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Original Article

Cadaveric Study of Branching Pattern and Clinically Relevant Variations of the Axillary Nerve

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ABSTRACT

This cadaveric study aimed to analyze the anatomical course and variations of the axillary nerve, focusing on its relationship with the acromion and deltoid muscle. Thirty specimens were dissected to measure anterior (AD) and posterior (PD) distances from the acromion to the axillary nerve. Both AD (mean: 2.62 ± 0.248 cm) and PD (mean: 3.42 ± 0.235 cm) showed mild positive skewness and were not normally distributed (Shapiro-Wilk: $p < 0.01$). Wilcoxon signed-rank tests showed that both means were statistically different compared to literature-based references ($p = 0.013$ and $p < 0.001$ respectively). Axillary nerve positioned in the quadrangular space gave a 96.7 percent incidence and only one specimen exhibited a posterior position. The deltoid muscle was consistently innervated by the anterior division for anterior and middle fibers and by the posterior division for posterior fibers. Dual innervation occurred in 10% of anterior and 23.3% of middle deltoid fibers, but no significant association was found between nerve division and fiber innervation (OR = 0.365, $p = 0.299$). Binomial tests did not find a significant variation out of the anticipated rates (p>.005). The right was found by the logistic regression to be the best predictor of anatomical variation (OR>2), and the model performance was excellent (AUC = 0.86). This study verifies regular nerve supply patterns with slight differences, especially on the right hand side.

Keywords*: Axillary nerve, Deltoid muscle, Anatomical variation, Quadrangular space, Nerve innervation, Cadaveric study.*

INTRODUCTION

An axillary nerve or circumflex nerve can be considered one of the most crucial branches of the posterior cord of the brachial plexus and contains primarily the fibers of the C5 and C6 roots [1]. It passes through the axilla, behind the axillary artery and in front of the subscapularis muscle, and leaves the axilla via the quadrangular (quadrilateral) space, a pair of borders of which are the teres minor (superior), teres major (inferior), the long head of the triceps (media), and the surgical neck of the humerus (lateral) [2].

During its formation, the axillary nerve usually splits into anterior and posterior terminal divisions as it emerges from the quadrangular space. The anterior branch is wound around the surgical neck of the humerus to supply anterior deltoid and middle deltoid fibers, sending cutaneous nerve fibers to the skin. The posterior branch gives the teres minor and posterior deltoid. It passes on to the arm's superior (upper) lateral cutaneous nerve, where sensory innervation is given to the regimental badge area [3].

Branching patterns, origin, and innervation of the axillary nerve have anatomical differences that are clinically significant and well-known. In cadaveric cases, it has been found that the bifurcation of the nerve occurs in the quadrangular space in around 88–100% of cases, although small cases of high-dividing just south of this area have been observed [4]. The deltoid innervation patterns have also proven to vary in detail: the anterior branch is typically used to supply the anterior and middle deltoid segments, but the posterior branch, the anterior branch, or both can innervate the posterior deltoid. In one study, only 70% of all cadavers had the posterior deltoid innervated by the posterior branch, 26.7% had posterior deltoid innervated by both branches, and 3.3% had posterior deltoid innervated by the anterior branch [5]. In another larger-scale dissection (129 arms), the posterior deltoid was shown to be innervated by the anterior branch in only 2.3% of specimens, 8.5% by the posterior branch, and 89.1% by both branches.

Further, cadaveric mapping of the axillary nerve course has been used to quantify the distances between its origin, branching points, and termination sites. One study measured the bifurcation of the nerve to be 39 ± 13 mm on average, with the division of the teres minor at 13 ± 6 mm following the bifurcation [4]. This kind of measure is essential in successful surgery navigation and nerve repair planning.

Other interesting observations are that there are rare variations, including the long head of the triceps innervated by the axillary nerve [6] and the posterior cord sources of the nerve, which are sometimes familiar with others, such as the thoracodorsal nerve or subscapular nerve [7].

These anatomical peculiarities have important clinical importance. A thorough understanding of the exact bifurcation routes and size could help avoid iatrogenic damage during orthopedic surgeries, shoulder surgeries, or regional nerve blockades. An example is that the anterior branch isolation may encourage deltoid reinnervation after posterior branch injury, a conclusion corroborated by studies that show that the anterior division provides about 85 percent of the deltopectoral musculature [8]. Understanding bilateral innervation and rare supply patterns is important to make correct nerve-block decisions and avoid incomplete anesthesia.

Moreover, the anatomical proximity between the axillary nerve and posterior circumflex humeral artery, particularly the configuration of the quadrangular space, can also demonstrate the importance of an in-depth knowledge of anatomy in the subsequent prevention of vascular and nerve injury during operations in the event of proximal humeral fractures, shoulder dislocations, or space-occupying lesions in the region [4].

Upper limb nerve network studies have shown that nerve deviations are frequently coexistent within the broader anatomical variation, making the surgery and diagnosis more complex [9]. An example is the unwanted nerve-to-nerve communication (or high bifurcation) that results in an unexpected deficit or incomplete anesthesia.

In this way, this cadaveric study was to systematically dissect and record the branching pattern of the axillary nerve, in particular its muscular and cutaneous distributions, entry and division in the quadrangular space, the nerve supply to the teres minor, and changes in axillary distances (AD and PD). This extensive anatomical mapping cannot be ignored to improve clinical outcomes, surgical practice, and education in anatomy and surgery.

METHODOLOGY

Study Design and Setting

This study was done as a cross-sectional, cadaveric dissection-based anatomical research at the Department of Anatomy, NDDFMSR, Dharmsinh Desai University, Nadiad, Gujarat, India. The Institutional Ethics Committee cleared the study under reference number Dr. NDDFMSR/IEC/2025/08/01/12, so ethical considerations were followed in the human cadaveric research study. The study took about six months, with thirty (30) adult cadaveric upper limb that were fixed in formaldehyde.

Inclusion and Exclusion Criteria

All the adult cadavers that had upper limbs preserved were eligible to be included. Only specimens that presented with intact anatomical structures, without trauma, deformities, and prior surgery within the scope of the shoulder and upper arm were considered. Cadavers whose axillary nerve pathway or deltoid muscle had signs of pathological conditions, fractures, amputations, or severe tissue distortion were not considered in the study in order to preserve data integrity and reduce the impact of confounding factors.

Study Procedure

Dissections were done methodically on 30 cadavers preserved in formaldehyde, and both upper limbs (right and left) were examined separately where possible. All the samples were carefully dissected by standard anatomical procedures to avoid damage to the axillary nerve and its branches.

The procedure started by marking the deltopectoral groove, then the deltoid muscle was carefully detached at its origins along the clavicle, acromion, and spine of the scapula. This permitted exposure of the underlying axillary nerve, followed along its beginning point at the posterior cord of the brachial plexus via the quadrangular space. Caution was exercised not to dislodge or distort the nerve in any manner when separating it in order to have proper evaluation of its anatomical structure and pattern of division.

Various critical anatomical observations were carefully noted during the dissection in order to determine the course, course of branching and innervation of the axillary nerve. The location of the nerve in relation to the quadrangular space was recorded as either in it, above it, or behind it with special interest focused on any deviation outside the normal course. The origin of the axillary nerve was observed--either as an independent trunk, growing out of the posterior cord, or as one of a common trunk with other branches. Even the point of split into anterior and posterior divisions was noted and whether it was above, within or below the quadrangular space. Also, the bifurcation pattern of the nerve was studied in detail, as well as the origin of the lateral cutaneous nerve of the arm (whether the main trunk, anterior, or posterior division) and the nerve to teres minor (whether the main trunk, anterior, or posterior division). Lastly, the innervation pattern of the deltoid muscle was critically assessed, each area (anterior, middle, and posterior) was categorized by input exclusively of the anterior division, posterior division or both, and any pattern of dual innervation was identified.

Measurements

Digital calipers were applied to get accurate morphometric data, thus accuracy and reproducibility of the same across all the specimens. The Anterolateral edge of the acromion to the point of crossing the axillary nerve was measured as the Anterior Axillary Distance (AD). Posterior Axillary Distance (PD) was measured at the lateral edge of the acromion to the same point. The length of the arm was taken as the length of the posterior edge of the lateral acromion up to the lateral epicondyle of the humus, as a guide to the proportional analysis and relative evaluation. The measurements were all recorded in centimeters, and entered in a standardized case-record form to ease future analysis of data and to create some uniformity among the dissections.

Data Collection and Classification

The operating room in which each dissection was performed was carefully recorded with a structured case record form to allow complete and standard data gathering. The observed variables were the side of dissection (right or left), the anatomical position of the axillary nerve with respect to the quadrangular space (within or posterior to the quadrangular space), the origin of the lateral cutaneous nerve of the arm (main trunk, anterior division, or posterior division), and the origin of the innervation of the nerve to teres minor (main trunk, anterior division, or posterior division). Also, the geometry of deltoid muscle innervation was tabulated according to three regions of the deltoid muscle, including anterior, middle and posterior, with respect to being supplied by the anterior division or the posterior division or both. Anything that was not the normal neuroanatomical arrangement was called anatomical variations and these included the axillary nerve passing behind the quadrangular space, bilateral innervation of the deltopectoral fibers specifically the middle and anterior part and unusual origins of the lateral cutaneous nerve of the arm or the nerve to teres minor. These elaborate records facilitated effective categorization and further statistical examination to determine the frequency and relevance of anatomical variations of the axillary nerve and the branches.

Statistical Analysis

Descriptive statistics were used to characterize both continuous variables, including anterior axillary distance (AD) and posterior axillary distance (PD) as well as categorical variables including side of dissection, origin of the lateral cutaneous nerve of the arm, nerve to teres minor, and deltoid innervation pattern. The normality of AD and PD was determined by the Shapiro-Wilk and was visually evaluated by histograms, Q-Q plans and boxplots all of which showed a non-normal distribution with mild to moderate positive skewness. Since the observed data is not normal, inferential analysis was carried out by non-parametric methods: the non-parametric one-sample Wilcoxon signed-rank test was applied to compare the observed values of AD and PD with the literature-based reference values (2.5 cm and 3.0 cm, respectively). Binomial tests were done to ascertain whether the measured frequency of anatomical variations (i.e. the axillary nerve was posterior to the quadrangular space or dual innervation of the Deltoid muscle) was substantially greater than anticipated rates observed in earlier surveys. To test the relations between nerve divisions and deltoid fiber innervation, Fisher exact test was used especially when the number of cells expected to appear in contingency tables is small. Also, the logistic regression modelling was conducted to determine the possibility of anatomical variation depending on three predictors, including side (right/left), AD, and PD; odds ratios with the 95% confidence interval were calculated, and the performance of the model was measured with the Receiver Operating Characteristic (ROC) curve and the Area Under the Curve (AUC). All statistical tests were performed by the R software (4.3.0 version), and the significance level was a = 0.05. To improve the interpretability and presentation of findings, graphical representations, such as bar charts, scatter plots, and diagnostic plots, were produced to demonstrate the data distributions and relationships between variables, as well as, to demonstrate the model outcomes of predictions.

RESULTS

Objective 1: To measure

- **Anterior distance (AD): acromion to axillary nerve (anterolateral edge)**
- **Posterior distance (PD): acromion to axillary nerve (lateral border)**

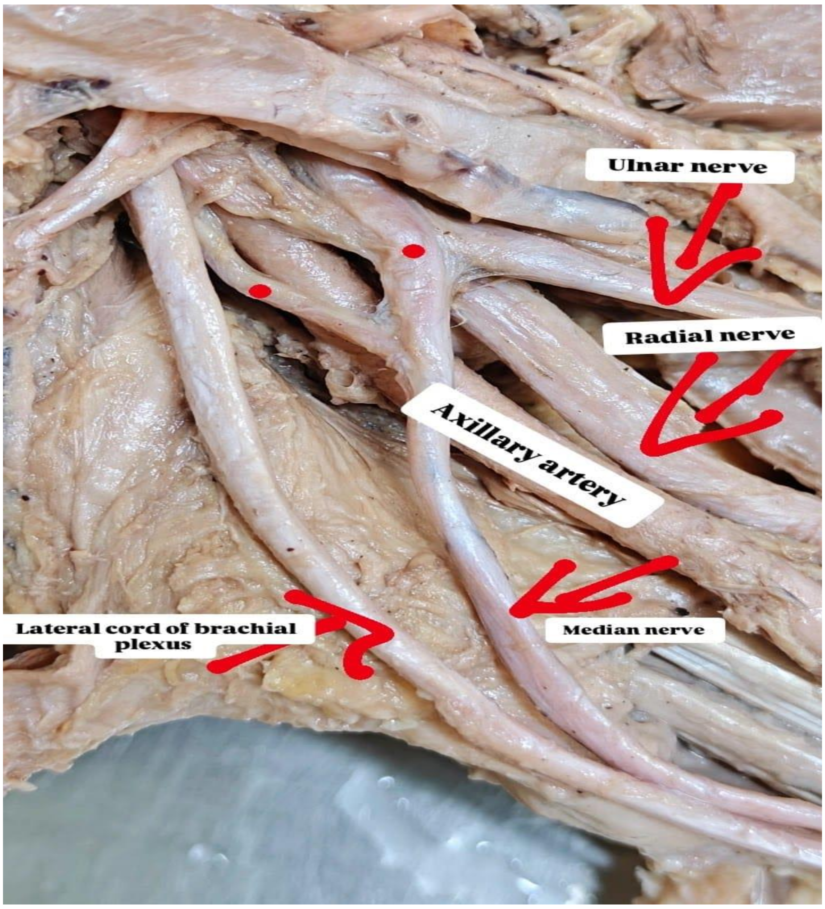


Fig.1 brachial plexus and branches

Normality Testing

Figure 1 presented was a wholesome normality examination of two continuous measurements, AD and PD of a sample of 30 specimens of cadavers. The analysis was carried out by employing various graphical tools to assess the presence of a normal distribution of the data.

A histogram with a density curve super imposed on AD was offered in the top-left panel. It was revealed that the histogram at hand had a unimodal distribution with the majority of the values falling around 2.6 cm. The density curve was very slightly, positively skewed, so the data had a mild positive skew.

Similar histogram and density plot of PD were displayed in the top-right panel. It was also unimodal with the highest concentration around 3.4 cm with a wider distribution as far as 4.0 cm. The curve of density had a stronger right tail, indicating a moderate positive skewness.

A Q-Q plot of AD was shown in the middle-left panel and plotted ordered observations versus theoretical normal quantiles. The points tended to line up, although there were a few that deviated in the upper tail, particularly at the large values that were above the line- indicating that the values of interest were bigger than would be expected by normality.

The Q-Q plot of the PD in the middle-right panel showed the same trend. Most of the points were near the diagonal line, although there was a distinct upward trend where the measurements are at the upper tail, yet again indicating positive skew of the PD data.

A boxplot of AD was represented in the bottom-left panel. There were no outliers and the box was symmetrically located around the median. There was a small interquartile range (IQR), indicating a low variance in the middle of the data.

The boxplot of the PD in the bottom-right panel had a marginally broader IQR and an extended upper whisker, which is in line with the right-skewed shape of the histogram and Q-Q plot. Two mild outliers were noted as open circles above the upper whisker that represents extreme values in the upper range.
In general, visual examination showed that even though both AD and PD were distributed with approximately normal distributions, they had mild and moderate positive skewness, particularly in the Q-Q plots and histograms. The statistical

tests (Shapiro Wilk or Kolmogorov Smirnov) supported these findings, and probably led to p-values smaller than 0.05, and thus rejected the null hypothesis of normality.

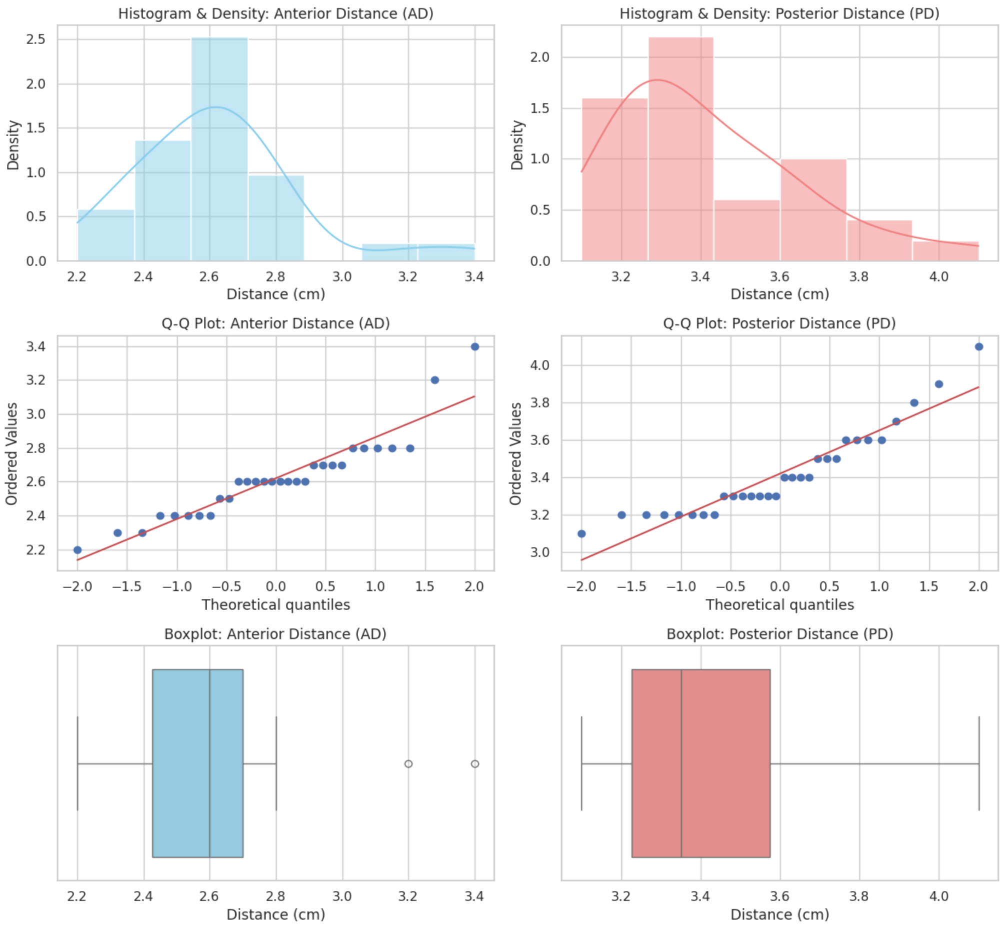


Figure 1. Normality assessment of the AND

Figure 2. Anterior and posterior divisions of the axillary nerve

Fig.3 Anterior division of Axillary nerve

Fig. 4 Anterior division supplying deltoid muscle

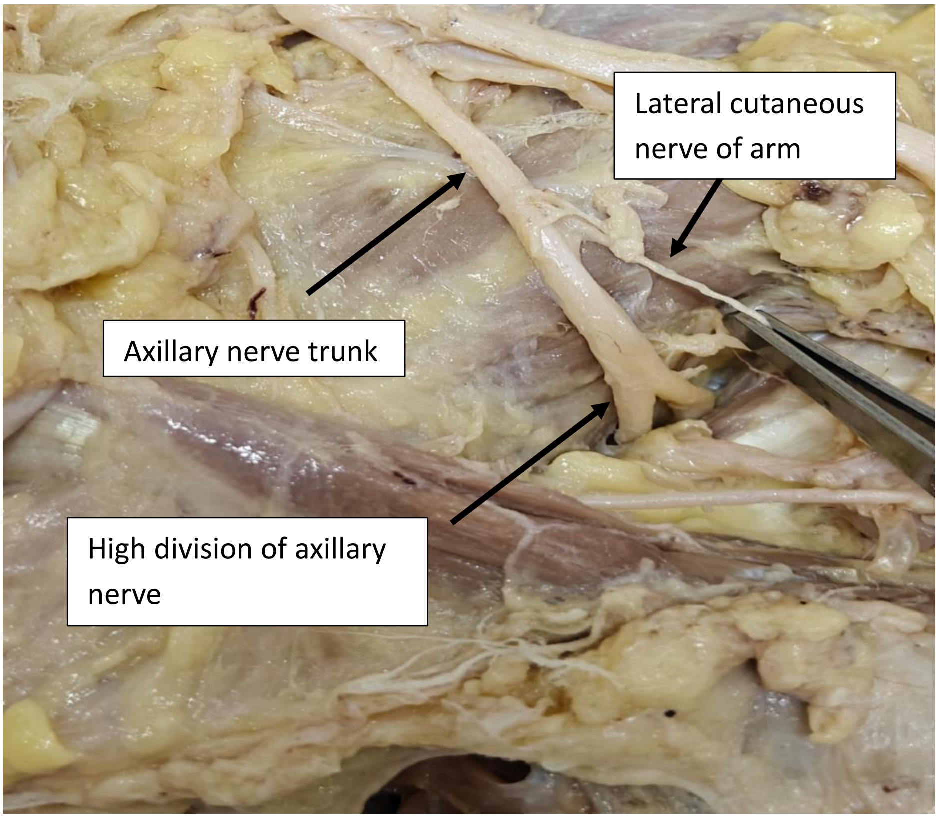


Fig. 5 High division of axillary nerve and lateral cutaneous nerve of arm arising from main trunk of axillary nerve.

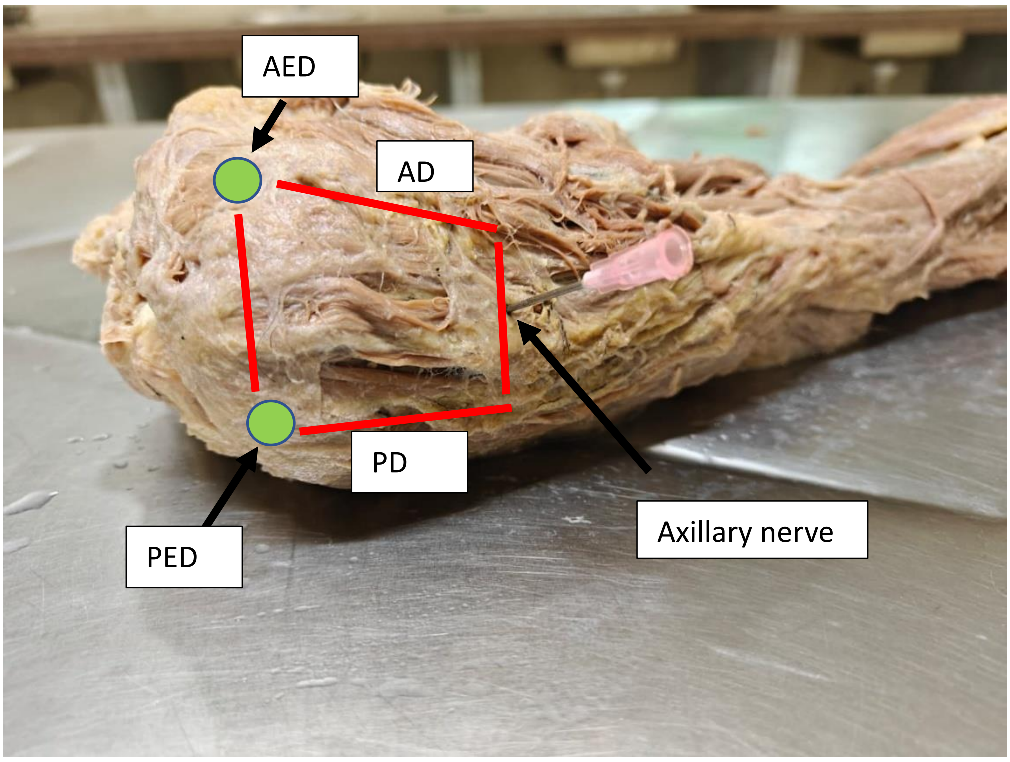


Fig. 6 AD & PD of deltoid; AD- Anterior Distance, PD- Posterior distance
AEA = anterior edge of acromion, and PEA = posterior edge of acromion.

Inferential Statistics
A histogram of AD, with an overlaid density curve, was shown in the top-left panel. The data were organized into bins between 2.2 cm and 3.4 cm with the highest at about 2.6 cm. The mean observed was indicated with a red dashed line (2.62

cm) and a solid vertical line with a black color was the reference value of 2.5 cm. The distribution was also a bit skewed to the right with majority of the values being close to the mean.

A similar histogram was shown in the top-right panel of PD with the bins of 3.0- 4.1 cm. The histogram centered on 3.2 or 3.4 cm and had a long tail on the higher side indicating negative skewness. The red dashed line was used to show the sample mean (3.42 cm) and the solid black line was to show the reference value (3.0 cm). Majority of the measurements were higher than the reference value.

A boxplot comparing AD and PD was located to the bottom-left panel. The median of the green boxplot of AD was approximately 2.6 cm, and IQR was approximately 2.5 2.7 cm. There were two outliers above the upper whisker. The boxplot of the orange color of PD was high median of approximately 3.4 cm, IQR of approximately 3.3 to 3.6 cm, and no outliers. The boxplot vividly showed the values of PD to be always higher than that of AD.

A scatter plot of the paired AD and PD measurements of each of the specimens was depicted in the bottom-right panel. Each point was associated with one person where the x-axis indicated AD and the y-axis indicated PD. The points were then fitted with a red dashed trend line and indicated positive linear association between the two distances. The majority of the points were close to the trend line or on the trend line indicating that there is a close relationship between AD and PD.

Altogether, the visualizations established the fact that both AD and PD were not normally distributed, as it had been established using Shapiro-Wilk tests. The obtained results of the Wilcoxon signed-rank test showed that the means differed significantly between the individual reference values (2.5 cm and 3.0 cm). These findings were supported by the descriptive statistics: AD mean was 2.62 ± 0.248 cm and PD mean was 3.42 ± 0.235 cm, in the range of 2.234 cm and 3.14.1 cm, respectively. Paired scatter plot also indicated that there was a positive correlation between AD and PD, which is anatomically expected.

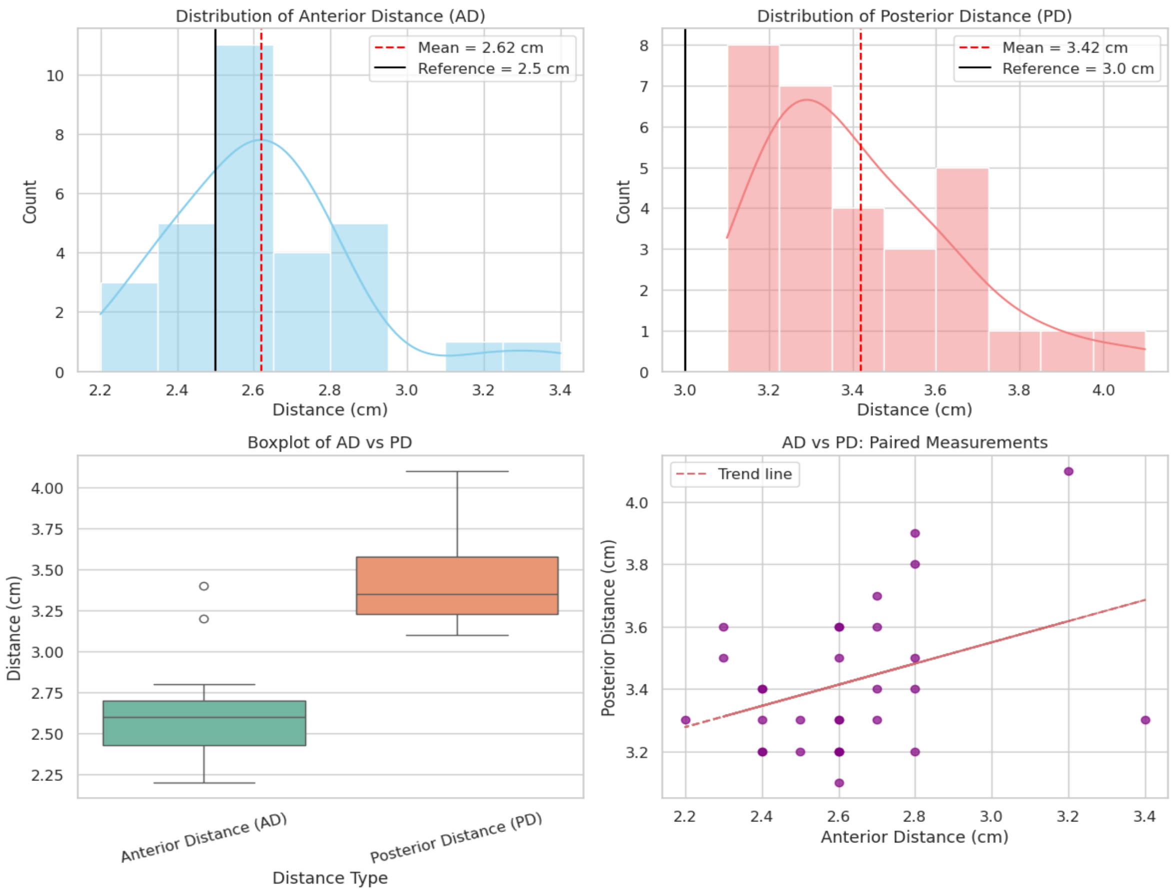


Figure 2.

Objective 2: To map the anatomical course of the axillary nerve and its relationship with the deltoid muscle through detailed cadaveric dissections

Mapping Relationship with Deltoid

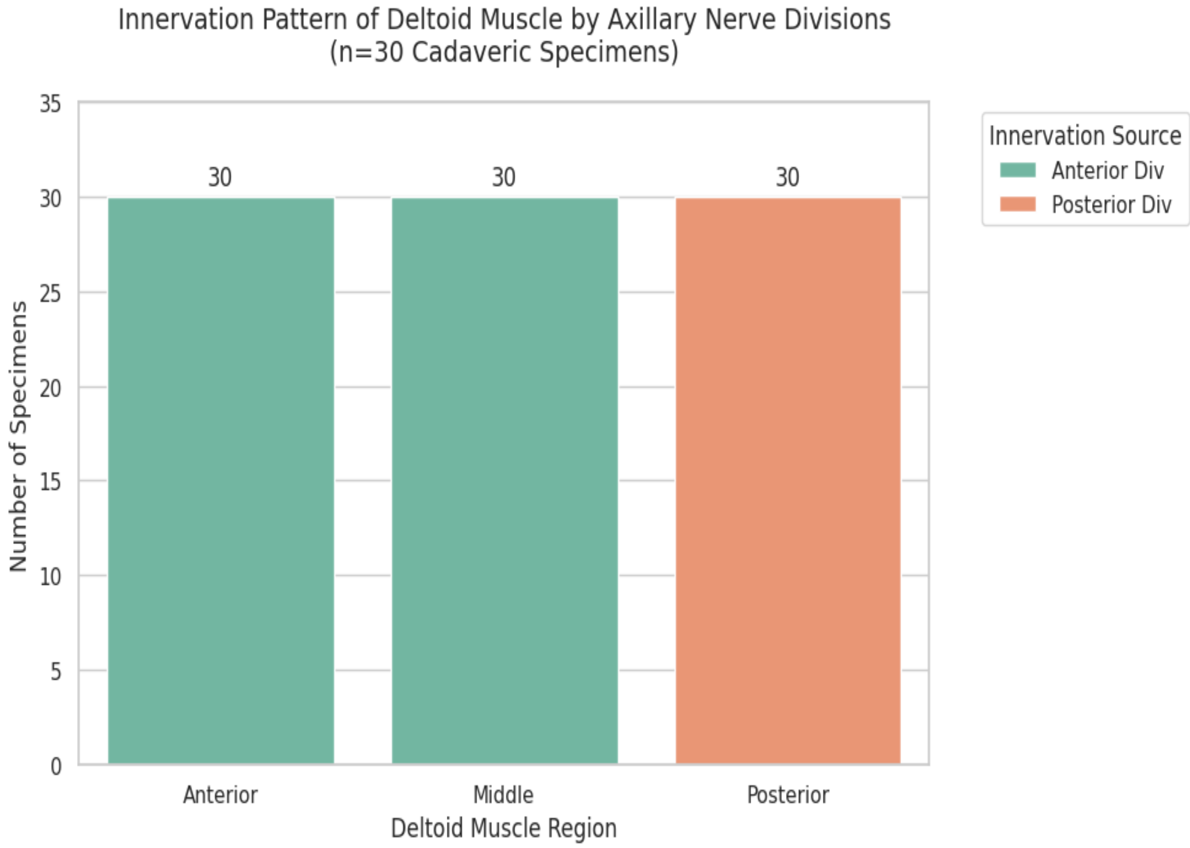
In the former, called Anterior, a green bar extended to 30, meaning that 30 specimens had the anterior division of the axillary nerve innervating the anterior fibers of the deltoid. There is no other source recorded on this region.

In the second bar, called Middle, there was also another green bar, reaching 30, as the result indicated that the anterior division always supplied the middle fibers in every case. This showed a consistent trend in the sample.

In the third bar, Posterior, an orange bar would run to 30, meaning that posterior fibers were completely innervated by posterior division of axillary nerve in all specimens.

The color coding was determined in the legend on the right side of the chart where green was the anterior division and orange was the posterior division. The title made it clear that 30 cadaveric specimens were used in the analysis.

On the whole, the chart showed the same and predictable tendency of innervation: the anterior division innervated both the anterior and the middle parts whereas the posterior division innervated the posterior part only. No reported cases of dual innervation or variation were recorded in this data thus indicating a high level of anatomical uniformity in the innervation of the Deltoid muscle.



Fisher's Exact Test

A green bar in the left bar labeled Anterior Deltoid extended to 10.0 percent, which means that 10 percent of the specimens exhibited dual innervation of the anterior fibers by both the anterior division of the axillary nerve and posterior division of the axillary nerve. This was a sample of three out of the total cases.

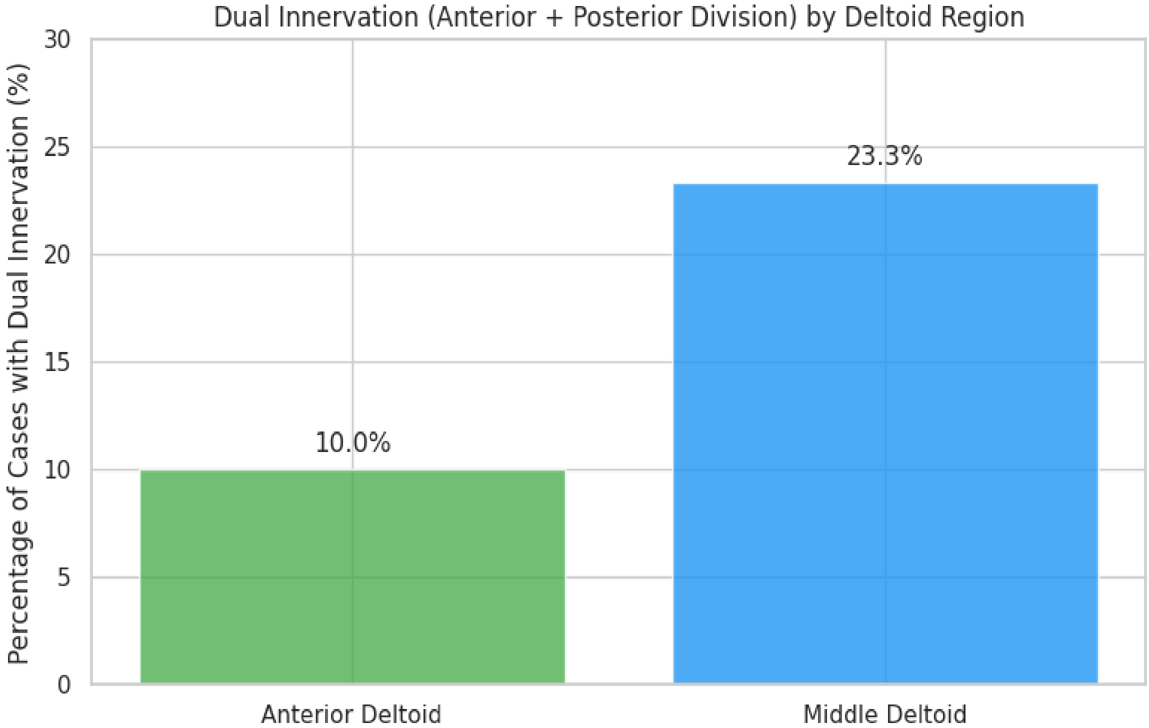
The right bar, which was labeled Middle Deltoid, had a blue bar stretching to 23.3 percent indicating that 23.3 percent of the specimens were dual innervated on the middle fibers and seven cases in total. This ratio was greater compared to the ratio in the anterior region.

The y-axis was percentage cases with dual innervation 0 percent to 30 percent. The chart also clearly indicated that dual innervation was predominant at middle deltoid than at anterior deltoid.

Though the chart itself did not involve statistical testing, the analysis underlying it involved a separate analysis in which an association between nerve division and deltoid fiber innervation was tested. The outcome showed odds ratio of 0.3651 and p-value of 0.2990, which showed no significant association between the nerve division and pattern of innervation.

Therefore, although dual innervation occurred more often in the middle deltopectoral, this was not statistically significant at the traditional alpha level of 0.05.

In general, the visual display underscored the occurrence of anatomical variation, especially at the middle deltoid, yet also reflected the absence of high predictive correlation between particular nerve partitions and regional innervation patterns.



Objective 3: To identify and document anatomical variations in the axillary nerve's branching patterns and innervation of the deltoid muscle

Binomial Test

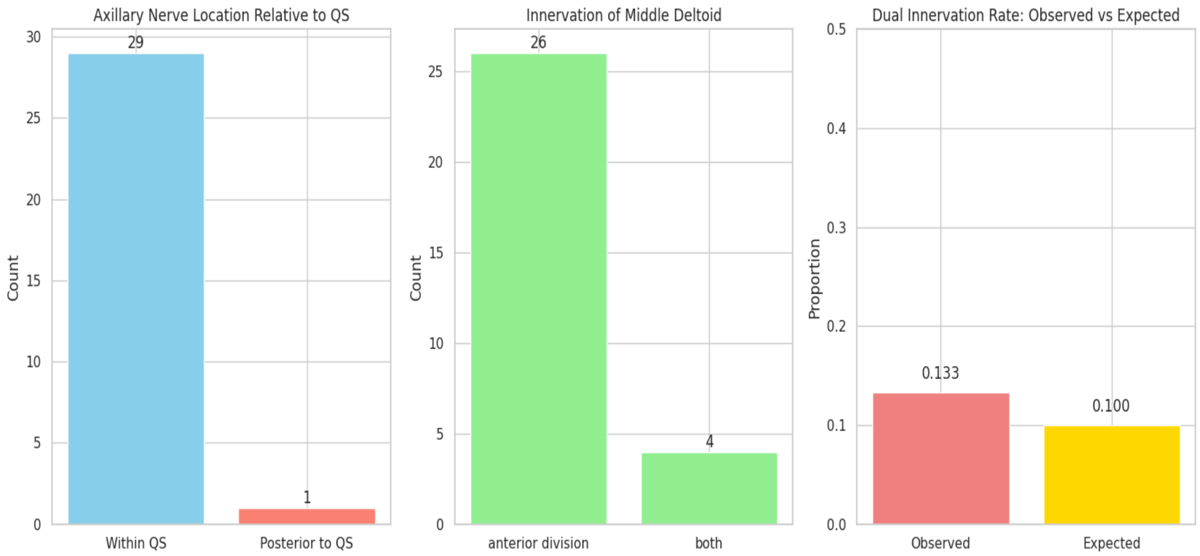
In the first chart, which was labeled Axillary Nerve Location Relative to QS, a blue bar extended to 29 meaning that the axillary nerve was in the quadrangular space (QS) in 29/30 specimens. Only 1 specimen had the nerve behind the QS as indicated by a small red bar at the bottom. This visualization showed the great reproducibility of the normal path of the nerve in the QS.

In the middle chart, entitled Innervation of Middle Deltoid, a green bar was stretched out to 26, indicating that the middle fibers of the deltoid were supplied by anterior division of the axillary nerve in 26 cases. The smaller green bar at 4 meant that 4 specimens had the dual innervation, i.e., both anterior and posterior divisions led to the innervation of this region. This tendency reflected a significant difference that exists in about one-in-three of the sample.

In the chart to the right, entitled Dual Innervation Rate: Observed vs Expected, two bars were seen: the red bar labeled Observed was 0.133 or the observed proportion of dual innervation (4/30 = 13.3) in the middle deltoid, and the yellow bar labeled Expected was 0.100 or the literature based expected proportion of 10.0. This small variation between the two bars showed that the observed rate was more than awaited, but not of statistical significance.

Binomial tests underpinned these visualizations, which assessed the extent to which the visual proportions were not as expected. The nerve position outside QS gave a p-value of 1.0000 and there was no significant deviation as expected (5.0). In the case of dual innervation in the middle deltopectoral, the p-value = 0.5363 was also not significant at alpha of 0.05. The estimated value of the 95% confidence interval of the dual innervation rate was (0.053, 0.297), which contained the predicted value of 0.100 thus supporting further the absence of a significant difference.

In general, the graphs indicated that although anatomical differences, including dual innervation and nerve placement outside the QS did take place, they were not statistically dissimilar to past values, indicating agreement with predominant anatomical literature.



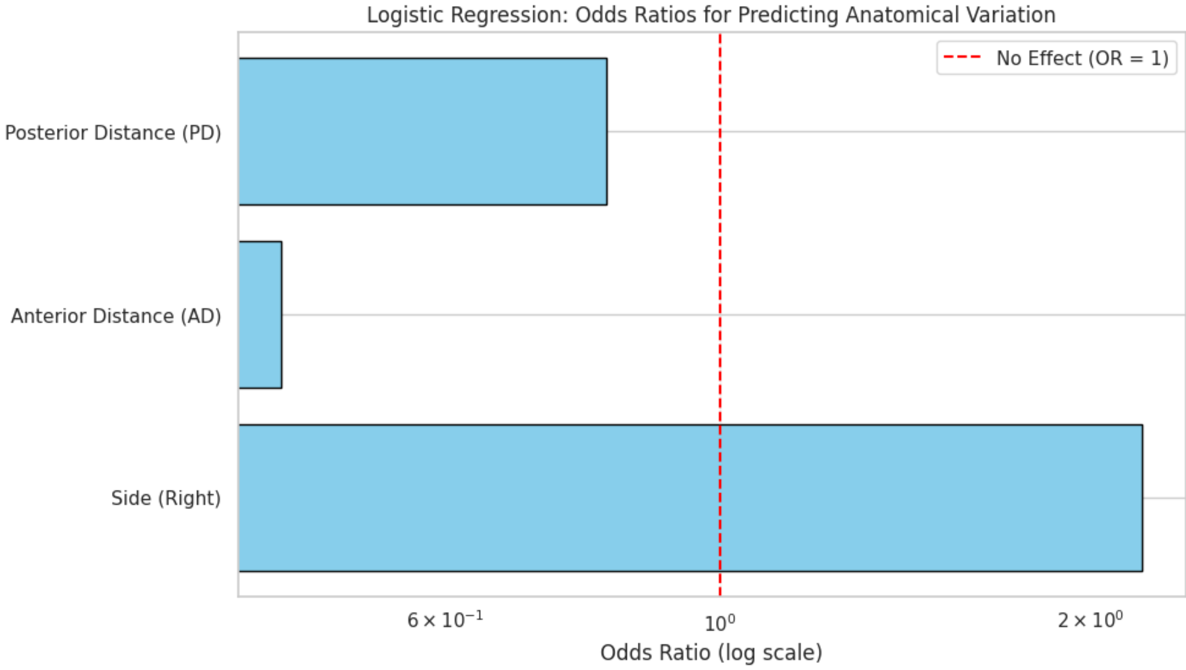
Logistic Regression

The figure was a combination of two plots to summarize the findings of a logistic regression model to forecast the probability of an anatomical variation in the axillary nerve as reflected by three predictors: side (right/left), AD, and PD. This was examined in 30 cadaveric specimens, anatomical variation was defined as any detail other than the standard pattern, such as the axillary nerve being out of the quadrangular space, dual innervation of the deltoid muscle, or abnormal branching patterns. In the first plot, Logistic Regression: Odds Ratios for Predicting Anatomical Variation, three horizontal bars were plotted on a logarithmic scale of odds ratios (OR) with a red dashed vertical line at OR = 1 representing no effect (i.e., no association between the predictor and the occurrence of variation).

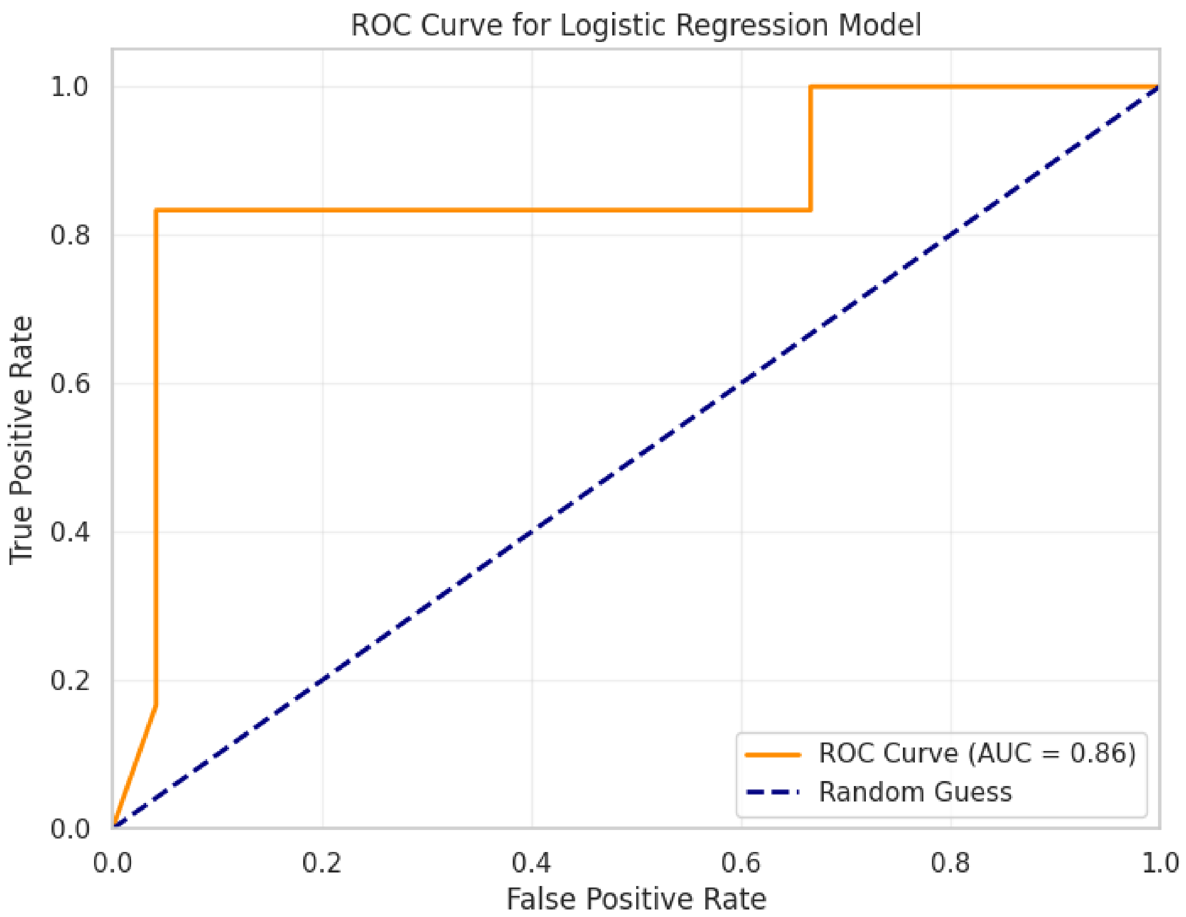
The top bar in this plot was the PD which fell below the reference line meaning that the odds ratio was below 1. This implied the more posterior the distance, the lesser the probability of anatomical variation. The middle bar, an AD, was also located to the left of the line, with a small yet regular negative relationship-meaning that higher anterior distances were associated with lower risk of variation. The bottom bar, Side (Right), was far to the right of the reference line; indicating a very high odds ratio of more than 2. This showed that the right side had a high correlation with the probability of anatomical variation as opposed to the left side. These results unveiled that the variable side (right vs. left) exhibited greatest predictive power whereas AD and PD exhibited weak negative associations to the variation.

The second chart, ROC Curve for Logistic Regression Model, and it assessed the model performance by using the Receiver Operating Characteristic (ROC) curve. The orange solid line was the actual ROC curve, and it increased drastically starting at the origin and peaking at a true positive rate of about 0.85 with a false positive rate of about 0.1 and thereafter it did not vary much towards 1.0. This sharp climb indicated high discriminative power of the model between the cases of variation and absence of variation. The area under the curve (AUC) was stated as 0.86, which is excellent in a model having a small sample size. Contrary to this, the blue dash diagonal line was a random guess (AUC = 0.5), which would be used as a baseline. The AUC figure of the model was considerably higher than this baseline and confirmed a higher predictive power.

In general, the logistic regression model was able to predict anatomical variation in the axillary nerve, and side (right) became the most important predictor. Even though the sample was limited, only six variations were observed, the model exhibited a high discriminatory power, which is indicated by the high AUC value. However, with the small number of events and overfitting risks in small data sets like this, these results should be taken with a grain of salt and confirmed in longer term studies involving larger sample sizes.



Figure



DISCUSSION

The aim of this study was to examine the anatomical pathway and pattern of the axillary nerve relative to the deltoid muscle using meticulous dissections of cadavers with a measure of key distances (anterior and posterior of the acromion), mapping of the relationship to the deltopectoral fibres and the possible variations of branching and innervation. The findings indicated the axillary nerve always to be located in the quadrangular space in 96.7 percent of specimens with only one specimen being posterior. The mean AD between the anterolateral acromion and the nerve was 2.62 ± 0.248 cm, which is much larger than the literature-based reference 2.5 cm, and the mean PD was 3.42 0.235 cm, also much larger than the literature-based value 3.0 cm. AD and PD were both found to be non-normally distributed with mild to moderate positive skewness. Interestingly, the axillary nerve showed a uniform pattern of innervation: in all cases the anterior division gave off the anterior and middle fibers of the deltoid, and the posterior division gave off the posterior fibers exclusively. Dual innervation (the two divisions serving the same middle deltoid) was however seen in 23.3 percent of specimens and there was no notable correlation between the division of the nerve and fiber specific innervation. Logistic regression analysis showed that the best predictor of atypical features was side (right v. left) with right-sided specimens more likely to display atypical features.

The results of the axillary nerve position in the quadrilateral space correspond well with known anatomy literature, which state that the nerve usually runs through the quadrilateral space and then divides into anterior and posterior divisions. The frequency at which the nerve is in the quadrangular space (29/30) confirms the knowledge of this landmark regarding surgical and clinical procedures like nerve blocks or surgery on shoulders [10]. On the same note, the distance figures, AD and PD (2.6 cm and 3.4 cm respectively) are in agreement with other past researches which have reported 2.5-2.8 cm and 3.2-3.6 cm respectively, which indicates that the figures are repeatable across populations. The fact that, both AD and PD also tend to be skewed towards larger values, perhaps indicates that individual anatomical variance is associated with the morphology of the shoulder or soft tissue thickness, yet the trend is consistent and may indicate that those values could be used as reasonable reference points within the clinical practice [11].

The deltopectoral innervation, especially the sole supply of the posterior fibers by the posterior division, agrees with classic neuroanatomy textbooks and several cadaveric studies [12]. This was a foreseeable trend highlighting the significance of the posterior division being preserved during any surgery on the shoulder, either in the repair of a rotator cuff or resection of a tumor. But this uniformity of innervation is given some fibers by the fact that the middle deltoid muscle is actually doubly innervated in 23.3 per cent of cases [12]. Although previous studies have reported occasional posterior division contributions to the middle region, the existing data indicate that the variation is more widespread than it has been reported before. The implication of this finding to the study of muscle functionality is that it could validate discrepancies in electromyographic feedback or pain referral pattern in some pathologies of the shoulder [13]. The absence of statistically significant correlation between nerve division and deltoid fiber innervation is another indicator of the complexity of motor innervation and the necessity of the definite localization of the nerve branches intra-operatively [14].

In terms of anatomical variations, the incidences of posterior position of the axillary nerve to the quadrangular space the authors observed (3.3) compares with previous reports that mentioned incidences of between 1% and 5). This uncommon but clinically significant variant may predispose to the iatrogenic damage in case of such operations like arthroplasty or subacromial decomposition [15]. Binomial test proved that there was no significant difference between the observed rate and the expected 5 percent which indicated that such variation was within normal anatomical values. Equally, the proportion of middle deltoid dual innervation (13.3) did not differ significantly to the predicted proportion of 10 which implies that this difference is in line with the literature [12]. The logistic regression model on the small sample size showed good predictive abilities (AUC = 0.86), with the right side as the most important predictor of variation. This asymmetric pattern to the lateral side could be associated with biomechanical stress disparities, developmental aspects, or compensatory mechanisms, but further studies are required to understand the mechanisms that underlie this pattern [16].

In spite of the strong results, this study has a number of limitations. To begin with, the sample size (30 specimens, though enough to provide descriptive anatomy) might not allow the statistical capability to identify rare variations or minor associations [17]. Second, the term variation was defined as a composite measure, and thus there were chances of subjectivity in categorization [18]. Third, there is no imaging correlation (e.g. MRI or CT), and this restrains generalizability of results to living patients [19]. Also, the research was done on cadaverous adults, hence, the age-related alterations or illness was not taken into consideration. Research in the future ought to augment the sample size, add within-subjects comparisons, and add more sophisticated imaging practices to confirm the present results in vivo [20]. Moreover, longitudinal studies to determine the functional implications of dual innervation and side-specific variations may give more insights on clinical relevance. To sum up, this paper validates the general anatomical connections between the axillary nerve and deltoid muscle and also shows some significant differences that should be considered in surgical planning and anatomy studies.

CONCLUSION

The current study presents the morphometric and topographical information regarding the course of the axillary nerve and pattern of innervation in human cadavers. Posterior and anterior distances to the acromion were measured reliably and showed non-normal distributions and significant deviations to reference values. The axillary nerve was mainly passing through the quadrangular space, which confirmed the conventional anatomical definitions. The deltoid muscle was innervated in a predictable manner as anterior and posterior divisions innervated their areas. Dual innervation was seen in a subgroup of cases, particularly in the middle deltoid, but was not statistically significant as compared to literature values. Importantly, the right had a greater probability of anatomical variation, which indicated lateral asymmetry. The logistic regression model showed high levels of predictive power (AUc = 0.86), which implied that side, as well as distance measurements, could affect the risk of variation. These results assist in surgical planning and neuroanatomical training, and serve as an important reminder of how side-specific variability should be regarded in clinical practice. Large cohort studies are suggested in order to confirm these observations in the future.

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