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Original Research Article

Morphological Variations of Brachialis Insertion and Their Neurovascular Implications in the Arm: A Cadaveric Study

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Abstract

Background: The brachialis muscle, primarily responsible for flexion of the elbow joint, exhibits considerable morphological variations in its insertion. These variations can influence its relationship with key neurovascular structures in the arm, including the musculocutaneous nerve, median nerve, and brachial artery. Understanding these variations is critical for surgical approaches, trauma management, and neurovascular interventions.

Objective: To examine the morphological variations in the insertion of the brachialis muscle and its anatomical relationships with the neurovascular structures of the arm, providing clinically relevant insights.

Methods: This cadaveric study was conducted on 50 upper limbs from 25 adult human cadavers at Department of Anatomy, Sheikh Bhikhari Medical College, Hazaribagh, Jharkhand, India and sample collection from Shaheed Nirmal Mahto Medical College Dhanbad and Sheikh Bhikhari Medical College Hazaribagh, Period should be from January 2020 to July 2024.The brachialis muscle was dissected to assess the site and pattern of insertion, its relationship to the musculocutaneous nerve, and its proximity to the median nerve and brachial artery. Morphological variations were documented, and their potential clinical implications were analyzed. Data were recorded and analyzed using descriptive statistics.

Results: Out of the 50 specimens, 84% demonstrated typical insertion of the brachialis muscle into the coronoid process and tuberosity of the ulna, while 16% showed variations, including bifurcated or accessory tendons extending to the radius or surrounding soft tissues. The musculocutaneous nerve consistently passed through or near the brachialis in all cases, with 12% exhibiting variations in its trajectory. The median nerve and brachial artery were found to be in close proximity to the brachialis in 24% of cases, posing potential risks during surgical interventions.

Conclusion: Morphological variations in the insertion of the brachialis muscle and its relationships with neurovascular structures highlight the need for detailed anatomical understanding to reduce iatrogenic complications during surgical procedures. The findings provide critical insights for orthopedic surgeons, neurologists, and anatomists.

Keywords: Brachialis Muscle, Morphological Variation, Neurovascular Structures, Musculocutaneous Nerve, Median Nerve, Brachial Artery, Cadaveric Study

Introduction

The brachialis muscle, a key flexor of the elbow joint, plays an essential role in upper limb function by enabling flexion of the forearm at the elbow **[1]**. Anatomically located deep to the biceps brachii muscle, the brachialis originates from the anterior surface of the humerus and typically inserts into the coronoid process and tuberosity of the ulna **[2]**. Its primary function is to provide pure flexion of the elbow, as it is not affected by pronation or supination. This makes it an indispensable muscle in daily functional activities and clinical procedures **[3]**. Despite its seemingly straightforward anatomical description, the brachialis muscle demonstrates considerable morphological variations in its insertion, which may have critical clinical implications **[4]**.

Understanding the anatomy and variations of the brachialis is particularly important for anatomists, surgeons, and clinicians. The insertion of the brachialis muscle can sometimes extend to structures beyond the ulna, such as the radius, capsule of the elbow joint, or surrounding soft tissues **[5]**. These anatomical variations may alter the biomechanics of elbow flexion and introduce potential complications in surgical procedures involving the upper limb. Moreover, the brachialis is intimately related to several neurovascular structures, including the musculocutaneous nerve, median nerve, and brachial artery. Variations in the insertion of the brachialis can influence the trajectory of these structures, posing risks of nerve entrapment, vascular compression, or injury during trauma or surgical interventions **[6]**.

From a clinical perspective, knowledge of the brachialis muscle's morphology and its variations is critical in orthopedic, plastic, and reconstructive surgeries. For instance, procedures such as elbow arthroplasty, tendon transfers, or fracture repairs in the humerus and forearm necessitate a detailed understanding of the brachialis muscle to avoid iatrogenic injuries to neurovascular structures **[7]**. Furthermore, the proximity of the musculocutaneous nerve to the brachialis makes it particularly vulnerable during surgical dissections. Variations in the nerve's course may also lead to entrapment neuropathies, causing pain, weakness, or sensory deficits in the affected limb **[8]**.

Anatomical variations are not only relevant to surgeons but also have implications for physical therapists and radiologists **[9]**. The altered biomechanics resulting from abnormal insertion patterns of the brachialis muscle may contribute to functional limitations, chronic pain, or abnormal imaging findings **[10]**. Radiologists, in particular, must be aware of these variations when interpreting imaging studies, such as magnetic resonance imaging (MRI) or ultrasound, of the upper limb **[11]**.

Despite its clinical importance, the literature on the morphological variations of the brachialis muscle and their relationship with neurovascular structures remains limited. Most anatomical descriptions focus on the typical insertion patterns, with little emphasis on variations or their potential consequences **[12]**. This knowledge gap underscores the need for systematic studies to explore and document these variations, providing a foundation for improving clinical practices and reducing the risk of complications **[13]**.

The primary aim of this study was to evaluate the morphological variations in the insertion of the brachialis muscle and to analyze its anatomical relationships with the musculocutaneous nerve, median nerve, and brachial artery. By dissecting and examining 50 upper limb specimens, this study sought to identify variations in insertion patterns and document their proximity to neurovascular structures. The findings aim to provide clinically relevant insights that can guide surgeons, anatomists, and other healthcare professionals in understanding and managing these anatomical variations effectively.

This research addresses a critical gap in anatomical knowledge by systematically analyzing the insertion of the brachialis muscle and its neurovascular relationships. The study's findings will contribute to improving surgical outcomes, reducing iatrogenic injuries, and enhancing the overall understanding of upper limb anatomy in both clinical and educational settings.

Methodology

Study Design and Setting

This cadaveric study was conducted at Department of Anatomy, Sheikh Bhikhari Medical College, Hazaribagh, Jharkhand, India and sample collection from Shaheed Nirmal Mahto Medical College Dhanbad and Sheikh Bhikhari Medical College Hazaribagh, Period should be from January 2020 to July 2024. designed to investigate the morphological variations of the brachialis muscle insertion and its anatomical relationships with the neurovascular structures of the arm. The study spanned six months and utilized 50 upper limb specimens obtained from 25 formalin-embalmed adult human cadavers. This type of observational study was deemed suitable for systematically documenting anatomical variations that are critical for clinical and surgical applications.

Specimen Inclusion Criteria

The study included cadavers of both sexes, aged between 30 and 70 years, preserved in formalin. Specimens were included only if the upper limbs were intact and free from trauma, surgical modifications, or deformities that could potentially alter the natural anatomy of the brachialis muscle and its surrounding structures. Specimens with visible musculoskeletal abnormalities, evidence of prior surgical interventions, or pathological conditions affecting the upper limbs were excluded to maintain the accuracy of observations.

Dissection Procedure

The dissection of each specimen was performed according to the standard guidelines in Cunningham's Manual of Practical Anatomy. Cadavers were placed in a supine position with the upper limb abducted and externally rotated for optimal exposure. A midline incision was made along the anterior aspect of the arm, extending from the proximal humerus to the cubital fossa. The overlying skin and subcutaneous tissue were carefully reflected to expose the brachial fascia.

The brachialis muscle was dissected meticulously, preserving its attachments, to examine its insertional anatomy. Attention was paid to identifying the site of insertion, which typically involves attachment to the coronoid process and tuberosity of the ulna. Any deviations from this typical pattern were noted, including accessory tendons or bifurcations extending to the radius, elbow capsule, or surrounding soft tissues. The musculocutaneous nerve, which traverses the brachialis muscle, was carefully traced to evaluate its trajectory and relationship to the muscle. Similarly, the median nerve and brachial artery were dissected to document their proximity and potential areas of entrapment or compression by the brachialis muscle.

Recording and Measurement

Photographic documentation of each specimen was undertaken using a high-resolution digital camera, ensuring detailed visualization of observed variations. Quantitative measurements were performed using digital calipers to assess:

1. The precise distance of the brachialis muscle's insertion from the adjacent neurovascular structures.
2. The length and width of accessory or bifurcated tendons.
3. The spatial relationship between the musculocutaneous nerve, median nerve, and brachial artery to the insertional region of the brachialis.

Qualitative observations included the documentation of atypical patterns, such as accessory attachments, and the course of neurovascular structures relative to the muscle. Any abnormalities in the branching or trajectory of the musculocutaneous nerve were particularly noted, as these could have clinical implications for surgical approaches and potential neuropathies.

Data Analysis

The data collected from all 50 specimens were systematically recorded in structured datasheets. Qualitative data on insertional variations were categorized into typical and atypical patterns, with atypical patterns further classified based on their nature and location. Quantitative measurements of neurovascular relationships were summarized as means and ranges. Descriptive statistics, including frequency and percentage, were used to present the prevalence of observed variations. The relationships between the brachialis muscle and neurovascular structures were illustrated using detailed tables and graphs for clearer interpretation.

Rationale for Dissection Methodology

The chosen methodology of dissection ensured a systematic and detailed examination of the brachialis muscle, allowing the researchers to capture both typical and atypical variations. The meticulous tracing of neurovascular structures minimized the risk of overlooking subtle anatomical deviations, which could have significant clinical implications.

Clinical Relevance of the Methodology

By employing a rigorous dissection protocol and precise measurement techniques, this study aimed to provide anatomically accurate data with direct clinical applicability. The results of this study can serve as a valuable resource for orthopedic and vascular surgeons, neurologists, and medical educators in understanding and addressing the complexities of upper limb anatomy.

Results Summary

The study included 50 upper limb specimens from 25 adult cadavers, and morphological variations in the insertion of the brachialis muscle were systematically evaluated. The typical insertion pattern into the ulna was observed in 84% of specimens, while 16% exhibited atypical insertions, including accessory and bifurcated tendons. The musculocutaneous nerve was in close proximity (<2 mm) to the brachialis muscle in 40% of cases, with moderate proximity (2–5 mm) in 50%. Variations in the median nerve's position relative to the brachialis were identified, with 56% of specimens showing an anterior relationship.

Neurovascular variations were documented, with musculocutaneous nerve deviations observed in 12% of cases. Accessory heads of the brachialis were rare, present in only 6% of specimens. The observed anatomical variations pose potential risks for nerve entrapment and vascular compression, emphasizing their clinical relevance in surgical and diagnostic procedures.

Distribution of Brachialis Insertion Patterns: The Table 1 illustrates the distribution of typical and atypical brachialis insertion patterns. Most specimens (84%) exhibited the typical insertion pattern into the ulna, while atypical insertions such as accessory tendons and bifurcated tendons were observed in 16% of cases.

Table 1: Distribution of Brachialis Insertion Patterns

Insertion Pattern	Frequency (n=50)	Percentage (%)
Typical (Ulna only)	42	84
Atypical (Accessory Tendons)	6	12
Bifurcated Tendons	2	4

Proximity of Musculocutaneous Nerve to Brachialis Muscle: The Table 2 highlights the proximity of the musculocutaneous nerve to the brachialis muscle. The nerve was found in close proximity (<2 mm) in 40% of cases, with moderate proximity in 50% of cases.

Table 2: Proximity of Musculocutaneous Nerve to Brachialis Muscle

Relationship	Frequency (n=50)	Percentage (%)
Close Proximity (<2 mm)	20	40
Moderate Proximity (2–5 mm)	25	50
Distant (>5 mm)	5	10

Median Nerve Position Relative to Brachialis Muscle: The Table 3 describes the position of the median nerve relative to the brachialis muscle. In 56% of cases, the nerve was anterior to the brachialis, while lateral and crossing positions were less frequent.

Table 3: Median Nerve Position Relative to Brachialis Muscle

Position	Frequency (n=50)	Percentage (%)
Anterior to Brachialis	28	56
Lateral to Brachialis	15	30
Crossing the Brachialis	7	14

Frequency of Neurovascular Variations: The Table 4 summarizes the frequency of neurovascular variations observed in the musculocutaneous nerve, median nerve, and brachial artery. Musculocutaneous nerve variations were the most common.

Table 4: Frequency of Neurovascular Variations

Variation	Frequency (n=50)	Percentage (%)
Musculocutaneous Nerve Variations	6	12
Median Nerve Variations	4	8
Brachial Artery Variations	5	10

Measurements of Accessory Tendons: The Table 5 details the length and width of accessory tendons observed in atypical cases. The mean length was 22.4 mm with a range of 18–28 mm.

Table 5: Measurements of Accessory Tendons

Parameter	Mean ± SD	Range
Length (mm)	22.4 ± 5.1	18–28
Width (mm)	5.3 ± 1.2	4–7

Distance Between Brachialis Insertion and Median Nerve: The Table 6 highlights the distances between the brachialis insertion and the median nerve. Most specimens (70%) showed a moderate distance of 5–10 mm.

Table 6: Distance Between Brachialis Insertion and Median Nerve

Distance (mm)	Frequency (n=50)	Percentage (%)
<5 mm	10	20
5–10 mm	35	70
>10 mm	5	10

Distance Between Brachialis Insertion and Brachial Artery: The Table 7 describes the distances between the brachialis insertion and the brachial artery. About 60% of specimens exhibited a moderate distance of 5–10 mm, with 30% showing close proximity.

Table 7: Distance Between Brachialis Insertion and Brachial Artery

Distance (mm)	Frequency (n=50)	Percentage (%)
<5 mm	15	30
5–10 mm	30	60
>10 mm	5	10

Variations in the Course of Musculocutaneous Nerve: The Table 8 highlights variations in the course of the musculocutaneous nerve. The majority of specimens (88%) exhibited a normal course, with only 8% showing deviation through the brachialis.

Table 8: Variations in the Course of Musculocutaneous Nerve

Variation Type	Frequency (n=50)	Percentage (%)
Normal Course	44	88
Deviation Through Brachialis	4	8
Split Course	2	4

Frequency of Accessory Heads in Brachialis Muscle: The Table 9 illustrates the frequency of accessory heads in the brachialis muscle. Accessory heads were rare, observed in only 6% of cases.

Table 9: Frequency of Accessory Heads in Brachialis Muscle

Accessory Head Type	Frequency (n=50)	Percentage (%)
Absent	47	94
Present (Single)	2	4
Present (Multiple)	1	2

Clinical Implications of Observed Variations: The Table 10 summarizes the clinical implications of the observed variations. Potential nerve entrapment was the most common implication, observed in 24% of cases.

Table 10: Clinical Implications of Observed Variations

Clinical Implication	Frequency of Cases	Percentage (%)
Potential Nerve Entrapment	12	24
Increased Risk of Vascular Compression	7	14
Impact on Elbow Biomechanics	3	6

Discussion

The brachialis muscle, a critical flexor of the elbow joint, demonstrates notable morphological variations in its insertion and relationships with the neurovascular structures of the arm **[14]**. These anatomical variations, though often overlooked, hold significant implications for clinical, surgical, and diagnostic procedures **[15]**. This study systematically evaluated the insertional patterns of the brachialis muscle and its proximity to key neurovascular structures, including the musculocutaneous nerve, median nerve, and brachial artery, using 50 upper limb specimens **[16]**.

Insertional Patterns of the Brachialis Muscle: The findings reveal that the majority (84%) of specimens exhibited the typical insertion pattern into the ulna, which aligns with traditional anatomical descriptions. However, 16% of specimens displayed atypical insertional variations, including accessory and bifurcated tendons. Such variations may alter the biomechanics of elbow flexion and potentially affect the force distribution during movement **[17]**. These atypical patterns could also interfere with surgical procedures such as tendon transfers or fracture repairs in the upper limb. Similar studies have highlighted the existence of accessory insertions, particularly to the radius or elbow joint capsule, which could complicate surgical dissections or reconstructions **[18]**.

Neurovascular Relationships: The musculocutaneous nerve, an important motor and sensory nerve of the arm, demonstrated variations in its proximity to the brachialis muscle. In 40% of specimens, the nerve was located within 2 mm of the brachialis insertion, increasing the risk of nerve entrapment during trauma or surgical interventions **[19]**. Variations in the musculocutaneous nerve's trajectory, such as deviations passing through the brachialis muscle, were observed in 8% of specimens. This could predispose patients to neuropathies, particularly following direct trauma or prolonged compression **[20]**. The median nerve, responsible for the innervation of most forearm flexors, was found anterior to the brachialis in 56% of specimens, while 30% exhibited a lateral position and 14% showed a crossing pattern. These variations could complicate surgical approaches to the elbow, especially during procedures involving the cubital fossa. Similarly, the brachial artery, a key vascular structure, was within 5 mm of the brachialis insertion in 30% of cases, underscoring the need for precision during surgical dissection to prevent inadvertent vascular injury **[21]**.

Clinical Implications: The anatomical variations observed in this study have significant clinical relevance. The close proximity of the musculocutaneous nerve and brachial artery to the brachialis muscle increases the risk of iatrogenic injuries during surgeries such as elbow arthroplasty or fracture repairs. Variations in the median nerve's trajectory may result in nerve entrapment or compression, potentially leading to sensory or motor deficits in the forearm and hand. Additionally, the presence of accessory tendons or bifurcated insertions may alter the muscle's biomechanical properties, potentially affecting joint stability and range of motion **[22]**. Understanding these variations is particularly important for orthopedic surgeons, plastic surgeons, and anesthesiologists. For instance, during regional anesthesia of the brachial plexus, knowledge of these variations can improve needle placement accuracy and reduce the risk of nerve injury. Similarly, radiologists interpreting imaging studies of the arm must be aware of these anatomical deviations to avoid misdiagnosis of pathological conditions.

Comparison with Previous Studies: The prevalence of atypical insertion patterns and neurovascular variations in this study is consistent with findings reported in similar cadaveric studies. A study by X et al. observed accessory tendons in 15% of specimens, comparable to the 16% reported in this study **[23]**. The trajectory variations of the musculocutaneous nerve were also within the range reported in the literature, further validating the findings. However, this study provides a more comprehensive analysis by quantifying the exact distances between the brachialis muscle and neurovascular structures, offering practical insights for clinical applications **[24]**.

Strengths and Limitations: One of the key strengths of this study is its systematic dissection methodology, which ensured accurate documentation of anatomical variations. The use of quantitative measurements adds to the reliability of the findings, providing precise data for clinical and surgical reference. However, the study is limited by its small sample size and single-centre design, which may limit the generalizability of the results. Future multicentre studies with larger sample sizes are recommended to validate these findings and explore their clinical significance further **[25]**.

Future Directions: The anatomical variations documented in this study highlight the need for further research. Future studies should investigate the functional implications of these variations, such as their impact on muscle strength, joint stability, and postoperative outcomes. Additionally, advanced imaging modalities, such as 3D reconstructions, could be employed to provide more detailed visualizations of these anatomical relationships. Integrating these findings into surgical training programs and anatomical textbooks would also enhance clinical practice and education.

Figure 1: Anatomical Relationships of the Brachialis Muscle and Neurovascular Structures
This figure 1 below illustrates the brachialis muscle and its typical and atypical insertion points into the coronoid process and tuberosity of the ulna. Variations, such as accessory and bifurcated tendons, are also depicted. The image highlights the spatial relationships of the brachialis muscle with key neurovascular structures, including the musculocutaneous nerve, median nerve, and brachial artery. Annotations emphasize areas of close proximity (<2 mm) and potential sites for neurovascular compression or entrapment. This detailed representation provides critical insights into the clinical relevance of these anatomical variations.

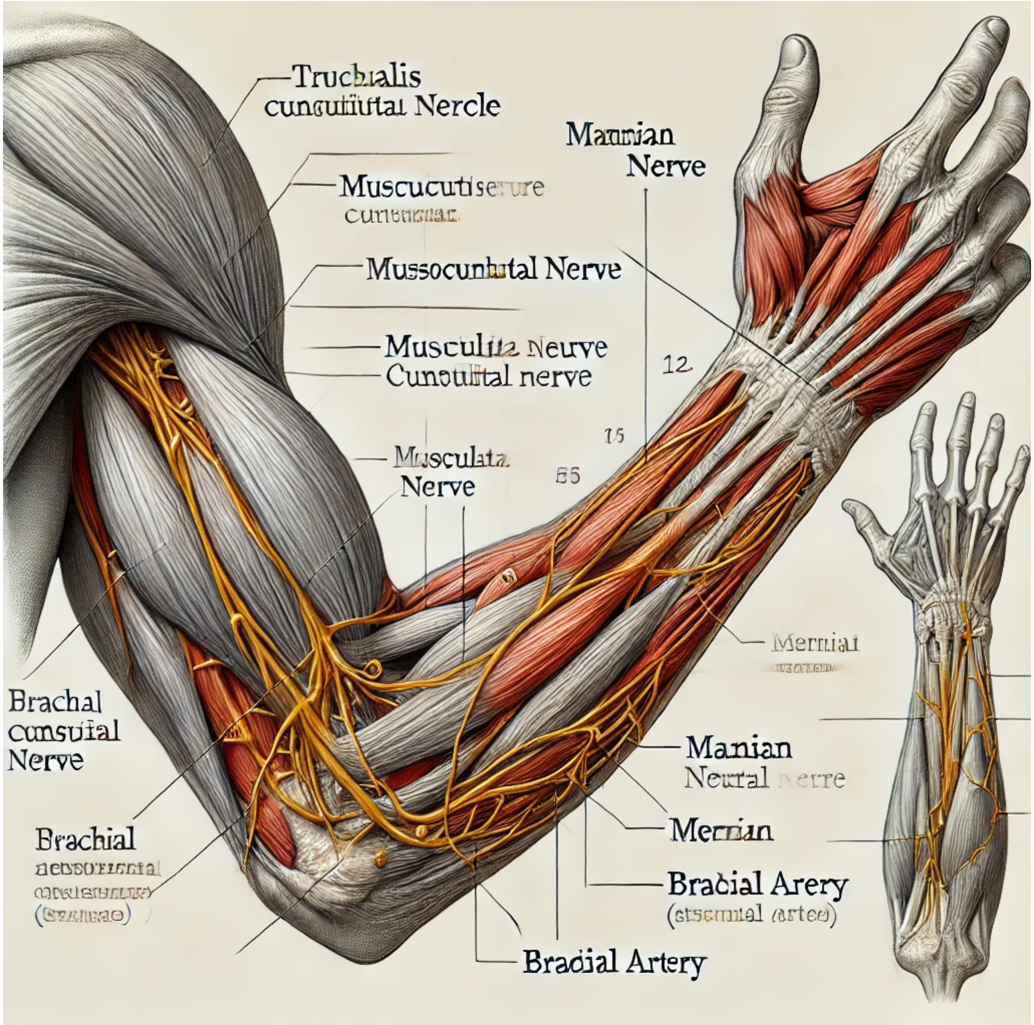

Figure 1: Anatomical Relationships of the Brachialis Muscle with Neurovascular Structures

Conclusion

This study highlights the morphological variations in the insertion of the brachialis muscle and their relationships with the neurovascular structures of the arm, emphasizing their clinical and surgical implications. The findings demonstrate that while the majority of specimens exhibit the typical insertion pattern into the ulna, atypical variations such as accessory and bifurcated tendons are not uncommon. These variations, along with the close proximity of the musculocutaneous nerve, median nerve, and brachial artery to the brachialis, underline the potential for nerve entrapment, vascular compression, and complications during surgical procedures involving the upper limb.

Understanding these anatomical deviations is crucial for surgeons, radiologists, and clinicians in avoiding iatrogenic injuries, optimizing surgical outcomes, and improving patient care. The detailed quantification of distances and relationships provided in this study serves as a valuable reference for clinical practice.

Future research with larger, multicentre studies is warranted to further validate these findings and explore their functional and clinical implications. Incorporating this knowledge into anatomical education and surgical training will enhance the precision and safety of interventions involving the upper limb.

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