the length of the humerus and arm [14]. These observations indicate that the distance from the acromion should not be used to assess an individual's deltoid splitting, but rather an anatomical assessment should be performed [15].

The anatomical variation of nerves was strongly correlated with identification and protection problems with the axillary nerve during surgery. Modification of retractor placement, shortening of the deltoid split or alteration of the planned exposure was required in 38.5% of patients with variant anatomy compared with only 6.8% of patients with a normal nerve course. The axillary nerve runs close to the surgical neck of the humerus and innervates the deltoid with anterior and posterior branches, and is susceptible during fracture reduction, application of a deltoid plate, screw insertion and over-retraction. Anatomical studies also have demonstrated that the acromion alone cannot be used as a reliable landmark. The upper end of the humeral head has, therefore, been recommended as another reference point, especially when placing locking screws [16].

Thirty percent of patients had anatomical variations with postoperative axillary nerve dysfunction, while only 5.1% of the normal anatomic group had postoperative axillary nerve dysfunction. The majority of deficits were neuropraxias and nine of the 11 patients with affected deficits improved during follow-up. From these results, it is proposed that dysfunction may occur due to trauma to a variant nerve course or retractor pressure or manipulation near a variant nerve course, rather than complete disruption of the course. In previous studies, the axillary nerve has been found to be the nerve most commonly injured in proximal humerus fractures due to its close proximity to the surgical neck. Electrophysiological examinations have also been shown to be useful in detecting some postoperative axillary nerve lesions that may not be apparent from a standard clinical examination. Thus, precise pre-operative neurologic evaluation and/or selective post-operative electromyography is beneficial, especially if sensory disturbance or weakness of the deltoid muscle is remaining [17].

Nerve dysfunction rate was also increased with the anterolateral approach compared with the deltopectoral approach. Anterolateral approach is direct to lateral proximal humerus, which may aid plate placement but crosses deltoid close to the course of the axillary nerve. Anatomal and clinical studies have been focused on the risk to the anterior motor branch during deltoid splitting. The deltopectoral approach does not involve splitting the deltoid and can be used with most proximal humerus fractures, but may necessitate a larger amount of soft-tissue retraction and may offer less direct lateral visualization. The results of the present study do not indicate superiority of the surgical approach in all situations, but the surgical approach should be chosen based on fracture configuration, surgeon experience and nerve position. Specific identification and protection of the nerve is especially crucial when a nerve is approached from the anterior lateral direction [18].

Patients with anatomical variations had less favourable functional recovery. Constant–Murley scores were lower, shoulder abduction was reduced and the complication rate was higher in these patients. This difference could be attributed to neurological dysfunction, increased surgical manipulation, and potentially longer exposure and rehabilitation may be delayed due to postoperative pain or weakness of the deltoid. The deltoid is the main muscle controlling shoulder abduction, so even slight damage to the axillary nerve can make movement difficult and hinder rehabilitation. However, the majority of neurological lesions healed in the follow-up period, which means that early detection, prevention of further compression and proper physiotherapy may lead to good recovery. If weakness persists, electrophysiological studies should be performed to differentiate neuropraxia from axonal injury and to decide if surgery is necessary [19, 20].

There are a few limitations of the present study. It was carried out in one centre with 85 patients, potentially reducing the applicability of the findings. Arm position, fracture displacement and soft tissue swelling, as well as the technique of measurement, can affect intraoperative measurements of anatomy. Unnecessary dissection may have left out small accessory branches as direct visualization of all terminal nerve branches was not possible. Surgical approach was not randomized and could have been influenced by surgeon preference and fracture complexity. Moreover, the low number of nerve injuries after surgery, prevented more variables from being included in a multivariable regression. To validate the associations observed, larger multicentric studies with uniform measurements, preoperative imaging, intraoperative nerve monitoring and follow-up are recommended.

CONCLUSION

Anatomical variations of the axillary nerve were relatively common among patients undergoing surgery for proximal humerus fractures and were associated with greater operative difficulty, longer surgical duration, increased blood loss and a higher risk of postoperative nerve dysfunction. Variant anatomy was also associated with reduced shoulder abduction, lower functional scores and more frequent postoperative complications. A short nerve-to-acromion distance, an anterolateral surgical approach and difficulty identifying the nerve were additional factors associated with postoperative dysfunction.

Careful preoperative neurological examination, awareness of variable nerve anatomy, controlled deltoid splitting and direct identification of the axillary nerve when necessary may reduce the risk of injury. Surgeons should avoid depending exclusively on a fixed acromial safe zone because the location and branching pattern of the nerve can differ considerably between patients. Individualized surgical planning and meticulous protection of the axillary nerve are essential for improving neurological and functional outcomes after proximal humerus fracture surgery.

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