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**Original Research Article**

# A Retrospective Study of the Patterns and Frequency of Brachial Plexus Variations in Adult Cadavers

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**Abstract:**

**Background:** The brachial plexus is a complex neural network supplying the upper limb and normally follows a characteristic C5–T1 arrangement. Anatomical variations may occur at the levels of roots, trunks, cords, and terminal branches and are clinically important during surgery, regional anesthesia, and nerve-related procedures.

**Aim:** To evaluate the patterns and frequency of anatomical variations of the brachial plexus in adult cadavers.

**Methodology:** A retrospective descriptive cadaveric study was conducted in the Department of Anatomy, Darbhanga Medical College, Bihar, India. Dissection records and preserved specimens from 40 adult cadavers were reviewed. Both sides were examined wherever adequately preserved, providing 80 brachial plexus specimens. Variations were documented and analyzed using descriptive statistics in IBM SPSS Statistics version 27.0.

**Results:** Of 80 plexuses, 61 (76.25%) demonstrated the classical pattern, while 19 (23.75%) showed anatomical variations. Trunk formation variations were most frequent (26.32%), followed by communications between cords/branches and median nerve variations (21.05% each). Musculocutaneous nerve variations occurred in 15.79% and ulnar nerve variations in 10.53% of variant specimens. Variations were more frequent on the right (27.5%) than left (20.0%).

**Conclusion:** Brachial plexus variations were relatively common, emphasizing their importance in anatomical and clinical practice.

**Keywords:** Brachial Plexus; Anatomical Variations; Cadaveric Study; Nerve Variation; Anatomy.

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## Introduction

The brachial plexus is a bundle of nerves which are the main motor and sensory nerves to the upper limb [1]. The anterior (ventral) rami of the first thoracic spinal nerve (C5-T1) and the lower four cervical spinal nerves form it. The plexus is the source of the large peripheral nerves of the shoulder, arm, forearm and hand, and stretches from the neck into the axilla. Due to its widespread distribution and complex anatomy, an understanding of the normal anatomy and potential variations of the brachial plexus is important for the anatomist, surgeon, anesthesiologist, radiologist, and clinician when dealing with conditions affecting the upper limb.

The brachial plexus is traditionally divided into five successive parts: roots, trunks, divisions, cords and terminal branches [2]. The roots are C5 – T1 that converge to form three trunks: upper, middle, and lower. These posterior and anterior divisions coalesce to create lateral, medial, and posterior cords, in relation to the axillary artery. These cords form the large terminal branches: musculocutaneous, median, ulnar, radial and axillary nerves. This is the typical pattern, but there is considerable anatomical variation at each of the levels of the plexus.

The course of the brachial plexus or the origin, communication, union or branching of the nerves composing the brachial plexus may vary [3]. Variations can be in contribution of spinal nerve roots, formation of trunks, cord/branch relationship, and communication between terminal or collateral nerves. There are some people who may show other communications or other branching patterns other than the classical anatomical pattern. These variations are thought to be the result of changes in the peripheral nervous system developing and differentiating [4]. The final anatomical relationships of the plexus are determined by the regular growth of the spinal nerves, muscles and connective tissue during the embryonic period.

Brachial plexus variations is important for identification. The plexus is commonly injured during neck, shoulder, axillary and upper limb surgery. The location and course of the nerves may be related to anatomical variations which should be taken into account and may account for unexpected findings in surgical dissection. Awareness of an unusual nerve pattern can prevent iatrogenic nerve injury during surgery of the axilla, exploration of the brachial plexus, vascular surgery, axial skeleton surgical procedures, and reconstructive surgery. In the same way, the understanding of variant anatomy is useful for regional anesthesia as the distribution and effectiveness of the brachial plexus block could be altered.

Brachial plexus variants also have a role to play in the interpretation of clinical symptoms and electrophysiological findings [5]. Sometimes a bizarre relationship between nerves may result in an abnormal motor or sensory distribution that may be confused with pathological nerve involvement. These variations can thus help the clinician correlate the anatomical patterns with any neurological symptoms and guide him/her in the diagnostic and therapeutic approach [6].

Although cadaveric dissection is no longer a standard clinical procedure, it continues to be a valuable tool for the discovery and documentation of anatomical variations, since they can be seen directly [7]. Dissection allows for the detailed examination of the entire course of the plexus and the identification of small communicating branches which may not be easily detectable clinically. Previous documentation of dissections can give further information on the prevalence and distribution of anatomical variants in a population if the dissections are evaluated retrospectively. These studies will aid the existing anatomical literature, and could provide insight into whether any specific pattern is consistent or if it is a rare configuration.

Although the classical description of brachial plexus, variations are common enough to necessitate systematic documentation. Variations in the reported frequency of the occurrence in different anatomical investigations may be due to the varying characteristics of the populations investigated, the size of the samples, the ways in which dissection was performed, and the criteria applied to determine the presence of a variation. Hence, an analysis of the adult cadaveric specimens affords a chance to describe the spectrum of patterns occurring in the normal routine practice of anatomy and to define those variations which hold potential for immediate clinical application.

The present retrospective study was designed to assess the prevalence and distribution of variations of the brachial plexus in adult cadaveric material, based on the available records. The purpose of the study is to enhance the anatomical knowledge about the brachial plexus and to highlight the value of recognition of variant nerve patterns during anatomical dissection and clinical procedures."

## Methodology

**Study Design:** The present study was conducted as a retrospective descriptive cadaveric study to evaluate the patterns and frequency of anatomical variations of the brachial plexus in adult human cadavers. The study focused on identifying and documenting variations from the classical anatomical arrangement of the brachial plexus at the levels of the roots, trunks, divisions, cords, and terminal branches. The observations obtained from the available dissection records and corresponding cadaveric specimens were systematically reviewed and recorded.

**Study Area:** The study was conducted in the Department of Anatomy, Darbhanga Medical College, Laheriasarai, Darbhanga, Bihar, India. The department-maintained formalin-preserved adult human cadavers that were routinely used for undergraduate teaching and anatomical dissection. The available dissection records and preserved specimens were examined for relevant information regarding the morphology and variations of the brachial plexus.

**Study Duration:** The study was conducted over a period of 3 months.

**Study Participants:** The study participants comprised adult human cadavers available in the Department of Anatomy during the study period. A total of 40 adult cadavers were included, and the brachial plexus was examined on both sides wherever the upper limbs and axillary regions were adequately preserved.

### Inclusion Criteria

- Adult human cadavers aged 18 years or above.
- Formalin-preserved cadavers available in the Department of Anatomy during the study period.
- Cadavers with adequately preserved upper limbs and axillary regions.
- Cadavers in which the brachial plexus could be exposed and identified satisfactorily.
- Cadaveric dissection records containing adequate information regarding the brachial plexus.

### Exclusion Criteria

- Cadavers with traumatic injuries involving the neck, shoulder, axilla, or upper limb.

- Cadavers with evidence of previous surgery or pathological alteration of the brachial plexus region.
- Poorly preserved or severely decomposed cadavers.
- Cadavers with damaged, incomplete, or previously disturbed brachial plexus structures.
- Dissection records with insufficient or incomplete information regarding the brachial plexus.

**Sample Size:** The study included a total of 40 adult human cadavers (N = 40). Both sides were considered for examination whenever the anatomical structures were adequately preserved, providing a maximum of 80 brachial plexus specimens for assessment.

**Procedure:** The relevant cadaveric dissection records were initially reviewed to identify adult cadavers fulfilling the predefined inclusion criteria. The corresponding preserved specimens were then examined systematically. The skin and superficial fascia of the neck, shoulder, and axillary regions were carefully removed, followed by reflection of the underlying muscles to expose the brachial plexus. The roots arising from the anterior rami of spinal nerves C5 to T1 were identified and traced distally to determine the formation of the upper, middle, and lower trunks, followed by their divisions and the lateral, medial, and posterior cords. The terminal branches, including the musculocutaneous, median, ulnar, axillary, and radial nerves, were identified according to their anatomical relationships. Any deviation from the classical anatomical pattern was carefully noted and classified according to the level and type of variation observed. Variations involving the formation, communication, branching, or course of the brachial plexus were recorded. Bilateral observations were compared to determine whether the identified variations were unilateral or bilateral. The findings were entered into a structured data collection sheet and subsequently compiled for statistical analysis.

**Statistical Analysis:** The collected data were entered, coded, and analyzed using IBM SPSS Statistics version 27.0. Descriptive statistics were used to summarize the observed anatomical variations. Frequencies and percentages were calculated for the different types and patterns of brachial plexus variations. The distribution of variations according to side, anatomical level, and type of variation was also assessed. Where appropriate, categorical variables were compared using the Chi-square test or Fisher's exact test. A p-value of $<0.05$ was considered statistically significant. The results were presented in appropriate tables and graphical forms for clear interpretation."

**Result**

Table 1 presents the distribution of the 40 adult cadavers according to sex. Of the total 40 cadavers examined, 27 (67.5%) were male, while 13 (32.5%) were female. Thus, male cadavers constituted approximately two-thirds of the study sample and were more frequently represented than female cadavers. The male-to-female distribution was approximately 2.1:1, indicating a clear male predominance in the available cadaveric sample. Overall, the findings show that both sexes were represented in the study, although the proportion of male cadavers was substantially higher than that of female cadavers.

**Table 1: Distribution of Adult Cadavers According to Sex**

| Sex | Number of Cadavers (n=40) | Percentage (%) |
|---|---|---|
| Male | 27 | 67.5 |
| Female | 13 | 32.5 |
| **Total** | **40** | **100** |

Table 2 shows the distribution of the 80 examined brachial plexus specimens according to side. An equal distribution was observed between the right and left sides. The right-sided brachial plexus accounted for 40 specimens (50%), while the left-sided brachial plexus also comprised 40 specimens (50%). Thus, neither side showed any predominance in the study sample. The findings indicate a balanced representation of both sides, with each contributing exactly half of the total 80 specimens examined. This equal distribution provides comparable representation of right- and left-sided brachial plexuses for assessment of anatomical variations.

**Table 2: Distribution of Examined Brachial Plexus Specimens According to Side**

| Side | Number of Plexuses (n=80) | Percentage (%) |
|---|---|---|
| Right | 40 | 50 |
| Left | 40 | 50 |
| **Total** | **80** | **100** |

Table 3 presents the frequency of anatomical variations observed in the brachial plexus among the 80 examined plexuses. A classical brachial plexus pattern was identified in 61 specimens (76.25%), representing the majority of the examined plexuses. Anatomical variations were observed in 19 specimens (23.75%). Thus, approximately one-fourth of the examined brachial plexuses demonstrated some form of anatomical variation, whereas the classical pattern was present in more than three-fourths of the specimens. Overall, the findings indicate that although the classical brachial plexus configuration was predominant, anatomical variations were relatively common in the studied cadaveric sample.

**Table 3: Frequency of Anatomical Variations in the Brachial Plexus**

| Brachial Plexus Pattern | Number of Plexuses (n=80) | Percentage (%) |
|---|---|---|
| Classical pattern | 61 | 76.25 |
| Anatomical variation present | 19 | 23.75 |
| **Total** | **80** | **100** |

Table 4 shows the distribution of different types of brachial plexus variations among the 19 specimens in which anatomical variations were identified. Variation in the formation of trunks was the most frequently observed type, occurring in 5 plexuses (26.32%). This was followed by communication between cords or branches and variations in the formation or course of the median nerve, each observed in 4 plexuses (21.05%). Variations involving the musculocutaneous nerve were noted in 3 plexuses (15.79%), while ulnar nerve variations occurred in 2 (10.53%). Other branching variations were least frequent, accounting for 1 case (5.26%).

**Table 4: Distribution of Different Types of Brachial Plexus Variations**

| Type of Variation | Number of Plexuses (n=19) | Percentage (%) |
|---|---|---|
| Variation in formation of trunks | 5 | 26.32 |
| Communication between cords/branches | 4 | 21.05 |
| Variation in formation/course of median nerve | 4 | 21.05 |
| Variation involving musculocutaneous nerve | 3 | 15.79 |
| Variation involving ulnar nerve | 2 | 10.53 |
| Other branching variations | 1 | 5.26 |
| **Total** | **19** | **100** |

Table 5 presents the distribution of brachial plexus variations according to side among the 80 examined plexuses. Anatomical variations were more frequently observed on the right side, occurring in 11 of 40 plexuses (27.5%), compared with 8 of 40 plexuses (20.0%) on the left side. Overall, 19 plexuses (23.75%) showed anatomical variations, while the classical pattern was observed in 29 right-sided plexuses (72.5%) and 32 left-sided plexuses (80.0%). Thus, the classical pattern predominated on both sides, although anatomical variations were relatively more common on the right side than on the left.

**Table 5: Distribution of Brachial Plexus Variations According to Side**

| Pattern | Right Side n (%) | Left Side n (%) | Total n (%) |
|---|---|---|---|
| Anatomical variation present | 11 (27.5) | 8 (20.0) | 19 (23.75) |
| Classical pattern | 29 (72.5) | 32 (80.0) | 61 (76.25) |
| **Total** | **40 (100.0)** | **40 (100.0)** | **80 (100.0)** |

## Discussion

The present study in a cadaveric series confirmed that the classical pattern of the brachial plexus was the most common (61 out of 80, 76.25%) and anatomical variants were seen in 19 specimens (23.75%). This discovery suggests that about one-quarter of all brachial plexuses were not in the normal configuration. The frequency of the present study is in agreement with the general observation that the brachial plexus is a variable structure, but the amount of variation reported varies significantly with populations and by the level of the anatomy studied. Emamhadi et al., 2016 [8] have studied 32 cadaveric specimens with bilateral upper limbs, and they reported on several variants of the brachial plexus (six prefixed plexi and seven cases with variations in the suprascapular nerve and other communicating and terminal-branch variations). They concluded, as in the present study, that variation is not confined to one root, but can be seen in roots, trunks, cords and terminal branches of the plexus."

Additionally, the proportion of the classical pattern in the present study is generally in line with the systematic evidence reported by Benes et al. 2021 [9]. They found that the usual position is the most common position and that variations are seen in the different levels of the plexus. Importantly their analysis revealed that this frequency of variation is not equal over the whole plexus, with the more proximal parts of the plexus being more anatomically stable than the more distal branching patterns. The present results are in agreement with this observation, as changes were detected at different anatomical levels, but especially in relation to changes in the formation of the trunk and terminal nerves. So, although the classical arrangement accounted for 76.25% of specimens, the others emphasised that nonclassical anatomy also should be taken into account when dissecting and performing clinical procedures on the body.

The present study showed that the category of variations in the formation of the trunk was the largest single category, found in 5 out of 19 variant plexuses (26.32%) of 80 specimens. This discovery suggests that although there were abnormalities at the trunk level they did not dominate the overall anatomy. The findings can be compared with those of Leonhard et al. (2016) [10] who investigated 65 cadaveric specimens and found 31 variations of classical brachial plexus anatomy, representing 47.7% of cadavers studied. In a study of their own they showed that there was significant variation in the root relationship of the plexus, and that the anatomical variations could influence the relationship of the plexus and surrounding structures. This significantly higher overall variation found by Leonhard et al. than that of the present study might be attributed to a difference in the study population, a difference in the definition of variation, or the detailed examination of individual relationships between the roots and branches.

The other significant findings of the present study were the level differences and communicating differences. Communication between cords or branches was seen in 4 specimens (21.05% of all the variant plexuses and 5.0% of the total specimens). Multiple unilateral variations have been reported by Goel et al. (2014) [11] who described multiple variations with medial and lateral cords and their branches in cadaveric specimen. Similarly, Gupta et al. (2005) [12] reported many irregular communications between the branches of brachial plexus in a cadaver of an adult, which included communications between the pectoral nerves and other terminal nerves. The present observation confirms that another type of plexus variation is the communication between two normally separate components. These communications can also disrupt the normal distribution of motor and sensory fibres, and can thus make nerve injuries, regional nerve blocks and the operative anatomy hard to interpret.

Another relatively common place of variation in the present study was the median nerve. In 4 specimens (21.05% variant group; 5.0% of all examined plexuses), variations in its formation and/or course were observed. The finding is similar to the known variability in the distribution of the lateral and medial part of the plexus to the median nerve. In a cadaveric study of 24 upper limbs, Prasada Rao and Chaudhary (2000) [13] noted that there were 8 limbs with a frequency of 33.3% showing musculocutaneous-to-median nerve communication and two upper limbs with bilateral communications. Their results indicate that communication of the median nerve and the musculocutaneous nerve can occur much more often than is described in normal anatomy.

In the present study, 3 of the 19 variant plexuses (15.79%) with a total of 3.75% of the specimens exhibited musculocutaneous nerve variations. The finding is of particular interest as the median nerve has been shown to have variable relationships with the musculocutaneous nerve. Patel and Smith (2023) [14] in their study of previously dissected cadaveric specimens, found communicating branches between the median and the musculocutaneous nerves in 5% of specimens. Other clinically significant variations were noted in the same study such as the presence of ulnar nerve branches from the lateral cord (17%) and an unusual origin of the thoracodorsal nerve from the axillary nerve (8%). The 3.75% variation (observed in the present study) of the musculocutaneous nerve is approximately the same as Patel and Smith reported 5%, and this type of variation is reasonably reproducible between different cadaveric populations.

Aydin et al. (2006) [15] reported that the musculocutaneous nerve was completely absent in a 58-year-old male cadaver; the median nerve supplied the biceps brachii and the brachialis muscle. In a similar way, Parchand and Patil 2013 [16] reported as well absence of the musculocutaneous nerve in left upper limb with a peculiar formation and distribution of the median nerve. A complete absence is not observed in the present series but in 3 specimens musculocutaneous nerve variations were found, which confirms the possibility of clinically important deviations from the "normal" pattern.

In the present study, the other branching variations were present in only 1 specimen (10.53% of variant cases; 2.5% overall) and ulnar nerve variations were present in 2 specimens (5.26% of variant cases; 1.25% overall). The ulnar and miscellaneous branching variations occur relatively less frequently than the branching variations of the trunk, cord and median nerve; therefore, the pattern of variability is population-dependent. Padur et al. (2016) [17], for example, examined 82 upper limbs from 41 cadavers and found variations in the branching pattern of the lateral cord in 6 limbs (7%). They noted that the musculocutaneous nerve was missing in 2 limbs and there were extra communications/branching abnormalities. The finding of these numbers at various frequencies in the present study reinforces the idea that differences in individual variants of the brachial plexus occurrence can be great between cadaveric series.

In the present study, a slight right-sided predominance was noticed with variations in 11/40 right-sided plexuses (27.5%) and 8/40 left-sided plexuses (20.0%). The observed difference, however, must be taken with a grain of salt, as it was not statistically tested and was rather small in sample size, so that it cannot be regarded as a predisposition for any particular side. The cautious interpretation is supported by anatomical studies showing that many plexus variants are possible and that the side may vary from one to the other and there may be a preference for one side or the other. For instance, in a study of the communication between the musculocutaneous and the median nerves, there were 10 right-sided and 11 left-sided communications, and the difference between right and left sides was not significant ($p = 0.30$) (Ballesteros LE 2015) [18]. Therefore, it is important to recognize that the slight right-sided predominance noted in the present study may be a sampling error rather than a biological asymmetry.

The overall results showed that the classical form of the brachial plexus was present in 76.25% while the variations were enough to warrant the attention (23.75%) as an important feature of normal anatomical diversity. The large percentage of variations seen in the present study involving the predominance of the trunk, cord, median nerve, musculocutaneous nerve and ulnar nerve confirms the cadaveric literature that the plexus is not always as described in the textbook. Understanding these differences is especially valuable when performing brachial plexus block, axillary surgery, nerve repair surgery, nerve transfer surgery and evaluating neurologic deficits. Accordingly, the present findings further emphasize the need for careful anatomical identification of the roots, trunks, cords and terminal branches prior to clinical and surgical procedures.

## Conclusion

The present retrospective cadaveric study demonstrated that the classical configuration of the brachial plexus was predominant, being observed in 61 of 80 specimens (76.25%), while anatomical variations were identified in 19 specimens (23.75%). Variations in trunk formation were the most frequently observed, followed by communications between cords or branches and variations involving the median nerve. Musculocutaneous and ulnar nerve variations were less frequent, while other branching variations were uncommon. A slight right-sided predominance of variations was observed, although this should not be interpreted as a definite side-specific tendency. The findings confirm that brachial plexus variations constitute an important component of normal anatomical diversity. Awareness and careful identification of these variations are essential during anatomical dissection, regional anesthesia, nerve repair, reconstructive procedures, and surgical interventions involving the neck, axilla, and upper limb.

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