

Review Article

Anatomical diversity of brachial plexus with embryological and clinical perspectives: a review

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ABSTRACT

The brachial plexus (BP) is the main neural source for the upper limb, and its anatomical variations are highly significant in clinical practice. It is a complex network of nerves that plays a crucial role in providing motor and sensory innervation to the upper limb. The clinical importance of the brachial plexus makes it essential for clinicians, surgeons, radiologists, and anaesthesiologists. Anatomical variations in its structure and connections with neighbouring nerves can complicate surgical procedures, diagnostic evaluations, and the management of nerve disorders. Variations in the upper limb nerves, such as the absence of certain nerves, interconnections, or unusual pathways, are common anatomical occurrences that can greatly affect clinical diagnosis and treatment. These variations may change innervation patterns or contribute to nerve compression syndromes, resulting in atypical clinical presentations. This review highlights the prevalence of upper limb variations and their clinical significance, stressing the importance of anatomical knowledge for accurate diagnosis and treatment. It also discusses the findings from recent studies and underscores the need for ongoing research to enhance diagnostic precision and surgical outcomes.

Keywords: Brachial plexus, Nerve variations, Neuropathies, Clinical relevance

INTRODUCTION

The human upper limb is a complex anatomical structure, with peripheral nerves playing a crucial role in neurophysiological functions. The upper limb is often prone to injury, making the brachial plexus an important focus for clinicians, anaesthesiologists, and surgeons.¹ The brachial plexus, formed by the anterior rami of the C5-T1 spinal nerves, is a key structure responsible for motor and sensory innervation of the upper limb. It is composed of roots, trunks, divisions, cords, and terminal branches. Understanding its anatomy is essential for performing regional anaesthesia, diagnosing nerve injuries, and avoiding complications during surgical procedures. A brachial plexus block is the preferred method of anaesthesia for upper limb surgeries.²

Variations in nerve anatomy, such as interconnections between nerves or unusual pathways, are commonly observed. While these variations are often asymptomatic, they can complicate the diagnosis of nerve injuries, compression syndromes, and neuropathies. These deviations are particularly significant in cases of trauma, compression injuries, and surgical procedures involving the axilla or upper arm.¹ Variations of the brachial plexus are categorized into three types: those arising developmentally, those with atypical neural connections between two nerves, and those caused by surrounding structures leading to entrapment neuropathies. This review provides an overview of brachial plexus anatomy, recent findings on brachial plexus variations, and their clinical importance, highlighting their impact on diagnostic processes and therapeutic decision-making.

ANATOMY OF BRACHIAL PLEXUS

The brachial plexus is a complex nerve network responsible for the innervation of the upper extremity. It originates from the anterior rami of spinal nerve roots C5-T1, with occasional contributions from C4 (prefixed plexus) and T2 (postfixed plexus). Among the five roots of the plexus, upper two roots unite to form the upper trunk, the lower two unite to form lower trunk and the central root runs on as the middle trunk. Each of the three trunks divide into an anterior and a posterior division

behind the clavicle. At the outer border of the first rib, the upper two anterior divisions unite to form the lateral cord, anterior division of lower trunk runs on the medial cord, while all the three posterior divisions unite to form the posterior cord. These cords enter the axilla and give off their branches around the third part of axillary artery. Its terminal branches include axillary, musculocutaneous, radial, median and ulna nerves, each with distinct motor and sensory functions (Figure 1).

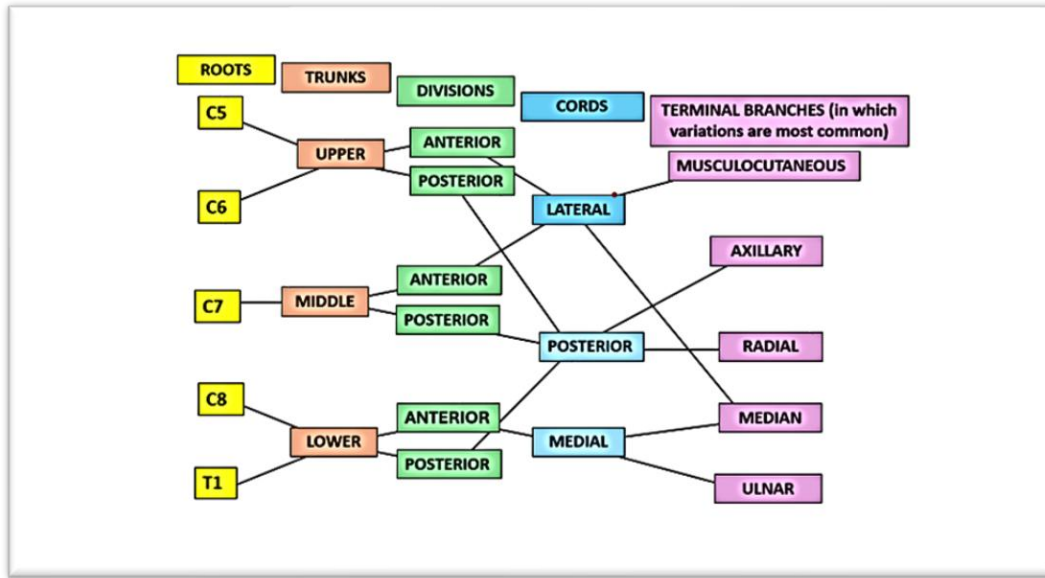


Figure 1: Formation of brachial plexus.

The axillary nerve travels backward through the quadrangular space, where it splits into two branches. The anterior branch innervates the deltoid muscle, while the posterior branch provides motor supply to the teres minor and the posterior portion of the deltoid. The musculocutaneous nerve supplies the coracobrachialis, biceps brachii, and brachialis muscles before continuing as the lateral cutaneous nerve of the forearm. The radial nerve controls the extensors of the arm and forearm, whereas the median nerve innervates the forearm flexors and thenar muscles. The ulnar nerve supplies the intrinsic muscles of the hand.³ The plexus is tethered at various points, such as the intervertebral foramen and axillary sheath, making it vulnerable to compression, avulsion, and surgical trauma. The plexus has an hourglass shape as it narrows between the clavicle and first rib, which is the most common site of injury.⁴

NERVE INJURIES OF BRACHIAL PLEXUS

Nerve injuries can arise from surgical positioning, trauma, or regional anaesthesia. Superior and middle trunk injuries often result in Erb's palsy, which is characterized by motor deficits in the C5/6 myotomes, such as loss of shoulder abduction and elbow flexion.⁵ Inferior trunk injuries lead to Klumpke's palsy, which manifests as ulnar nerve

distribution deficits, including claw hand deformity and radial deviation of the wrist. In some cases, these injuries may also involve Horner's syndrome due to damage to sympathetic fibres. The ulnar nerve is particularly vulnerable at the medial epicondyle, where injury can result in cubital tunnel syndrome. Median nerve damage affects hand pronation and sensation and is often associated with carpal tunnel syndrome. Radial nerve compression at the spiral groove can lead to wrist drop and sensory loss in the posterior compartment of the arm.⁴

MORPHOLOGICAL VARIANTS OF BRACHIAL PLEXUS

The brachial plexus can exhibit three types of variations. The first type is a developmental variation, which arises during embryological development and results in the abnormal formation of a nerve. An example of this is the median nerve originating from three or four roots. The second type involves atypical neural connections between the two nerves, such as the commonly observed communication between the musculocutaneous nerve and the median nerve. The third type occurs due to surrounding structures causing entrapment neuropathies, such as the ligament of Struthers compressing the median nerve (Figure 2).

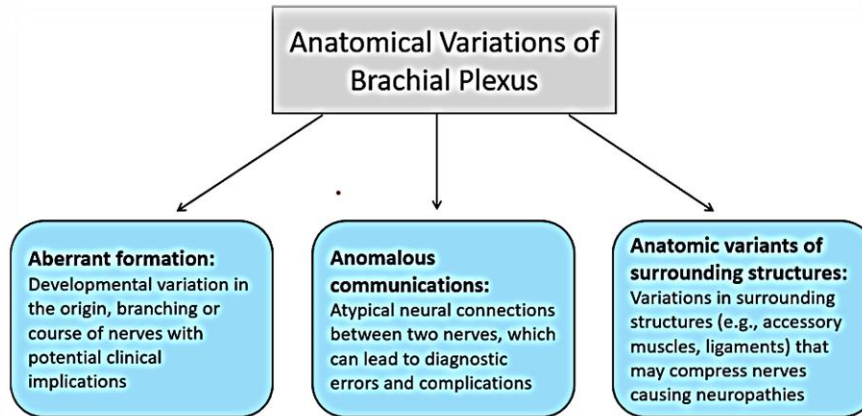


Figure 2: Morphological variants of brachial plexus.

Table 1: Anatomical variations in brachial plexus and its branches.

Takkallapalli et al⁶	Posterior part of deltoid is supplied only by posterior division in 78.33%, by both anterior and posterior divisions in 15% and only by anterior division in 6.7%
Marios et al⁷	Axillary nerve split into anterior and posterior branches within quadrangular space in 65% of cases, and within deltoid muscle in 35% of cases.
Rezzouk et al⁸ & Komala et al⁹	Axillary nerve can supply the long head of triceps, which is typically innervated by radial nerve
Deseze et al¹⁰	Motor branch to long head of triceps arises from axillary nerve or posterior cord, not radial nerve.
Guru et al¹¹	Variations in the ulnar nerve formation were found where the lateral cord contributed to the formation of ulnar nerve.
Goel et al¹²	Ulnar nerve emerging from the medial cord via two roots that unite to form a single trunk.
Das et al¹³	Communication between the ulnar nerve and the medial cutaneous nerve of the forearm
Emamhadi et al¹⁴	Communication between the ulnar nerve and lateral cord was observed
Munjamkar P¹⁵	Formation of ulnar nerve by two roots, Communication between the ulnar nerve and the medial cutaneous nerve of the forearm
Sachdeva et al¹⁶	Rare origin of ulnar nerve from median nerve
Gupta et al¹⁷	Similar variation in ulnar nerve formation with contribution from medial root of median nerve
Fazan et al¹⁸	Prevalence of ulnar nerve receiving a communicating branch from musculocutaneous nerve (30%).
Ozguner et al¹⁹ & Arachchi et al²⁰	Communication between radial and ulnar nerves at high humeral level
Marathe et al²¹	Communication between radial nerve and medial cutaneous nerve of forearm.
Kumari et al²²	Reported formation of median nerve by 3 roots in 26.4% and 4 roots in 1.8% of cases.
Encarnacion et al²³	Median nerve formed by 3 roots in 20.2% and 4 roots in 2.4% of cases.

FREQUENT VARIATIONS IN BRACHIAL PLEXUS ANATOMY

Anatomical variations in the are well-documented. Among the terminal branches, the musculocutaneous nerve (MCN) and radial nerve (RN) are the most frequently affected. Common variations include communicating branches (CBs) between the MCN and median nerve (MN), high bifurcation of the RN, and CBs between the

axillary nerve (AN) and RN. These variations can occur unilaterally or bilaterally and are often associated with specific ethnic and biological characteristics (Table 1).

EMBRYOLOGICAL INSIGHTS OF BRACHIAL PLEXUS VARIATIONS

Embryological development is crucial for the formation and variations of the nerves that make up the brachial

plexus, including the musculocutaneous nerve (MCN) and median nerve (MN). Around the fifth week of pregnancy, the upper limb bud appears near the lower cervical and upper thoracic somites. Motor and sensory axons derived from the neural crest cells grow into the mesenchyme of the developing limb bud which are guided by growth cones, neurotrophic factors, and extracellular matrix proteins. By the seventh week of development, the roots, trunks, divisions, cords, and terminal branches of the plexus are formed. Axonal connections with developing limb muscles are then strengthened to ensure coordinated motor and sensory functions. Disruptions during the embryological development caused by genetic, vascular, or mechanical factors, can result in abnormal formation of the brachial plexus. Variations in signalling between mesenchymal cells and neuronal growth cones can lead to the differences in normal path, branching, or connections of the nerves.²⁴

The musculocutaneous nerve and median nerve share a common embryological origin, and their fibres may overlap or fail to separate completely during development, leading to anatomical variations such as the absence of the musculocutaneous nerve, communication between the musculocutaneous nerve and median nerve, or direct innervation of muscles by branches from the lateral cord or median nerve.²⁵ From an evolutionary standpoint, the musculocutaneous nerve may have developed from the median nerve, as in lower vertebrates, arm flexors are mainly innervated by the median nerve, and the musculocutaneous nerve is absent. This evolutionary connection may explain variations like the absence of the musculocutaneous nerve or its communication with the median nerve.²⁶ Overall, embryological development is the foundation for the formation of the brachial plexus and its branches, and disruptions or changes in signalling and growth processes during development can lead to variations in nerve anatomy. Understanding these processes is essential for interpreting anatomical variations and their clinical importance.

CLINICAL RELEVANCE OF BRACHIAL PLEXUS VARIATIONS

Variations in the brachial plexus have significant impacts on diagnostic accuracy, surgical planning, and treatment outcomes. Lack of awareness of these variations can lead to misdiagnosis, ineffective treatments, and accidental injuries during medical procedures. These variations can affect sensory and motor innervation, resulting in unusual clinical presentations, such as communicating branches between the musculocutaneous nerve and the median nerve, which can complicate the diagnosis of nerve injuries, neuropathies, and entrapment syndromes. Peripheral nerves in the upper limb may become trapped at different anatomical locations, causing neuropathic pain and weakness.²⁷ Additionally, brachial plexus variations increase the risk of nerve injuries during procedures like shoulder surgeries, humeral fracture repairs, and regional anaesthesia. For instance, failing to recognize a high

bifurcation of the radial nerve can result in incomplete nerve repair and ongoing neurological issues. These variations also have therapeutic importance, as understanding them is crucial for planning nerve transfer techniques, reconstructive surgeries, and regional anaesthesia. Nerve variations can affect the effectiveness of nerve blocks and neurotization procedures. Moreover, vascular complications may occur due to loops formed by communicating branches around arteries, potentially leading to vascular compression, ischemic changes, or arterial injury during surgeries.²⁵

CONCLUSION

A comprehensive understanding of the brachial plexus anatomy is crucial for performing safe and effective surgical and anaesthetic procedures. Anatomical variations in the terminal branches of the brachial plexus are clinically significant and must be carefully considered during diagnostic evaluations, surgical planning, and therapeutic interventions. Ongoing research is vital for further understanding these variations and improving clinical outcomes. Better recognition and documentation of the brachial plexus deviations will help to reduce the complications and enhance the patient care.

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