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Morphological Variations of the Brachial Plexus and Their Clinical Significance in Regional Anaesthesia, Trauma and Reconstructive Surgery of Upper Limb

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Abstract

Background: The brachial plexus is a complex neural network supplying the upper limb and demonstrates considerable anatomical variability. Recognition of these variations is important for regional anaesthesia, management of traumatic nerve injuries, and reconstructive surgery.

Objective: To study the morphological variations of the brachial plexus in adult human cadavers and assess their potential clinical significance in regional anaesthesia, upper-limb trauma, and reconstructive surgery.

Materials and Methods: A descriptive cross-sectional cadaveric study was conducted in the Department of Anatomy, Government Medical College, Surat, Gujarat, over a period of two years. A total of 25 adult human cadavers, providing 50 upper limbs and 50 brachial plexuses, were examined. Standard anatomical dissection was performed to identify the roots, trunks, divisions, cords, terminal branches, communicating branches, and their relationship with the Axillary artery. Morphological variations were documented according to their anatomical level, side, and nerve involved. Findings were analysed using frequencies and percentages.

Results: Of the 50 brachial plexuses examined, 36 (72.0%) showed the conventional pattern, while 14 (28.0%) demonstrated morphological variations. Root-level variations were observed in 2 (4.0%), trunk-level variations in 1 (2.0%), division-level variations in 1 (2.0%), cord-level variations in 2 (4.0%), and terminal branch variations in 6 (12.0%) plexuses.

Communication between the Musculocutaneous and median nerves was observed in 6 (12.0%) plexuses. Additional communicating or anomalous branches were identified in 2 (4.0%) plexuses, while variations in the relationship with the Axillary artery were observed in 3 (6.0%) plexuses.

Conclusion: Morphological variations of the brachial plexus are relatively common and may occur at different anatomical levels. Awareness of these variations is essential for accurate nerve identification and may improve the safety and effectiveness of regional anaesthesia, trauma surgery, and reconstructive procedures of the upper limb.

Keywords: Brachial plexus, anatomical variation, cadaveric study, Musculocutaneous nerve, median nerve, regional anaesthesia, upper-limb surgery.

Introduction

The brachial plexus is a complex network of peripheral nerves that provides the principal motor and sensory innervation to the upper limb. It is conventionally formed by the anterior rami of the fifth cervical to the first thoracic spinal nerves (C5–T1). These roots unite to form three trunks - upper, middle and lower - which subsequently divide into anterior and posterior divisions. The divisions reorganize to form the lateral, medial and posterior cords, from which the major terminal nerves of the upper limb arise. Although this arrangement represents the typical anatomical pattern, considerable morphological variations of the brachial plexus have been described. [1,2]

Variations may occur at any level of the plexus, including the roots, trunks, divisions, cords and terminal branches. Variations in the formation and branching of the Musculocutaneous and median nerves are particularly well documented. Communications between these two nerves may occur at different levels of the arm and may differ in their anatomical course and pattern. Such variations may alter the expected distribution of motor and sensory fibres and may occasionally produce unusual clinical manifestations. [3,6]

Anatomical knowledge of the brachial plexus is particularly important in regional anaesthesia. Brachial plexus blocks are widely used for anaesthesia and analgesia during upper-limb procedures, and their success depends on accurate identification of the relevant neural structures. Anatomical variations in the formation, branching and course of the plexus may influence the distribution of local anaesthetic and may contribute to incomplete or unexpected blockade. A thorough understanding of normal and variant anatomy is therefore important when performing inter scalene, Supraclavicular, infraclavicular and Axillary approaches to brachial plexus blockade. [2,7]

The brachial plexus is also vulnerable to injury during trauma involving the neck, shoulder and upper limb. Traumatic plexus injuries may involve the roots, trunks, cords or terminal branches and can result in significant motor and sensory deficits. Anomalous nerve courses or communications may influence the clinical pattern of neurological deficits and may complicate surgical identification of injured nerves. Knowledge of these anatomical variations can therefore be useful during exploration and management of traumatic nerve injuries. [8] Brachial plexus anatomy is equally important in reconstructive and peripheral nerve surgery. Procedures such as neurolysis, nerve grafting and nerve transfer require precise identification of donor and recipient nerves. Variations in nerve origin, branching and communication may have implications for the selection and preservation of neural structures during reconstructive procedures. [8,9]

Cadaveric anatomical studies provide an opportunity to directly visualize and document these variations. Previous cadaveric studies have demonstrated considerable variability in the formation and branching patterns of the brachial plexus, including variations in root contribution, cord formation, terminal branches and communications between peripheral nerves.[1,3,4]

The present study was therefore undertaken to systematically examine the brachial plexus in 25 adult human cadavers, comprising 50 upper limbs, with particular emphasis on morphological variations involving the roots, trunks, divisions, cords, terminal branches, communicating branches and their relationship with the axillary artery. The study also considered the potential clinical significance of these anatomical variations in regional anaesthesia, upper-limb trauma and reconstructive surgery.

Materials and Methods

Study Design and Setting

The present study was designed as a descriptive cross-sectional cadaveric anatomical study and was conducted in the Department of Anatomy, Government Medical College, Surat, Gujarat. The study was carried out over a period of two years. The study aimed to identify and document morphological variations in the brachial plexus and to assess their potential clinical relevance in regional anaesthesia, trauma, and reconstructive surgery of the upper limb.

Study Material and Sample

The study was conducted on 25 adult human cadavers, providing a total of 50 upper limbs and 50 brachial plexuses for examination. Both sides were studied independently wherever the brachial plexus was adequately preserved. Thus, the unit of anatomical observation was the individual brachial plexus, with a total sample of 50 plexuses.

Inclusion Criteria

Adult human cadavers available in the Department of Anatomy for anatomical dissection during the study period were included. Cadavers in which the brachial plexus and its major components could be adequately exposed and identified were considered suitable for the study.

Exclusion Criteria

Cadavers with severe decomposition, extensive damage to the neck or Axillary region, previous surgical alteration of the relevant region, or inadequate preservation of the brachial plexus preventing proper anatomical identification were excluded from analysis.

Ethical Considerations

The study was performed on human cadavers available for teaching and anatomical dissection in the Department of Anatomy, Government Medical College, Surat. All applicable institutional and legal requirements governing the use of human cadaveric material were followed. No identifying information related to individual cadavers was collected or reported.

Dissection Technique

Standard anatomical dissection techniques were employed for exposure of the brachial plexus. The cadaver was placed in the appropriate anatomical position. An incision was made over the neck, shoulder, and upper limb as required, and the skin and superficial fascia were carefully reflected.

The pectoral region and Axilla were exposed by reflecting the pectoral is major muscle and, where necessary, the pectoral is minor muscle. The neurovascular structures within the Axilla were identified. The brachial plexus was carefully dissected from its proximal to distal extent.

The roots, trunks, divisions, and cords of the brachial plexus were identified in relation to the Axillary artery. The terminal branches, including the Musculocutaneous, median, ulnar, radial and Axillary nerves, were subsequently traced. Care was taken to preserve the nerves and their communications during dissection.

The procedure was performed bilaterally, and findings from the right and left sides were recorded separately.

Assessment of Morphological Variations

Each brachial plexus was systematically examined for variations in:

- Formation and contribution of the roots
- Formation and arrangement of the trunks
- Division patterns
- Formation and arrangement of the cords
- Origin and course of terminal branches
- Variations in the Musculocutaneous nerve
- Communications between the Musculocutaneous and median nerves
- Variations in the formation of the median nerve
- Variations in the radial, ulnar and Axillary nerves
- Additional or unusual branches
- Relationship of the brachial plexus to the Axillary artery and surrounding anatomical structures
- Any other morphological variation encountered during dissection

A variation was recorded only when the anatomical pattern differed clearly from the conventional description of the brachial plexus.

Documentation of Findings

The anatomical findings were recorded systematically for each specimen. The side of occurrence (right or left), type of variation, anatomical level, nerve involved, and relationship with adjacent structures were documented.

Representative specimens were photographed after adequate exposure and identification of the relevant structures. Where applicable, measurements of identifiable nerve segments or distances between relevant anatomical landmarks were recorded using an appropriate measuring instrument.

Classification of Variations

The observed variations were classified according to their anatomical location as:

1. Root-level variations
2. Trunk-level variations
3. Division-level variations
4. Cord-level variations
5. Terminal branch variations
6. Communications between nerves
7. Variations in the relationship of the plexus with the Axillary artery or surrounding structures

The frequency and distribution of each variation were recorded.

Clinical Significance

The anatomical variations identified were interpreted with respect to their potential clinical significance. Particular emphasis was placed on their relevance to brachial plexus regional anaesthesia, where variations in nerve formation and course may influence the distribution and effectiveness of nerve blocks.

The findings were also considered in relation to upper-limb trauma and surgical exploration, where an atypical nerve course may influence the pattern of nerve injury or identification of neural structures. Their relevance to reconstructive and peripheral nerve surgery, including nerve repair, nerve grafting, and nerve transfer procedures, was also considered.

Statistical Analysis

The observations were entered into a data sheet and analysed using descriptive statistical methods. Categorical variables were expressed as frequency and percentage. The prevalence of each morphological variation was calculated using the total number of brachial plexuses examined (n = 50) as the denominator.

The distribution of variations according to side was also recorded. Where appropriate, differences between right- and left-sided observations were assessed using suitable statistical tests. A p-value <0.05 was considered statistically significant.

Results and Observations

During the two-year study period, a total of 25 adult human cadavers were examined in the Department of Anatomy, Government Medical College, Surat. Since both upper limbs were studied, a total of 50 brachial plexuses were available for anatomical evaluation. Each plexus was examined systematically for variations involving the roots, trunks, divisions, cords, terminal branches, communicating branches, and their relationship with the Axillary artery and surrounding structures.

Table 1: Distribution of Brachial Plexuses According to Side

Side	Number of plexuses	Percentage
Right	25	50.0
Left	25	50.0
Total	50	100.0

Of the 50 brachial plexuses examined, 25 (50.0%) were from the right upper limbs and 25 (50.0%) were from the left upper limbs.

Table 2: Overall Distribution of Morphological Variations

Finding	Number of plexuses	Percentage
Conventional pattern	36	72.0
Morphological variation present	14	28.0
Total	50	100.0

A conventional brachial plexus pattern was observed in 36 (72.0%) plexuses, whereas morphological variations were identified in 14 (28.0%) plexuses.

Table 3: Distribution of Variations According to Anatomical Level

Anatomical level	Number of plexuses	Percentage of total plexuses (n=50)
Root-level variation	2	4.0
Trunk-level variation	1	2.0
Division-level variation	1	2.0
Cord-level variation	2	4.0
Terminal branch variation	6	12.0
Communicating branch variation	2	4.0
Total	14	28.0

The maximum number of variations in this dataset involved the terminal branches, accounting for 6 (12.0%) of the 50 brachial plexuses.

Table 4: Root-Level Variations

Root-related finding	Number	Percentage of total plexuses (n=50)
Variation in root contribution	2	4.0
Conventional root contribution	48	96.0
Total	50	100.0

Root-level variations were identified in 2 (4.0%) plexuses, while 48 (96.0%) showed the conventional root contribution.

Table 5: Trunk and Division-Level Variations

Finding	Number	Percentage of total plexuses (n=50)
Trunk variation	1	2.0
Division variation	1	2.0
No trunk/division variation	48	96.0
Total	50	100.0

One (2.0%) plexus showed a variation at the trunk level and one (2.0%) showed a variation involving the divisions of the plexus.

Table 6: Cord-Level Variations

Finding	Number	Percentage of total plexuses (n=50)
Cord variation	2	4.0
Conventional cord arrangement	48	96.0
Total	50	100.0

Variations in the arrangement or formation of the cords were observed in 2 (4.0%) brachial plexuses.

Table 7: Terminal Branch Variations

Terminal branch involved	Number	Percentage of total plexuses (n=50)
Musculocutaneous nerve	2	4.0
Median nerve	2	4.0
Ulnar nerve	1	2.0
Radial nerve	1	2.0
Axillary nerve	0	0
Total	6	12.0

Terminal branch variations were observed in 6 (12.0%) plexuses. Variations involving the Musculocutaneous and median nerves were observed more frequently than those involving the ulnar and radial nerves.

Table 8: Musculocutaneous – Median Nerve Communication

Finding	Number	Percentage of total plexuses (n=50)
Communication present	6	12.0
Communication absent	44	88.0
Total	50	100.0

Communication between the Musculocutaneous and median nerves was observed in 6 (12.0%) brachial plexuses. The remaining 44 (88.0%) plexuses showed no such communication.

Table 9: Additional Communicating or Anomalous Branches

Finding	Number	Percentage of total plexuses (n=50)
Additional communicating/anomalous branch present	2	4.0
Not observed	48	96.0
Total	50	100.0

Additional communicating or anomalous branches were identified in 2 (4.0%) plexuses.

Table 10: Relationship of Brachial Plexus with Axillary Artery

Relationship	Number	Percentage
Conventional relationship	47	94.0
Anatomical variation in relationship	3	6.0
Total	50	100.0

The usual relationship of the cords of the brachial plexus with the Axillary artery was observed in 47 (94.0%) plexuses. Variation in the anatomical relationship was identified in 3 (6.0%) plexuses.

Discussion

The brachial plexus demonstrates considerable anatomical variability despite having a relatively consistent conventional pattern of formation. In the present study, 50 brachial plexuses obtained from 25 adult human cadavers were examined systematically for variations involving the roots, trunks, divisions, cords, terminal branches, communicating branches and their relationship with the axillary artery.

In the present study, 36 (72.0%) plexuses showed the conventional anatomical pattern, whereas morphological variations were identified in 14 (28.0%) plexuses. The presence of variations in more than one anatomical level highlights the importance of considering the brachial plexus as a variable neural network rather than a completely fixed anatomical structure. Previous cadaveric studies have similarly demonstrated variations involving the roots, trunks, divisions, cords and terminal branches of the plexus. In a study of 32 cadavers, variations were reported in the formation of the plexus as well as in terminal branches and communicating patterns. [1]

In the present study, variations were classified according to their anatomical level. Root-level variations were observed in 2 (4.0%) plexuses, while trunk-level and division-level variations were each observed in 1 (2.0%) plexus. Root and trunk variations are clinically relevant because they can modify the expected arrangement of neural fibres before they reach the peripheral nerves. Similar variations in the root and trunk components of the brachial plexus have been reported in previous anatomical studies. [1,2]

Cord-level variations were observed in 2 (4.0%) plexuses in the present study. The cords represent an important anatomical transition between the divisions of the plexus and the terminal nerves. Variations at this level may alter the expected origin of peripheral nerves and may create difficulties during surgical dissection or identification of neural structures. Cadaveric studies have documented variations in cord formation and their relationships with surrounding structures. [1,10]

The most prominent group in the present study consisted of terminal branch variations, observed in 6 (12.0%) plexuses. Variations were identified involving the Musculocutaneous, median, Ulnar and radial nerves. The Musculocutaneous and median nerves are particularly variable because of their developmental relationship and their frequent communicating branches. Previous studies have reported a wide range of variations involving these nerves. [3,6]

A particularly important finding in the present study was communication between the Musculocutaneous and median nerves, observed in 6 (12.0%) plexuses. Such communications are among the most frequently described variations of the brachial plexus. Venieratos and Anagnostopoulou classified these communications according to their relationship with the coracobrachialis muscle and demonstrated that the communication may occur proximal or distal to the point where the Musculocutaneous nerve pierces the muscle.[5] Other cadaveric investigations have also demonstrated considerable variation in the frequency, direction and anatomical level of these communicating branches. [4,6]

The clinical importance of Musculocutaneous–median nerve communication lies in the possibility of altered motor and sensory innervation. A lesion of one nerve proximal to the communicating branch may produce an unexpected neurological deficit because some fibresmay be distributed through the communicating pathway. Conversely, an injury distal to the communication may produce a pattern that does not correspond to the expected distribution of the involved nerve. These variations therefore have relevance during surgical procedures involving the arm and shoulder and during the assessment of peripheral nerve injuries. [4,6]

The finding of terminal branch and communicating variations is also relevant to regional anaesthesia. Successful brachial plexus blockade requires an understanding of the anatomical organization and possible variations of the plexus. Variations in nerve formation or branching may influence the distribution of local anaesthetic and may contribute to incomplete blockade of selected nerve territories. Knowledge of these variations, together with appropriate anatomical localization and ultrasound guidance where applicable, can assist in improving the reliability of regional anaesthetic techniques. [2,7]

In the present study, additional communicating or anomalous branches were observed in 2 (4.0%) plexuses. Such branches may be clinically significant because they can provide alternative pathways for nerve fibres. Previous anatomical investigations have reported communicating branches between different components of the brachial plexus and between terminal nerves. Recognition of these branches is important during surgical dissection because inadvertent division may result in unexpected neurological deficits. [1,3,6]

The relationship of the brachial plexus with the Axillary artery was also assessed. In the present study, the conventional relationship was observed in 47 (94.0%) plexuses, while variation in the relationship was identified in 3 (6.0%) plexuses. The cords of the brachial plexus are conventionally described in relation to the second part of the Axillary artery. Anatomical deviations from this relationship may be important during Axillary approaches to the plexus, vascular procedures and regional anaesthetic techniques. A detailed understanding of this three-dimensional relationship is therefore important for avoiding inadvertent neural or vascular injury. [1,2]

From a trauma perspective, variations in the course and branching of the brachial plexus may influence the clinical presentation of nerve injuries. Traumatic brachial plexus injuries may involve different anatomical levels and require accurate identification of the affected structures before reconstructive treatment. The presence of communicating branches may result in overlapping or atypical patterns of neurological deficit. Therefore, awareness of anatomical variations can assist in clinical examination, interpretation of imaging and surgical exploration. [8]

The findings are also relevant to reconstructive surgery and peripheral nerve procedures. Surgical management of brachial plexus injuries may include neurolysis, nerve grafting, nerve transfer and other reconstructive procedures. Accurate identification of the origin and course of nerves is essential for appropriate selection of donor and recipient nerves. Anatomical variations may therefore have implications for surgical planning and preservation of functional neural pathways. [8,9]

The frequency of individual variations differs considerably among cadaveric studies. This may be related to differences in sample size, population, methods of dissection, criteria used for defining a variation and the specific components of the plexus examined. For example, studies focusing specifically on Musculocutaneous – median nerve communication have reported substantially different frequencies, demonstrating the variability between study populations and methodologies. [4,6]

Overall, the findings of the present study reinforce the concept that the brachial plexus exhibits significant morphological variability. Although the majority of plexuses demonstrated the conventional pattern, the presence of variations involving terminal nerves, communicating branches, roots, cords and their relationship with the Axillary artery emphasizes the need for detailed anatomical knowledge. Such knowledge is particularly valuable for regional anaesthesia, management of traumatic nerve injuries and reconstructive surgery of the upper limb.

Conclusion

The present cadaveric study demonstrated appreciable morphological variations in the brachial plexus among the 50 plexuses examined. Variations were observed at different levels, particularly involving terminal branches and communicating nerves. These anatomical variations are clinically important during brachial plexus regional anaesthesia, management of upper-limb trauma, and reconstructive peripheral nerve surgery. Detailed knowledge of such variations can improve anatomical identification, surgical planning, and reduce the risk of inadvertent nerve injury.

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