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Anatomical Variations of the Brachial Plexus in Human Cadavers and Their Clinical Implications: A Descriptive Observational Cadaveric Study.

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Abstract

Background:
The brachial plexus is the principal neural network of the upper limb and demonstrates considerable anatomical variability. These deviations are clinically important because they can alter the interpretation of neurological deficits, complicate surgical exposure, and influence the success of regional anesthesia.

Objectives:
To document the anatomical variations of the brachial plexus in human cadavers and to assess their potential clinical implications.

Methods:
This observational cadaveric study was conducted in the Department of Anatomy, ASRAMS, Eluru, Andhra Pradesh, India, from January 2024 to December 2025. Thirty brachial plexuses were dissected and examined for variations in trunk formation, median nerve formation, and communications involving the musculocutaneous nerve. Findings were recorded systematically and expressed as frequencies and percentages.

Results:
The classical anatomical pattern was observed in 19 specimens, whereas 11 showed variations. Variations in trunk formation were the commonest finding, followed by altered median nerve formation and communications between the musculocutaneous and median nerves. The median nerve showed normal two-root formation in most specimens, while additional roots were identified in a small proportion. The musculocutaneous nerve followed the usual course in the majority, but communicating branches with the median nerve were noted in a few specimens.

Conclusion:
Anatomical variations of the brachial plexus were present in more than one-third of the examined specimens. Variations were particularly frequent in the trunk pattern and median nerve configuration, underscoring the need for detailed anatomical knowledge during surgical, anesthetic, and diagnostic procedures involving the neck, axilla, and upper limb.

Recommendations:
Routine awareness of possible brachial plexus variations should be emphasized in anatomy teaching, preoperative planning, microsurgical procedures, and peripheral nerve block training. Larger multicentric cadaveric and imaging-based studies are recommended to refine anatomical mapping and improve clinical safety.

Keywords: *Brachial plexus, anatomical variation, cadaver, median nerve, musculocutaneous nerve, clinical anatomy.*
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Introduction

The brachial plexus is a complex network formed predominantly by the anterior rami of the C5 to T1 spinal nerves and is responsible for motor and sensory innervation of the upper limb. Because of its elaborate developmental pattern, the plexus shows considerable variability in the arrangement of roots, trunks, cords, and terminal branches. Even small departures from the classical description can have substantial anatomical and clinical significance. Cadaveric studies remain an essential method for identifying these departures and for clarifying the morphology of neural structures that are directly relevant to operative anatomy and regional anesthesia [1-4].

Reported variations include prefixed and postfixed plexuses, anomalous formation of trunks, unusual relationships of cords to the axillary artery, altered formation of the median nerve, absence or atypical course of the musculocutaneous nerve, and abnormal communicating branches between major terminal nerves [3-8]. Among these, communications between the musculocutaneous and median nerves are especially important because they can influence the pattern of motor weakness and sensory loss after trauma, entrapment, or iatrogenic injury [5-10]. Similarly, aberrant roots contributing to the median nerve can confuse surgeons during axillary dissection, complicate nerve repair, and influence the spread of local anesthetic during brachial plexus blockade [4,11-13].

From a clinical perspective, detailed knowledge of brachial plexus anatomy is crucial for orthopedic, plastic, vascular, trauma, and neurosurgical procedures involving the neck, shoulder, axilla, and arm. Anatomical variants can increase the risk of inadvertent nerve injury, lead to unexpected operative findings, and produce atypical neurological presentations. Imaging specialists and anesthesiologists also benefit from awareness of these variants, particularly during ultrasound-guided nerve blocks and during evaluation of thoracic outlet syndrome or upper limb neuropathies [1,3,4,8,9,14]. Such knowledge is equally useful in anatomical education because cadaveric demonstrations help correlate textbook descriptions with the true diversity encountered in practice. Despite the growing literature, regional cadaveric data remain valuable because the frequency and pattern of variations are not uniform across studies or populations.

In view of these considerations, the present observational study was undertaken to examine the anatomical variations of the brachial plexus in human cadavers at a tertiary teaching institution. The objectives of the study were to identify the frequency of normal and variant brachial plexus patterns, document specific variations in trunk formation and terminal branch configuration, assess variations in the formation of the median nerve and communications involving the musculocutaneous nerve, and highlight the clinical implications of these findings for surgery, anesthesia, and diagnostic practice.

Methodology

Study design and setting

This was a hospital-based cross-sectional observational cadaveric study conducted in the Department of Anatomy, Alluri Sitaram Raju Academy of Medical Sciences (ASRAMS), Eluru, Andhra Pradesh, India, over a two-year period from January 2024 to December 2025. ASRAMS is a tertiary medical teaching institution with an attached teaching hospital that provides undergraduate and postgraduate medical education, broad specialty clinical services, and super-specialty patient care services. The Department of Anatomy supports undergraduate medical teaching, cadaveric dissection training, osteology teaching, histology practical sessions, anatomical demonstrations, museum-based learning, cadaver preservation, and anatomy-related academic research. The study was carried out using adult human cadaveric specimens available in the department for routine teaching and academic dissection. The objective was to document the anatomical pattern of the brachial plexus and identify clinically relevant variations in its roots, trunks, cords, and terminal branches.

Study material

A total of 30 brachial plexuses from well-preserved human cadaveric upper limb specimens were included in the final analysis. Each plexus was treated as an individual specimen for anatomical observation. The sample size represented all eligible specimens available during the study period and was therefore based on specimen availability rather than hypothesis-driven power estimation. Side-wise distribution of the examined specimens included 18 right-sided and 12 left-sided brachial plexuses.

Inclusion and exclusion criteria

Adult cadaveric specimens with intact neck, axillary, and upper arm regions and with adequately preserved neurovascular structures were included. Specimens showing

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marked trauma, prior dissection damage, severe decomposition, gross congenital deformity, or loss of identifiable neural structures in the area of interest were excluded. Only specimens in which the trunks, cords, and major terminal branches could be traced confidently were documented.

Dissection procedure.

Each specimen was dissected systematically. Skin, superficial fascia, and deep fascia were reflected from the lower part of the neck, axilla, and proximal arm. The clavicular and pectoral regions were exposed where necessary to visualize the roots and trunks proximally and the cords and terminal branches distally. The roots contributing to the plexus, formation of the upper, middle, and lower trunks, the relationship of cords to the axillary artery, the formation of the median nerve, and the course of the musculocutaneous nerve were examined in detail. Particular attention was paid to accessory roots, prefixed or postfixed patterns, atypical fusion of trunks, and communicating branches between the musculocutaneous and median nerves, as emphasized in earlier cadaveric studies [4-8,11].

Data collection and analysis.

Observations were entered in a structured proforma immediately after dissection. Each brachial plexus was categorized as either classical or variant. Variants were further grouped according to the part affected, namely trunk formation, median nerve formation, communication between the musculocutaneous and median nerves, and prefixed or postfixed pattern. Descriptive statistics were used for analysis. Frequencies and percentages were calculated for each anatomical pattern, and the side distribution of variations was recorded. No inferential statistical comparison was planned because the study objective was descriptive anatomical documentation rather than hypothesis testing.

Ethical considerations.

The study was conducted after obtaining permission from the Institutional Ethics Committee, Alluri Sitaram Raju Academy of Medical Sciences, Eluru, Andhra Pradesh, India, for the use of cadaveric material meant for academic and research purposes. All specimens were handled with due respect and in accordance with accepted ethical principles for cadaver-based anatomical research. No personal identifiers were used at any stage of documentation, and the observations were reported in aggregate form only.

Results

A total of 30 brachial plexuses from human cadavers were carefully dissected and examined to identify anatomical variations in the formation and branching pattern of the plexus. Of the 30 specimens studied, 18 (60.0%) were from the right side, and 12 (40.0%) were from the left side. The classical anatomical pattern of the brachial plexus was observed in 19 specimens (63.3%), while variations were identified in 11 specimens (36.7%) (Table 1).

Table 1. Overall distribution of normal anatomy and anatomical variations of the brachial plexus (n = 30)

Pattern observed	Number	Percentage (%)
Normal anatomical pattern	19	63.3
Anatomical variations	11	36.7
Total	30	100

Among the specimens showing variations, several differences were noted in the formation of trunks, median nerve formation, and communications between major terminal branches. The most frequent variation involved trunk formation, identified in 4 specimens (13.3%), followed by variations in the formation of the median nerve in 3 specimens (10.0%). Communication between the musculocutaneous and median nerves was observed in 2 specimens (6.7%). Prefixed and postfixed brachial plexus patterns were found in 1 specimen each (3.3%) (Table 2).

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Table 2. Types of anatomical variations observed in the brachial plexus (n = 30)

Type of variation	Number	Percentage (%)
Variation in trunk formation	4	13.3
Variation in median nerve formation	3	10.0
Communication between the musculocutaneous and the median nerve	2	6.7
Prefixed brachial plexus	1	3.3
Postfixed brachial plexus	1	3.3
No variation observed	19	63.3

The formation of the median nerve was analyzed in all specimens. In 27 brachial plexuses (90.0%), the median nerve showed the usual formation by one lateral root from the lateral cord and one medial root from the medial cord. In the remaining 3 specimens (10.0%), an additional root or accessory contribution was noted, indicating a variant pattern of formation (Table 3).

Table 3. Formation pattern of the median nerve (n = 30)

Formation pattern	Number	Percentage (%)
Normal formation (one lateral root and one medial root)	27	90.0
Variant formation with additional root/contribution	3	10.0
Total	30	100

The musculocutaneous nerve followed the normal course in 28 specimens (93.3%), piercing the coracobrachialis and continuing between the biceps brachii and brachialis muscles. In 2 specimens (6.7%), a communicating branch between the musculocutaneous and median nerves was observed in the arm, representing the principal variation involving this terminal nerve in the present series (Table 4).

Table 4. Variations involving the musculocutaneous nerve (n = 30)

Pattern	Number	Percentage (%)
Normal course of the musculocutaneous nerve	28	93.3
Communication with the median nerve	2	6.7
Total	30	100

Overall, anatomical variations were present in approximately one-third of the dissected specimens. Variations were concentrated mainly in trunk formation and median nerve configuration, whereas the majority of terminal branches retained the conventional pattern. These findings indicate that the brachial plexus exhibits clinically relevant variability even in a modest cadaveric sample and

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reinforce the need for procedural caution during interventions involving the axilla and upper limb.

Discussion

The present cadaveric study demonstrated that 36.7% of the examined brachial plexuses showed anatomical variations. This supports the view that the brachial plexus is a variable neural structure rather than a uniform pattern. The proportion recorded in the current series is lower than the prevalence reported by Han et al., but it remains within the broad range described across dissection-based studies [1]. Emamhadi et al. and Leonhard et al. emphasized that important variations can occur at different levels of the plexus, particularly in the roots and trunks, with direct implications for surgery and diagnosis [2,3].

In the present study, variations in trunk formation represented the most frequent abnormality. This is important because alterations at the trunk level can change the downstream arrangement of divisions, cords, and terminal branches. Leonhard et al. showed that proximal plexus variations can modify the relationship of neural structures to the scalene musculature and complicate assessment of thoracic outlet symptoms [3]. The identification of one prefixed and one postfixed plexus is consistent with the recognized spectrum of developmental variation. Chaudhary et al. described unusual trunk patterns associated with postfixed plexuses and highlighted their relevance during operative exposure of the lower neck and supraclavicular region [14].

Variant formation of the median nerve was the second most frequent observation in this study. The median nerve showed an accessory root in 10.0% of specimens, whereas the conventional two-root pattern was present in 90.0%. This rate is lower than the frequencies reported by Ghosh et al. and Passey et al., who found a substantial proportion of specimens with three-root or four-root formation [12,13]. Pandey and Shukla demonstrated that abnormalities in median nerve formation are often associated with altered relations to the axillary artery and adjacent communicating branches, increasing vulnerability during axillary dissection [4]. Such variants are directly relevant in nerve repair, tumor excision, and image-guided brachial plexus block procedures.

Communication between the musculocutaneous and median nerves was observed in 6.7% of the present series. Although this frequency is lower than that described in larger studies, the finding remains clinically important because even a single communicating branch can alter the pattern of motor deficit after nerve injury. Venieratos and Anagnostopoulou proposed a widely used classification of such communications based on their relation to the coracobrachialis muscle [5]. Loukas et al., Maeda et al., Ballesteros et al., and Budhiraja et al. documented the recurrent occurrence of these communications and stressed their importance in surgical anatomy [6-9]. Kaur et al. and Padur et al. described complex variations involving altered innervation patterns or unusual lateral cord branching that can mislead intraoperative nerve identification [10,11].

Generalizability: Although this study was conducted in a single institution with a modest specimen count, its findings remain clinically relevant because the documented variants resemble patterns reported across multiple cadaveric series from different populations. The observations are therefore applicable to anatomy teaching, surgical planning, and peripheral nerve block practice in comparable tertiary-care settings. However, larger multicentric anatomical and radiological studies would improve external validity and allow more refined population-level estimates.

Conclusion

The present observational cadaveric study demonstrates that anatomical variations of the brachial plexus are common and clinically meaningful. More than one-third of the examined specimens showed deviations from the classical pattern. Variations in trunk formation constituted the most frequent abnormality, followed by altered formation of the median nerve and communications between the musculocutaneous and median nerves. These findings reinforce the importance of meticulous anatomical knowledge during operative procedures in the neck, axilla, and upper limb, as well as during regional anesthesia and interpretation of atypical neurological deficits. Careful awareness of such variants can contribute to safer surgical dissection, more accurate diagnosis, and improved procedural outcomes.

Limitations

The study was limited by a relatively small sample size and a single-center design. Detailed demographic data of all cadavers were not available for subgroup analysis. Morphometric measurements were not included, and radiological correlation was not performed. Because the work was descriptive, no inferential statistical comparison between sides or patterns was undertaken. These constraints restrict the precision of prevalence estimation in broader populations.

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Recommendations

Future studies should include larger sample sizes, multicentric cadaveric collections, and correlation with radiological imaging such as ultrasound or magnetic resonance neurography. Detailed morphometric analysis of roots, trunks, cords, and communicating branches would strengthen the anatomical database. Training programs in anatomy, surgery, orthopedics, plastic surgery, and anesthesiology should incorporate structured teaching on brachial plexus variations. Preoperative imaging and careful intraoperative dissection should be encouraged in procedures involving the supraclavicular, infraclavicular, axillary, and proximal arm regions to reduce avoidable nerve injury, improve the accuracy of regional nerve block techniques, and support safer management of upper-limb neuropathies.

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Abbreviations

ASRAMS – Alluri Sitarama Raju Academy of Medical Sciences;
MCN – Musculocutaneous nerve;
MN – Median nerve;
C5, C6, C7, C8, T1 – Cervical and thoracic spinal nerve roots;
SD – Standard deviation

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The study had no funding.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

MRR-Concept and design of the study, results interpretation, review of literature, and preparation of the first draft of the manuscript. Statistical analysis and interpretation, revision of manuscript.
SVS results interpretation, review of literature, preparation of the first draft of the manuscript, and revision of the manuscript.
PRH-review of literature and preparing the first draft of the manuscript, revision of the manuscript.

Data availability

Data available on request

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Dr. M. Ranadheer Reddy is an Associate Professor in the Department of Anatomy at Alluri Sitaram Raju Academy of Medical Sciences, Eluru, Andhra Pradesh, India. He is actively involved in undergraduate medical teaching, anatomical dissection training, and academic activities in anatomy. His areas of professional interest include gross anatomy, embryology, histology, and medical education. He has contributed to departmental teaching programs and supports research-oriented learning among medical students.
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