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Original Research Article

Anatomical Variations in the Formation and Branching Pattern of the Brachial Plexus: A Cadaveric Study.

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Abstract

Background: Anatomical variations of the brachial plexus are clinically important during upper-limb surgery, regional anaesthesia, and peripheral nerve interventions.
Objective: To evaluate anatomical variations in the formation and branching patterns of the brachial plexus in adult human cadavers.
Materials and Methods: This descriptive observational cadaveric study included 150 brachial plexuses. The roots, trunks, divisions, cords, terminal branches, and communicating nerves were examined through standard anatomical dissection. Variations were recorded and analysed using descriptive statistics.
Results: Anatomical variations were identified in 54 (36.0%) specimens, while 96 (64.0%) demonstrated normal anatomy. The mean age was 48.2 ± 14.6 years. Prefixed and postfixed formations occurred in 10.7% and 2.7%, respectively. Superior trunk and lateral cord variations were observed in 5.3% and 6.7%. Musculocutaneous nerve variations were most frequent (12.0%), followed by median nerve variations (10.7%). Communicating branches were identified in 12.0%, predominantly between the musculocutaneous and median nerves (9.3%).
Conclusion: Anatomical variations of the brachial plexus were common, particularly involving root formation and terminal branching. Awareness of these variations is essential for safe surgical and anaesthetic procedures.
Keywords: Brachial plexus, Anatomical variations, Cadaveric study, Musculocutaneous nerve, Median nerve.
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Introduction

The brachial plexus is a complex network of peripheral nerves responsible for providing motor and sensory innervation to the upper limb. It is typically formed by the anterior rami of the fifth, sixth, seventh, and eighth cervical spinal nerves and the first thoracic spinal nerve (C5–T1). These nerve roots unite to form three trunks, which subsequently divide into anterior and posterior divisions and reorganize into three cords before giving rise to the terminal branches. The lateral, medial, and posterior cords are named according to their relationship with the second part of the axillary artery. The terminal branches, namely the musculocutaneous, median, ulnar, axillary, and radial nerves, supply the muscles and skin of the upper extremity. Although the classical arrangement of the brachial plexus is well established, considerable anatomical variations may occur at different levels of its formation, organization, and branching pattern [1,2].

Anatomical variations of the brachial plexus may involve the contribution of spinal nerve roots, formation of trunks, arrangement of divisions and cords, origin of collateral and terminal branches, and the presence of abnormal communicating branches between peripheral nerves. Variations in root contributions may result in a prefixed brachial plexus, characterized by an additional contribution from the fourth cervical spinal nerve (C4), or a postfixed brachial plexus, in which the second thoracic spinal nerve (T2) contributes to its formation. Other variations include abnormal union or separation of trunks, atypical formation of cords, altered relationships with the axillary artery, and unusual origins of terminal nerves. Such variations may occur unilaterally or bilaterally and can influence the distribution of motor and sensory fibers in the upper limb [1,3,4].

The frequency of anatomical variations in the brachial plexus has been investigated in several cadaveric studies, demonstrating substantial differences in their occurrence and morphological characteristics. A systematic review and meta-analysis by Benes et al. involving 40 studies and 3,055 upper limbs reported that the classical arrangement of roots forming trunks was present in approximately 84% of cases, whereas the typical arrangement of divisions forming cords was observed in 96% of cases. The pooled prevalence of prefixed and postfixed brachial plexuses was 11% and 1%, respectively. Additional communicating branches between components of the brachial plexus were identified in approximately 5% of cases. These findings indicate that anatomical variations are not uncommon and that their prevalence differs according to the component of the plexus examined [1].

Variations in the branching pattern of the brachial plexus are particularly important because of their potential influence on peripheral nerve distribution and clinical presentation. The musculocutaneous nerve may communicate with the median nerve, while the median nerve may receive additional roots from the lateral cord. Similarly, variations in the origin of the axillary, thoracodorsal, subscapular, and pectoral nerves have been documented. Rastogi et al., in a cadaveric study involving 74 upper extremities, observed variations in the formation and branching pattern of the posterior cord, including unusual origins of the axillary and thoracodorsal nerves. Such findings highlight the morphological diversity of the brachial plexus and the importance of recognizing atypical nerve arrangements during anatomical dissection and surgical exploration [5–8].

The clinical significance of brachial plexus variations extends to several specialties, including orthopaedic surgery, neurosurgery, plastic and reconstructive surgery, vascular surgery, radiology, and anaesthesiology. Surgical procedures involving the neck, supraclavicular region, axilla, shoulder, and upper arm require detailed knowledge of the normal and variant anatomy of the brachial plexus to minimize inadvertent nerve injury. Variations in the course or branching of peripheral nerves may increase their susceptibility to traction, compression, or accidental damage during surgical dissection. Furthermore, atypical nerve connections may alter the expected distribution of neurological deficits following trauma or nerve lesions, thereby complicating clinical examination, diagnosis, and surgical planning [3,5,7,9].

Knowledge of anatomical variations is also important during regional anaesthesia, particularly interscalene, supraclavicular, infraclavicular, and axillary brachial plexus blocks. The effectiveness and safety of these procedures depend on accurate identification of neural structures and their relationships with surrounding muscles and blood vessels. Variations in the arrangement of roots, trunks, cords, or terminal branches may contribute to unexpected patterns of sensory or motor blockade and may complicate ultrasound-guided needle placement. Similarly, awareness of abnormal nerve communications is essential during peripheral nerve repair, nerve grafting, and nerve transfer procedures, where precise identification of nerve origins and courses is necessary to achieve optimal functional outcomes [3,9,10].

Recent cadaveric investigations have further emphasized the diversity of brachial plexus anatomy. Han et al. examined 60 formalin-fixed cadavers and identified anatomical variations in 66.7% of the cadavers. The reported variations involved the roots, trunks, divisions, cords, and communicating branches, with communicating nerve variations representing a prominent finding. Similarly, other cadaveric investigations have demonstrated differences in the origins of collateral branches and the formation of terminal nerves. These observations reinforce the need for systematic anatomical assessment of the brachial plexus rather than relying exclusively on the classical descriptions presented in standard anatomical textbooks [2,6,8,11].

Despite the availability of several anatomical studies, considerable heterogeneity exists in the reported prevalence and patterns of brachial plexus variations. Differences in cadaveric sample size, geographical origin, dissection methods, classification systems, and anatomical structures examined may contribute to these variations. Furthermore, some studies have focused primarily on individual components, such as the posterior cord or median nerve, rather than evaluating the formation and branching pattern of the brachial plexus as a whole. Detailed cadaveric examination therefore remains valuable for identifying uncommon anatomical configurations, documenting their frequency, and improving the understanding of their possible clinical implications [1,2,5,12].

The present cadaveric study was undertaken to examine the anatomical variations in the formation and branching pattern of the brachial plexus. It aims to document deviations from the classical arrangement of roots, trunks, divisions, cords, and terminal branches, identify abnormal communicating branches, and assess the distribution of these variations in the dissected specimens. The findings are expected to contribute to existing anatomical knowledge and provide clinically relevant information for surgeons, anaesthesiologists, radiologists, and other healthcare professionals involved in the diagnosis and

management of conditions affecting the neck, axilla, and upper limb.

Methodology:

Study Design and Setting

The present descriptive, observational cadaveric study was conducted in the Department of Anatomy to assess anatomical variations in the formation and branching pattern of the brachial plexus. Standard anatomical dissection techniques were used to examine the roots, trunks, divisions, cords, and terminal branches. A total of 150 brachial plexuses obtained from adequately preserved adult human cadaveric specimens were included. Each brachial plexus was considered an individual anatomical unit for analysis.

Inclusion Criteria

Adult cadaveric specimens of either sex with intact and adequately preserved brachial plexuses, allowing clear identification of their formation and branching patterns, were included.

Exclusion Criteria

Specimens showing extensive trauma, previous surgical alterations, advanced decomposition, damaged neural structures, or incomplete preservation preventing accurate anatomical assessment were excluded.

Cadaveric Dissection Procedure

Cadavers were positioned supine, and the cervical, supraclavicular, and axillary regions were dissected using standard techniques. The skin, fascia, and overlying muscles were carefully reflected to expose the brachial plexus. The nerve roots were identified between the scalene muscles and traced distally through the trunks, divisions, and cords to their terminal branches. The relationship of the cords with the axillary artery was examined, and any deviations from the classical anatomical arrangement were documented.

Assessment of Anatomical Variations

Each brachial plexus was examined for variations in root contributions (normal, prefixed, or postfixed), trunk formation, divisions, cord arrangement, and branching patterns. Particular attention was given to the origins of the musculocutaneous, median, ulnar, axillary, and radial nerves and the presence of abnormal communicating branches. Findings were classified as normal or variant and further categorized according to the anatomical component involved. Right- and left-sided variations were recorded separately.

Documentation of Findings

All anatomical findings were recorded using a structured proforma. The presence, type, and location of variations were documented, and representative specimens were photographed for anatomical comparison.

Outcome Measures

The primary outcome was the overall prevalence of anatomical variations among the 150 brachial plexuses. Secondary outcomes included the frequencies of root, trunk, division, cord, terminal branching, and communicating nerve variations, along with their side-wise distribution.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics (version 27). Categorical variables were expressed as frequencies and percentages. Associations were assessed using the Chi-square test or Fisher's exact test, as appropriate. McNemar's test was considered for paired right–left comparisons from the same cadaver. A p-value of less than 0.05 was considered statistically significant.

Results:

A total of 150 brachial plexus specimens were included in the study. The mean age was 48.2 ± 14.6 years. The highest proportion of specimens belonged to the 41–50-year age group (26.0%), followed by 51–60 years (24.0%) and above 60 years (20.0%). Among the specimens examined, 96 (64.0%) were from males and 54 (36.0%) were from females. Both right- and left-sided brachial plexuses were equally represented, with 75 (50.0%) specimens on each side (Table 1).

The classical anatomical arrangement of the brachial plexus was observed in 96 (64.0%) specimens, whereas 54 (36.0%) demonstrated one or more anatomical variations. Thus, anatomical variations were identified in approximately one-third of the examined specimens (Table 2, Figure 1).

The classical C5–T1 root formation was observed in 128 (85.3%) specimens. Among root variations, prefixed formation involving C4 contribution was the most frequent, occurring in 16 (10.7%) specimens, followed by postfixed formation involving T2 contribution in 4 (2.7%) specimens and other variations in 2 (1.3%). Normal trunk formation was observed in 134 (89.3%) specimens. Superior trunk variations were the most common trunk abnormalities, identified in 8 (5.3%) specimens, followed by inferior trunk variations in 4 (2.7%), middle trunk variations in 3 (2.0%), and multiple trunk variations in 1 (0.7%).

Variations involving the anterior and posterior divisions were identified in 5 (3.3%) and 3 (2.0%) specimens, respectively. Among cord variations, the lateral cord was most frequently involved in 10

(6.7%) specimens, followed by the posterior cord in 8 (5.3%) and medial cord in 6 (4.0%) specimens (Table 3).

Terminal branching variations were most frequently observed in the musculocutaneous nerve, involving 18 (12.0%) specimens, followed by the median nerve in 16 (10.7%), axillary nerve in 7 (4.7%), radial nerve in 5 (3.3%), and ulnar nerve in 4 (2.7%) specimens.

Communicating nerve variations were identified in 18 (12.0%) specimens. Musculocutaneous–median nerve communication was the most common pattern, observed in 14 (9.3%) specimens, whereas other nerve communications were present in 4 (2.7%). No communicating nerve variation was observed in 132 (88.0%) specimens (Table 4).

The proportion of anatomical variations showed a numerical increase with advancing age, from 27.8% in the 18–30-year age group to 43.3% among specimens aged above 60 years. The prevalence of variations was 29.6%, 35.9%, and 38.9% in the 31–40, 41–50, and 51–60-year age groups, respectively. However, the association between age group and anatomical variations was not statistically significant (reported p=0.742).

Anatomical variations were more frequently observed among male specimens (38.5%) than female specimens (31.5%), although the difference was not statistically significant (reported p=0.388). Similarly, right-sided specimens demonstrated a slightly higher frequency of variations (38.7%) compared with left-sided specimens (33.3%), without a statistically significant association (reported p=0.495) (Table 5, Figure 2).

Of the 150 brachial plexus specimens examined, 96 (64.0%) demonstrated no anatomical variation, while 31 (20.7%) exhibited a single variation. Two anatomical variations were identified in 16 (10.7%) specimens, whereas 7 (4.7%) demonstrated three or more variations. Overall, 23 (15.3%) specimens exhibited multiple anatomical variations, accounting for 42.6% of the 54 specimens with variant anatomy (Table 6, Figure 3).

Table 1. Demographic and Anatomical Characteristics of Cadaveric Specimens (N = 150)

Parameters	Frequency (n)	Percentage (%)
Age (years)		
18–30	18	12.0
31–40	27	18.0
41–50	39	26.0
51–60	36	24.0
>60	30	20.0
Mean age ± SD (years)	48.2 ± 14.6	—
Sex		
Male	96	64.0
Female	54	36.0
Side of brachial plexus		
Right	75	50.0
Left	75	50.0

Table 2. Overall Prevalence of Anatomical Variations in the Brachial Plexus (N = 150)

Anatomical pattern	Frequency (n)	Percentage (%)
Normal anatomical pattern	96	64.0
Variant anatomical pattern	54	36.0
Total	150	100.0

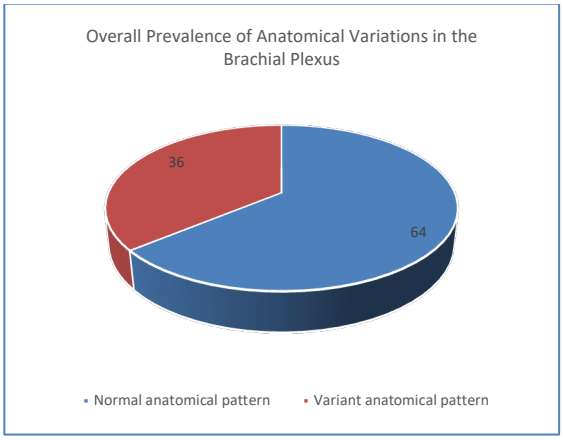


Figure 1. Overall Prevalence of Anatomical Variations in the Brachial Plexus

Table 3. Distribution of Anatomical Variations in Roots, Trunks, Divisions, and Cords (N = 150)

Anatomical component	Pattern of variation	Frequency (n)	Percentage (%)
Root formation	Normal (C5–T1)	128	85.3
	Prefixed (C4 contribution)	16	10.7
	Postfixed (T2 contribution)	4	2.7
	Other variations	2	1.3
Trunk formation	Normal formation	134	89.3
	Superior trunk variation	8	5.3
	Middle trunk variation	3	2.0
	Inferior trunk variation	4	2.7
	Multiple trunk variations	1	0.7
Division variations	Anterior divisions	5	3.3
	Posterior divisions	3	2.0
Cord variations	Lateral cord	10	6.7
	Medial cord	6	4.0
	Posterior cord	8	5.3

Table 4. Distribution of Terminal Branching and Communicating Nerve Variations (N = 150)

Anatomical variation	Frequency (n)	Percentage (%)
Terminal branching variations		
Musculocutaneous nerve	18	12.0
Median nerve	16	10.7
Ulnar nerve	4	2.7
Axillary nerve	7	4.7
Radial nerve	5	3.3
Communicating nerve variations		
Musculocutaneous–median nerve communication	14	9.3
Other nerve communications	4	2.7
No communicating variation	132	88.0

Table 5. Association of Age, Sex, and Side With Anatomical Variations (N = 150)

Parameters	Normal (n=96)	Variant (n=54)	p-value	Statistical test
Age group (years)				
18–30	13 (72.2 %)	5 (27.8 %)		
31–40	19 (70.4 %)	8 (29.6 %)		
41–50	25 (64.1 %)	14 (35.9 %)	0.742	Chi-square
51–60	22 (61.1 %)	14 (38.9 %)		
>60	17 (56.7 %)	13 (43.3 %)		
Sex				
Male	59 (61.5 %)	37 (38.5 %)	0.388	Chi-square

Female	37 (68.5 %)	17 (31.5 %)		
Side				
Right	46 (61.3 %)	29 (38.7 %)	0.49 5	Chi-square
Left	50 (66.7 %)	25 (33.3 %)		

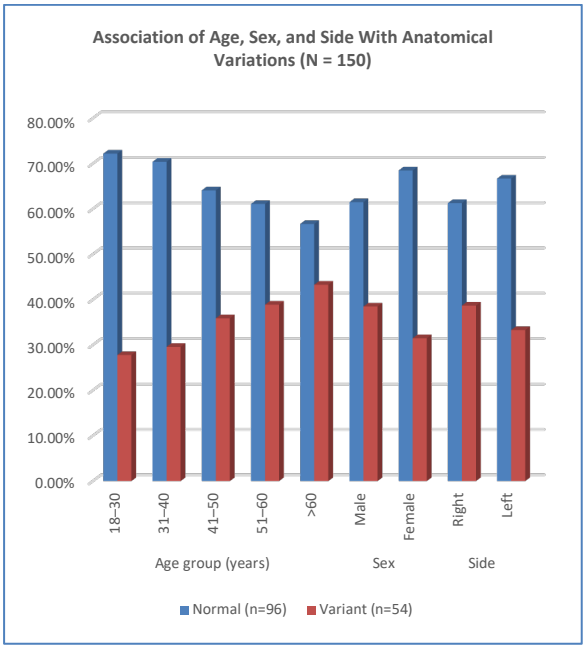


Figure 2. Association of Age, Sex, and Side With Anatomical Variations (N = 150)

Table 6. Distribution of Single and Multiple Anatomical Variations (N = 150)

Number of anatomical variations	Frequency (n)	Percentage (%)
No variation	96	64.0
Single variation	31	20.7
Two variations	16	10.7
Three or more variations	7	4.7
Total	150	100.0

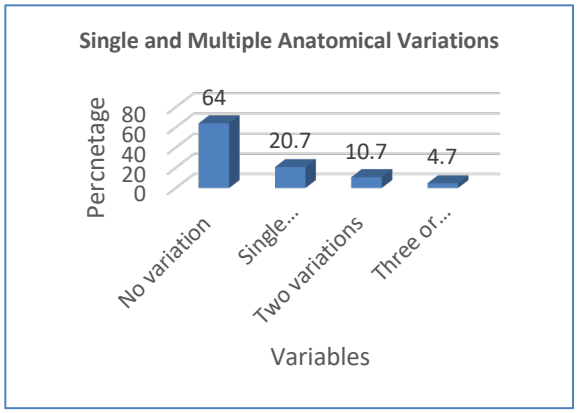


Figure 3. Distribution of Single and Multiple Anatomical Variations (N = 150)

Discussion

In the present study, 150 brachial plexuses were examined, with a mean age of 48.2 ± 14.6 years. The majority belonged to the 41–50-year age group (26.0%), followed by 51–60 years (24.0%). Male specimens constituted 64.0%, while females accounted for 36.0%. Both sides were equally represented. Fazan et al. [13] examined 54 upper extremities from 27 cadavers aged 37–76 years, including 21 males and six females. Their study similarly highlighted the importance of evaluating anatomical variations across different demographic characteristics.

In the present study, anatomical variations were observed in 54 (36.0%) brachial plexuses, while 96 (64.0%) demonstrated normal anatomy. Claassen et al. [14], in their examination of 167 cadaveric arms, reported anatomical variations in 60 (36.0%) specimens, closely corresponding to our findings. They observed median nerve variations in 28.0% and musculocutaneous nerve variations in 8.0% of specimens. Fazan et al. [13] also documented considerable variations in brachial plexus formation and branching among 54 upper extremities, supporting the frequent occurrence of anatomical deviations.

The classical C5–T1 root arrangement was observed in 128 (85.3%) specimens, while prefixed and postfixed formations were identified in 16 (10.7%) and 4 (2.7%) specimens, respectively. Fazan et al. [13] reported normal root formation in approximately 72.0% and prefixed formation in 24.0% of specimens, with postfixed formation also documented. The higher frequency of prefixed formation in their study may reflect differences in sample size, population characteristics, and anatomical classification.

Normal trunk formation was observed in 134 (89.3%) specimens, while 16 (10.7%) demonstrated

variations. Superior trunk variations were most frequent (5.3%), followed by inferior (2.7%) and middle trunk variations (2.0%). Anterior and posterior division variations occurred in 3.3% and 2.0%, respectively. Among the cords, lateral cord variations were most common (6.7%), followed by posterior (5.3%) and medial cord variations (4.0%). Fazan et al. [13] reported superior trunk variations in two of 54 specimens and atypical posterior cord formation in five (9.0%) specimens. Their findings demonstrate the variability of trunk and cord arrangements, although the distribution differed from the present study.

In the present study, musculocutaneous nerve variations were most frequent (12.0%), followed by median (10.7%), axillary (4.7%), radial (3.3%), and ulnar nerve variations (2.7%). Claassen et al. [14] reported median nerve variations in 28.0% and musculocutaneous nerve variations in 8.0% of specimens, indicating a different distribution of terminal branching abnormalities. Clarke et al. [15] described an unusual formation of the musculocutaneous and median nerves through intraneural dissection, demonstrating the complexity of atypical nerve arrangements and their potential surgical significance.

Communicating branches were observed in 18 (12.0%) specimens, predominantly between the musculocutaneous and median nerves (9.3%). Clarke et al. [15] reported an unusual musculocutaneous–median nerve connection involving complex fascicular arrangements. Similarly, Di Stefano et al. [16] identified median-to-ulnar nerve communication in 53 limbs from 36 patients, with type II communication accounting for 74% of affected limbs. Although their study was electrophysiological rather than cadaveric, it highlighted the clinical significance of abnormal nerve communications in interpreting peripheral neuropathies.

Anatomical variations were more frequent among male specimens (38.5%) than female specimens (31.5%) and on the right side (38.7%) compared with the left side (33.3%). These differences were not statistically significant ($p=0.388$ and $p=0.495$, respectively, in the analysis). The frequency of variations increased numerically from 27.8% in the 18–30-year age group to 43.3% among specimens older than 60 years. Fazan et al. [13] similarly reported no substantial influence of sex or side on anatomical variations. However, because brachial plexus variations are developmental, the apparent age-related trend should not be interpreted as a causal relationship.

In the present study, 31 (20.7%) specimens demonstrated a single variation, 16 (10.7%) exhibited two variations, and 7 (4.7%) showed three or more variations. Fazan et al. [13] also documented multiple anatomical abnormalities, including atypical median nerve formation in 52.0% and communicating branches between the lateral cord and ulnar nerve in 30.0% of specimens. These findings indicate that variations may coexist at different levels of the brachial plexus.

Conclusion

The present study demonstrated anatomical variations in 36.0% of the 150 brachial plexuses examined, with variations involving the roots, trunks, cords, and terminal branches. Musculocutaneous nerve variations (12.0%) and prefixed root formation (10.7%) were prominent findings. Detailed knowledge of these variations is essential for accurate surgical dissection, regional anaesthesia, and prevention of iatrogenic nerve injuries.

Limitations

The cadaveric design limited direct clinical and electrophysiological correlation, while differences in specimen preservation and dissection techniques may have influenced the identification of smaller nerve branches. The findings may not be generalizable to all populations, and bilateral observations from the same cadaver require appropriate statistical consideration.

Ethical approval

Ethical approval for this study was obtained from the Institutional Ethics Committee prior to the commencement of the study. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and applicable institutional guidelines.

Informed Consent

Written informed consent was obtained from all participants prior to their enrolment in the study.

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Conflict of Interest Declaration

The authors declare no conflict of interest.

Data Availability Statement

All data generated or analysed during this study are available from the corresponding author upon reasonable request.

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