ORIGINAL RESEARCH

Anatomical Variations of the Brachial Plexus: a cadaveric study

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Abstract

Objective: Variations of the brachial plexus are a lot commoner than presumed and a better understanding of such variations are of crucial importance to achieve successful results in surgical procedures. The aim of our study was to describe the anatomical variations of the brachial plexus in Sri Lankan adult cadavers.

Methods: Bilateral upper limbs of cadavers used for routine dissection from January 2023 to September 2024, were examined and the trunks, cords and terminal nerves were described. Images were taken and variations were carefully noted and recorded.

Results: Sixty brachial plexuses in 30 cadavers (19 males and 11 females) with a mean age at death of 70.75 years (SD=10.31) were observed. Prevalence of variations was 40%. We report 7 (11.6%) prefixed and 1 postfixed (1.6%) brachial plexuses, variant connections between lateral and medial cords (5 – 8.3%), variant connection between lateral cord and median root of median nerve1(1 - 1.6%), rare variant of only two cords (posterior and combined medial lateral to form an anterior cord), absent musculocutaneous nerve (2 - 2.3%) and musculocutaneous nerve giving a branch to the median nerve (3 – 5%).

Conclusion: Variations of the brachial plexus are quite common and highly variable and therefore require constant reporting to provide medical personal with information that could prevent iatrogenic injury and help in proper diagnosis of cases.

Keywords: Brachial plexus, roots, trunks, divisions, cords, anatomical variations

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Introduction

A sound knowledge of the arrangement of nerves in the limbs are of clinical importance since injuries to the upper limb are common and can be debilitating (1). There is very little room for error in treatment of neurological injuries and in the presence of variations can hinder the surgical process and reduce the quality of the outcome (2,3). Anatomical variations of brachial plexus are not as rare as the practicing doctor may presume (4-6). More than 50% of anatomical variations in the nervous system have been reported to belong to the brachial plexus (4).

The brachial plexus supplies both motor and sensory innervations to the upper limb (4). The anterior rami of the 5th cervical (C5) to the 8th cervical (C8) and the first thoracic spinal nerve (T1) form the brachial plexus (4). The brachial plexus extends from the neck, moving laterally towards the apex of the axilla and then entering the anterior compartment of the arm (4). The brachial plexus has 5 roots, 3 trunks, 6 divisions, 3 cords and five terminal branches. The roots C5, C6, C7, C8 and T1 exit the spinal canal below its corresponding vertebra. The trunks are formed by the union of C5 and C6 to form the upper trunk, C7 is the middle trunk, while the C8 and T1 form the lower trunk. Each trunk divides into anterior and posterior divisions, and combination of these form the cords. Thus, the posterior cord is formed by the three posterior divisions, which includes all segments, while the lateral cord is by the fusion of the anterior divisions of the upper and middle trunks carrying C5 - C7 roots, and the medial cord is the continuation of the anterior division of the lower trunk containing C8 and T1 roots. The cords give rise to the five terminal branches: the lateral cord continues as the musculocutaneous nerve, the medial cord, as the ulnar nerve, and the posterior cord, as the radial nerve. Cross-communication between the lateral and medial cords form the median nerve (4) (Figure 1). Anatomical variations in the pattern of the brachial plexus can be linked to developmental anomalies of the trunks, divisions or cords and can be explained through neuronal growth cones (7).

Approximately 50% of the population show at least a minor variation in the pattern of the brachial plexus, pre-fixed brachial plexus, being one of the commoner variations (8). Variations in branching patterns of the cords have also been reported regularly (9, 10).

Much variability in the frequency of brachial plexus variations have been reported from all over the world, with regional differences also being reported. Though case reports and several surveys on the brachial plexus variations have been done in Sri Lanka, we aim to report several rare variants and frequencies of common variants to add to the available information.

Methods

All cadavers dissected between January 2023 to September 2024 for routine dissections by the 2021 and 2022 batches of medical students and 2021 batch of allied health science students at the Department of Anatomy, Faculty of Medicine, Peradeniya were studied. All cadavers were formalin preserved for at least 3 months.

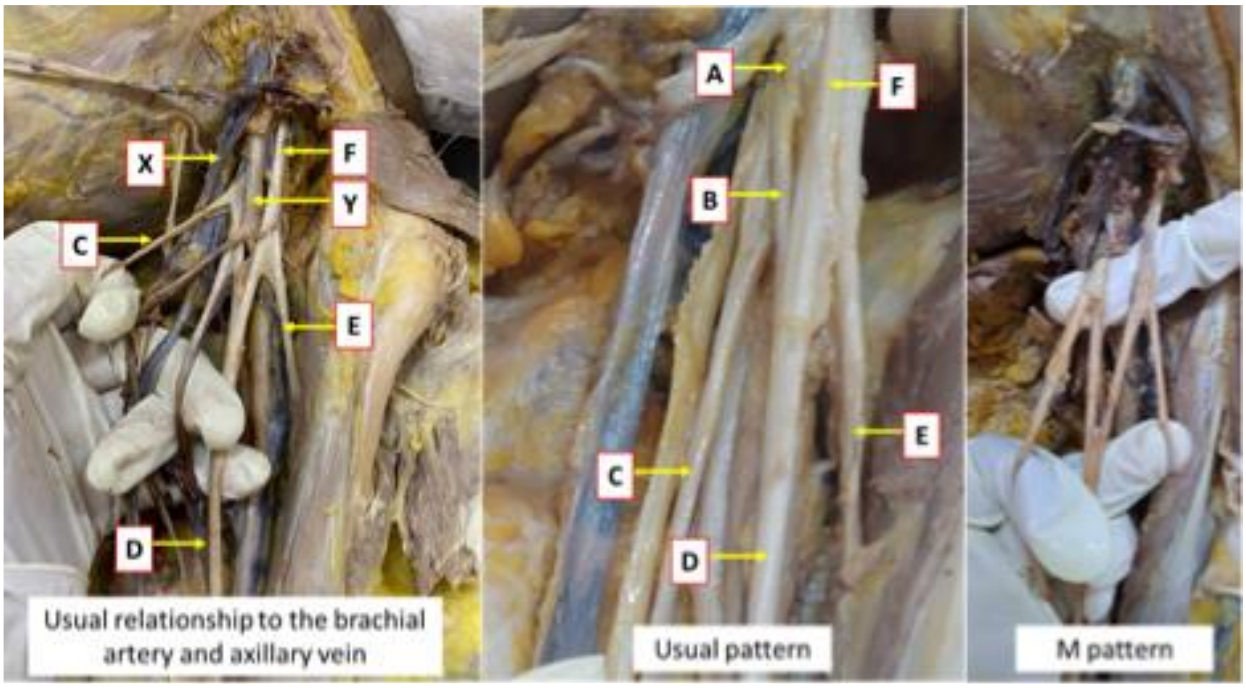

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Figure 1. commonest pattern of the brachial plexus: X -axillary vein, Y – axillary artery, A – medial cord, B medial root of median nerve, C – ulnar nerve, D – median nerve, E – musculocutaneous nerve, F – lateral cord. I -relationship of the cords and nerves to the axillary artery and vein, II – usual pattern of the cords and nerve branches, III – ulnar nerve, medial root of median nerve, lateral root of median nerve and musculocutaneous nerve showing the typical M pattern

The dissection protocol for upper limb described in Grant's Dissector was used. Dissections were conducted under the guidance of the anatomy teachers (investigators). All brachial plexuses were assessed at root, trunk, division and branch levels. Pathways of the branch nerves were not further assessed. All variations were carefully recorded and photographed.

Results

A total of 30 adult cadavers (60 upper limbs), 19 males and 11 females with a mean age at death of 70.75 years (SD=10.31) were included in the sample. Twenty-five variations were detected in 23 plexuses out of the 60 studied (41.6%). The variations are presented in table 1. In one cadaver we found two variations as, connections between lateral and medial cord on the right side and a connection between the lateral cord and the medial root of the median nerve. All other variations were found only on one side with the other side showing the usual pattern.

Table 1: Variations observed in the brachial plexus

Part of the plexus	Number with usual pattern - n (%)	Number with variations - n (%)	Variation
Roots of the plexus	54 (87.5%)	7 (11.6 %)	pre-fixed (fourth cervical root contributed to the origin): all on the left side with usual pattern on the right
		1 (1.8 %)	post-fix (second thoracic spinal root contributed to the origin) on the left side with usual pattern on the right side
Branches arising from the roots		1 (1.8%)	Bilateral long thoracic nerve formed higher up seen to pierce the Scalenus Medius muscle on the left side with usual pattern on the right side
Divisions			No variations were observed
Cords		1 (1.8%)	Only two cords were present on the left side: posterior cord and a cord that combined medial and lateral cords placed anteriorly (anterior cord). – rare variant (Figure 2) Right side showed the usual pattern
		2 (3.3%)	Connection between the lateral cord and the medial root of the median nerve on the left side. Right side showed the usual pattern (Figure 3)
		5 (8.3%)	Connection between the medial and lateral cords (Figure 4). 3 on the left and 2 on the right side with 4 cadavers having the usual pattern on the right side
Branches		1 (1.8%)	Ulnar, median and musculocutaneous nerves were seen arising from a single anteriorly placed cord – rare variant (Figure 2)
		1 (1.8%)	Biceps and coracobrachialis were being supplied by branches from the lateral cord (Figure 4)
		2 (3.3%)	Absence of musculocutaneous nerve
		1 (1.8%)	Lateral and medial cords were connected, and the median and musculocutaneous nerves arose from the lateral cord. The median nerve did not arise from two roots (Figure 5), with usual pattern on the right side
		3 (5%)	Musculocutaneous nerve was seen to give a communicating branch to the median nerve Type II - Le Minor's Classification.

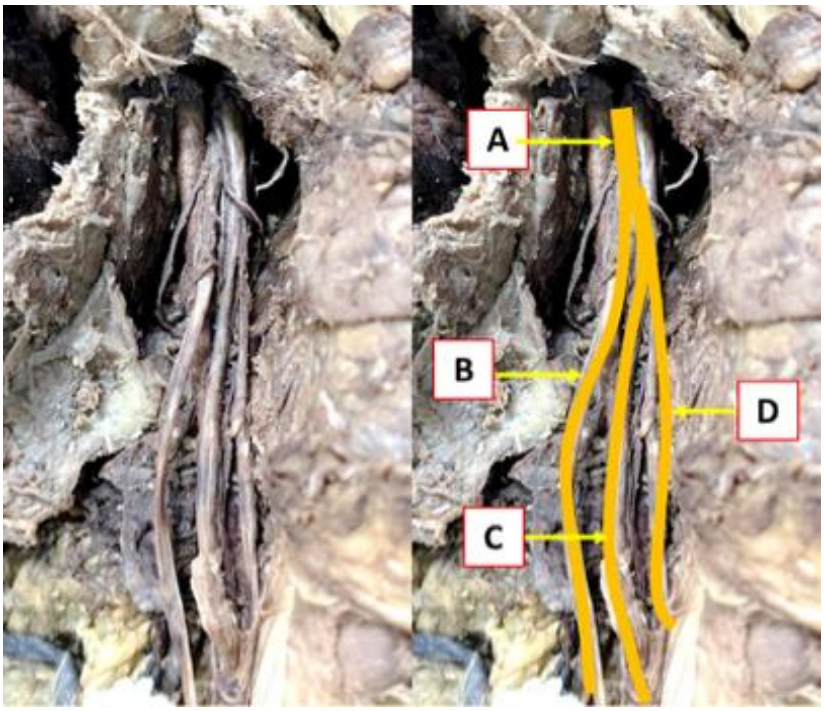

Figure 2: Only two cords were present on the left side: the posterior cord and an anteriorly placed cord that combined medial and lateral cords. The ulnar, median and musculocutaneous nerves were seen arising from this anterior cord. A – anterior cord, B – ulnar nerve, C – median nerve, D – musculocutaneous nerve

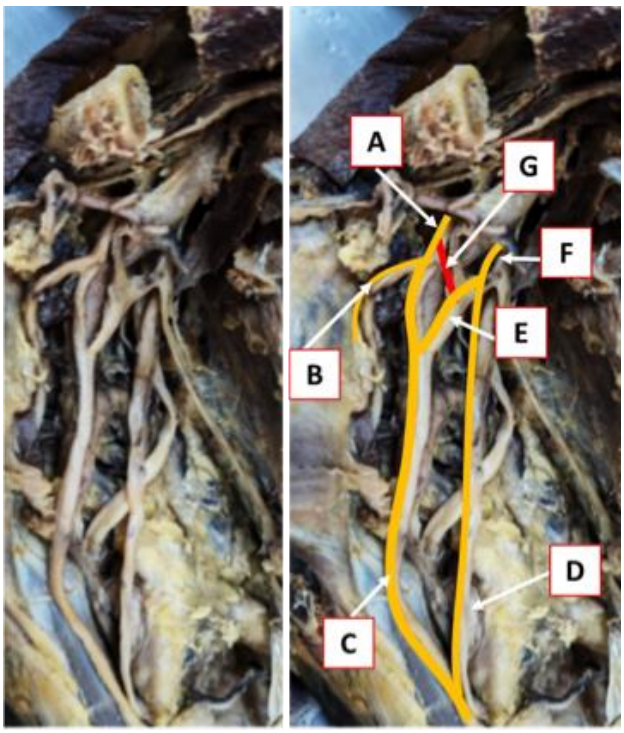

Figure 3: A variant connection is seen on the left side between the lateral cord and the medial root of the median nerve: A – lateral cord, B – musculocutaneous nerve, C – median nerve, D - ulnar nerve, E - medial root of median nerve, F- medial cord G - variant connection

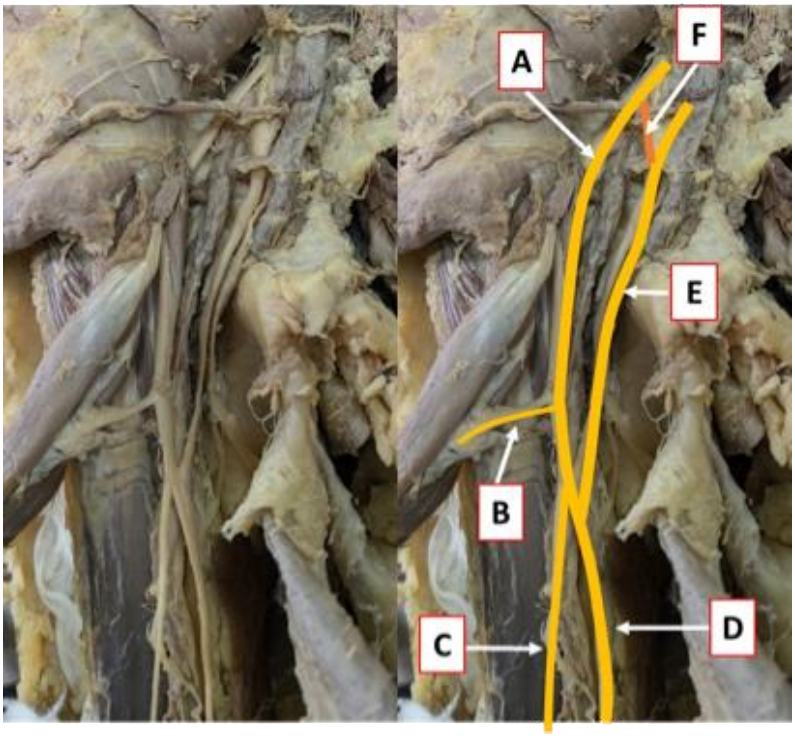

Figure 4: Connection between the medial and lateral cords: A lateral cord, B = branch to the biceps brachii, C – median nerve, D – ulnar nerve, E – medial cord, F - variant connection

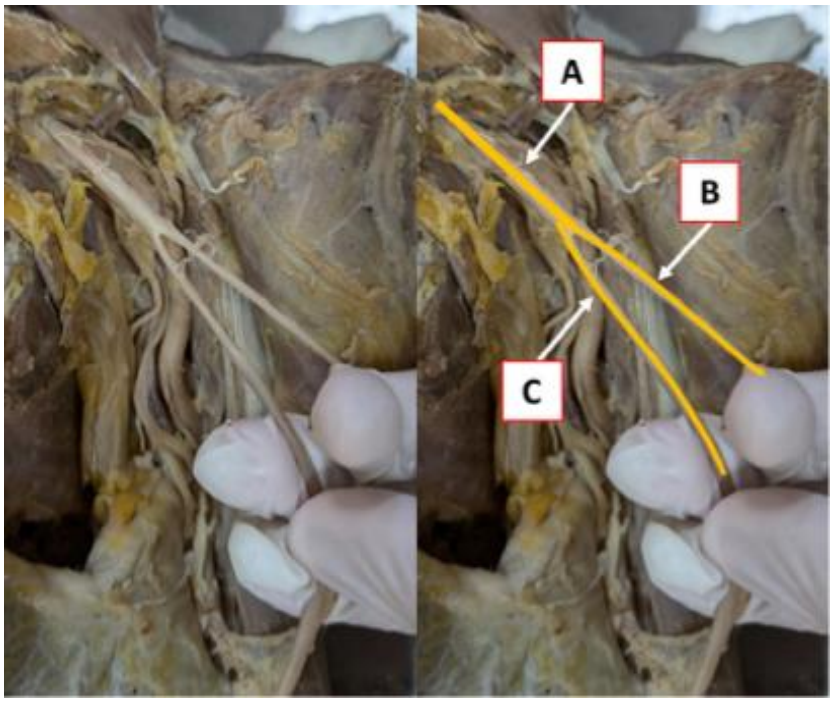

Figure 5: Lateral and medial cords were connected, and the median and musculocutaneous nerves were seen to arise from the lateral cord. Medial and lateral roots of the median nerve were absent. A – lateral cord, B musculocutaneous nerve, C – median nerve

Discussion

Anatomical variations in any region of the body are highly relevant for invasive medical procedures that rely upon an assumption of generally described textbook anatomy. When it comes to nerves and nerve plexus it becomes even more complicated due the wide array of variations described throughout the nervous system. It is crucial that clinicians, especially surgeons, are aware of how common clinically relevant nerve variations are in the upper limb (10). Such knowledge is essential in order to avoid compromising patient care and to improve patient outcomes. These variations are particularly important for plastic surgeons during nerve grafting and free flap transfers, and for general surgeons during axillary clearance surgeries. Moreover, recent studies have linked brachial plexus variations to specific types of neuralgias (6,11,12).

Recent meta-analyses have also revealed that there seems to be substantial variability in reported frequencies of variations among studies, suggesting that regional differences may exist (13). Therefore, reporting of variations from around the world is important for clinical practice.

We studied 60 brachial plexuses in Sri Lankan cadavers and detected 25 variations (41.6%). We aimed to add to the already published data on variations in the brachial plexus. While reporting several commonly described variations, we also report 3 rare variants that have not been reported before to the best of our knowledge.

In a recent study by Patel and Smith (2023) conducted in USA, they report that only 40% of the plexuses included in their study had the classical M pattern and all others showed different variations (60%) (14). These values are consistent with another recent study by Han et al (2024) conducted in China, who report a prevalence of 66% (15). This is rather a high value compared to our observations and some other earlier studies conducted in Iran and the Cech republic (6, 13). We are aware that under reporting may have occurred since medical students were involved in the process. However, due to regional variation in prevalence and differences in reporting styles between studies make it difficult to come to a conclusion.

The pre or postfixed brachial plexus are a variation at the root level that is commonly reported. Prefixed plexuses have a component of the C4 nerve root, while post fixed ones have a contribution from T2 nerve root. The overall prevalence of the prefixed and postfixed brachial plexus is reported to be around 9 - 11% and 1 – 3 %, respectively (8, 12, 14). We report similar values for both types (11.6% and 1.6%). Furthermore, it is reported that most of the variations occur unilaterally and almost exclusively on the left side. This was true in our study where the root variations were unilateral and on the left side in all 8 cases (12).

It is reported that the classical arrangement of trunks occurs in approximately 84% of cases and that of divisions in 96% of cases (5). We did not encounter any variations in the trunks or the divisions in our sample. However, Hans et al reports 8.5% trunk anomalies and 2.1%

variations in the divisions (15). Patel and Smith (2023) also report few such variations at these levels (14). Further careful studies maybe required to find such variations in the Sri Lankan populations. Since dissections were done and initially reported by medical students there can be under reporting, and this is a limitation of our study. Even though we instructed students to report any unusual features to their demonstrators or lecturers it may not have occurred. Future studies where finer dissections are carried out by the instructors are necessary.

Variations resulting in nerve branches piercing the scalene muscles are commonly reported and are associated with a higher risk of thoracic outlet syndrome symptoms (14 - 17). We observed one unilateral long thoracic nerve piercing the scalenus medius muscle, while Emamhadi et al (2016) report 6 in their study on 32 adult cadavers (6).

Connections between the medial and lateral cords high up have been reported in several studies (6,14,15). We observed two such cases where there were connections between the two cords and between the lateral cord and the medial root of the median nerve. A connection between the lateral cord and the medial root of the median nerve has not been reported to date to the best of our knowledge. This kind of variation may cause different symptoms in nerves entrapment and other nerve injuries making clinical diagnosis difficult.

We report a rare variant that has not been reported before where only two cords were present. The posterior cord was present deep to the axillary artery as usual and continued as the radial nerve. However lateral and medial cords could not be identified, and a single cord was found lying anteriorly. This cord gave rise to ulnar, median and musculocutaneous nerves. Further, another rare variant where the medial and lateral cords are combined to form a single cord and ulnar, musculocutaneous and median nerves arise from this cord was also observed. It is not clear how the root is distributed to each nerve and what type of signs and symptoms may have been present if this doner had developed any neurological condition or nerve injury.

The terminal branches of the brachial plexus have been found to be more variable than the trunks and cords, retaining the usual arrangement in approximately 75% of cases (18). We observed slightly higher prevalence of variations with only 65% showing the usual pattern.

The complete absence of the musculocutaneous nerve and a complete takeover of the innervations of the coracobrachialis, the biceps and the brachialis muscles by the median nerve is said to be an unusual variation of the brachial plexus and have been reported before (19, 20). We observed two cadavers with absent musculocutaneous nerve, where the coracobrachialis is supplied by the median nerve.

We observed a case with a communicating branch between the musculocutaneous nerve and median nerve. This was initially reported by Li Minor in 1990 and is known as the type II in his classification. While a median nerve that received communicating branches from

the musculoskeletal nerve might not have dramatic clinical symptoms in a patient without lesions, any damage to the latter could affect the nerve territory of the former (6, 14). In all cases, nerve variants could cause unexpected presentations in cases of lesions, which may result in misdiagnoses (16).

The limitation of this study is that dissections were initially done by medical students and even though we gave them specific instructions that such study was on going and that they must dissect carefully and report variations as soon as they were found, under reporting and not paying attention to structures may have caused us to miss certain variations specially those of the medial and lateral pectoral and cutaneous nerves which are reported in other studies.

We believe that we have reported several common and extremely rare variants and possibly two new variants in our study. We hope that these findings will aid the clinician in making proper diagnoses and avoiding or minimizing iatrogenic injuries while performing surgical procedures.

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