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Original Article

Anatomy Section

Variation in the Formation and Branching Pattern of Brachial Plexus in the Human Foetuses: A Morphometric Cross-sectional Study

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ABSTRACT

Introduction: The brachial plexus is a variable nerve plexus in its formation and branching pattern. Variations in the brachial plexus are not uncommon, and its area of supply and associations with other adjacent anatomical structures require clinical and surgical attention.

Aim: To find out any anatomical variations in the formation and branching pattern of the brachial plexus in human foetuses.

Materials and Methods: A morphometric prospective observational study was conducted from January 2020 to July 2022, on 30 stillborn or Intrauterine Dead (IUD) human foetuses were taken in the study. Gestation age from 28 to 40 weeks of gestation were included in the study, while those with gross anomalies or morphological anomalies of the cranium and vertebral column were excluded. The dissection includes vertical midline incision of the skin from the external occipital protuberance to the lower limit of the thoracic vertebra (T12). The skin was cut in the midline and reflected laterally. All superficial and deep muscles of the neck were dissect out to clear the cervical and thoracic parts of the vertebral column. The vertebral column was cut and opened to visualise the spinal cord and spinal nerves. Based on gestational age, the foetuses were divided into three groups: four in the first group (28-31 weeks), twelve in the second group (32-35 weeks), and fourteen in the third group (36-40 weeks) were divided for descriptive purposes. The gender of foetuses was determined based on the external genitalia.

Results: A total of 60 brachial plexuses were dissected, of which 49 (81.66%) had the usual anatomical formation of the trunks: the upper trunk formed by C5 and C6 roots, the middle trunk by the C7 root, and the lower trunk by the C8 and T1 roots. Eleven (18.34%) plexuses presented variations in trunk formation. Specifically, 8 (13.3%) brachial plexuses were of the prefix type, where the upper trunk was formed by the C5 and C6 roots with an additional contribution from the C4 root; there was inter-branch communication between C6 and C7 in one (1.7%) case; the middle and lower trunks united by C7, C8, and T1 roots formed the lower trunk in another (1.7%) case, and finally, one (1.7%) case exhibited the post-fix type.

Conclusion: In this study, out of the 30 foetuses examined, 11 showed variations, which is not uncommon. The prefix type of brachial plexus is quite common among the possible variations, although anatomists and neurosurgeons cannot ignore the possibility of other variations, like post-fix type or communication between the roots of the brachial plexuses.

Keywords: Cord, Fetus, Postfix, Prefix, Root

INTRODUCTION

The brachial plexus is a neural network that delivers motor, sensory, and sympathetic fibers to the upper extremities. It runs from the posterior triangle of the neck to the axilla. The complex process of anastomotic connection formation in the brachial plexus gives rise to nerves of wide cutaneous and motor supply, which are divided and joined in successive orders. This complexity explains the many differences that might be noticeable in particular situations. In newborns, Neonatal Brachial Plexus Palsy (NBPP) happens due to the over-stretching of the brachial plexus during delivery [1].

Damage to the brachial plexus results in sensorimotor loss and injuries such as brachial plexus neuropraxia, brachial plexus rupture, brachial plexus neuroma, and brachial neuritis. It can result into contractures to the bones and joints of the upper limb in cases of incomplete recovery. However, the majority of the time, patients heal on their own [2]. The ratio of Obstetric Brachial Paralysis (OBP) occurs in approximately 1 to 3 cases per 1,000 live births [3]. The injuries that affect the upper trunk of the plexus (C5-C6), where there is a meeting point of six nerves, are called Erb-Duchenne palsy. The paralysis involving the lower trunk (C8-T1) is called Klumpke palsy. Moreover, there may be complete paralysis, in which there is avulsion of all nerve roots [4].

The brachial plexus is a very complex anatomical structure due to the frequent differences in the organisation and distribution of its branches. Medical issues associated with these variances include anaesthesia blocks, surgical techniques, diagnosing nerve compressions brought on by trauma or tumours, experiencing inexplicable clinical symptoms, and the potential for irreversible damage to these structures [5]. The authors have published two sections of this work. In the first section, the authors measured the length of the spinal cord and its level of termination in third-trimester gestational age foetuses. In the second section, they measured the length of the filum terminale in the same foetuses [6,7]. The authors concluded that the mean length of the spinal cord was 14.74±1.45 cm, with a range from a minimum of 10.95 cm to a maximum of 16.60 cm. The majority of spinal cords terminate at the L2 level, followed by the L3 and L4 levels [6].

In another study, the length of the filum terminale in third-trimester foetuses was measured, and it was concluded that the association between gestational age (weeks), length of filum terminale, and length of spinal cord among all foetuses, as well as between males and females separately, was statistically significant [7]. Therefore, the goal of the current study was to identify every potential anatomical variation in the development and branching pattern of the brachial plexus in human foetuses.

MATERIALS AND METHODS

This study was a morphological cross-sectional study conducted on a total of 30 foetuses from January 2020 to July 2022 in the Department of Anatomy, Uttar Pradesh University of Medical Science, Saifai, Uttar Pradesh, India. The IUD foetuses were collected from the anatomy museum and obstetrics and gynaecology departments of the same institute. The University Ethical Committee gave the necessary ethical clearance for the foetus collection (Ref. no 665/UPUMS/DEAN/2019-20/EC no 2019/20 dated 08-07-2019). Informed parental consent was taken before collecting the foetuses for the study.

Procedure

The foetuses were divided into 3 groups based on gestational age for descriptive purposes-:

First group-: 4 foetuses of 28-31 weeks. **Second group-:** 12 foetuses of 32-35 weeks. **Third group-:** 14 foetuses of 36-40 weeks. The gender of the foetuses was ascertained by looking at their external genitalia. The age of the foetus was determined by ultrasonographic reports and by measuring crown-rump length (CR length), foot length, femur length, Bi-parietal Diameter (BPD), Antero-Posterior Diameter (APD), and Abdominal Circumference (AC).

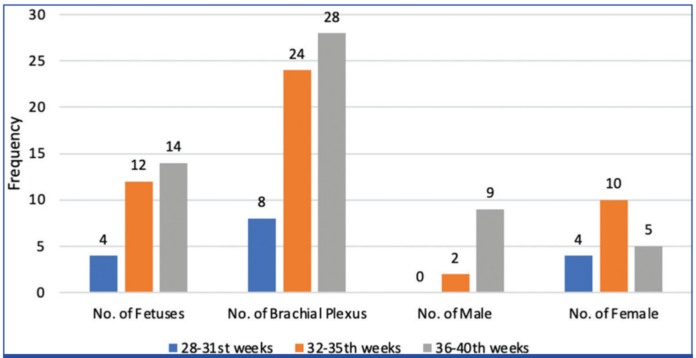
Foetuses with gestations ranging from 28 to 40 weeks were included in this study; however, foetuses with gross anomalies or morphological anomalies of the skull or spinal column were excluded from the study. The dissection involved a vertical midline incision of the skin from the external occipital protuberance upto the twelfth thoracic vertebra (T12). A midline cut was made in the skin and reflecting laterally. In order to open the cervical and thoracic portions of the spinal column, all of the neck's superficial and deep muscles were severed and dissected. The cervical and thoracic vertebrae were cleared out individually. A scalpel and scissors were used to cut the lamina and transverse processes. A single researcher dissected the brachial plexus of every foetus in order to standardise the process. The brachial plexus can be divided into prefix type or postfix type depending on the contribution from the C4 nerve rootlet or T2 nerve rootlet, respectively [8].

STATISTICAL ANALYSIS

The data were managed on a Microsoft excel spreadsheet. Statistical analysis was done by using the Statistical Package for the Social Sciences (SPSS 29.0) program. The data were expressed in the form of frequency in percentage.

RESULTS

Out of a total of 30 studied foetuses, 19 foetuses (63.3%) were female, and rest 11 were male (36.7%) gender, in which 14 foetuses (46.7%) belonged to the third group, followed by 12 in the second group (40.0%), and only four in the first group (13.3%) [Table/Fig-1].



[Table/Fig-1]: Gestational age groupwise and genderwise distributions of studied foetuses.

A total of 60 brachial plexuses were dissected, out of which 49 (81.66%) had the usual anatomical formation of the trunks. The upper trunk was formed by C5 and C6 roots, the middle trunk by the C7 root, and the lower trunk by the C8 and T1 roots. While 11 (18.34%) plexuses presented variations in the trunk formation [Table/Fig-2].

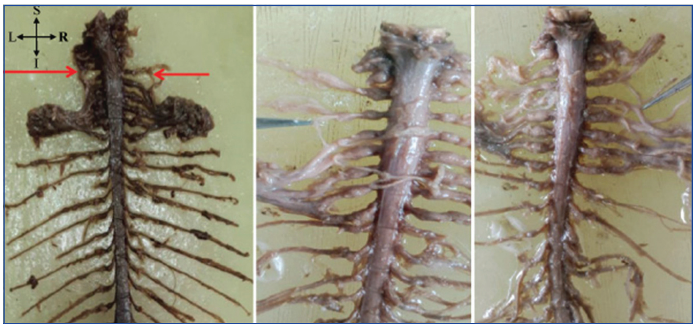
In this study, the authors noted that five foetuses showed variations in the brachial plexus in the 36th to 40th weeks gestational age group, in which three pre-fix types, one post-fix type, and one intercommunication between the C6 and C7 levels. While in 32-35th weeks gestational age group, one foetus had bilateral variation, one had a left-side pre-fix type, and one showed a middle and lower trunk fused type of variation in the brachial plexus. However, in the 28th to 31st weeks gestational age group, only one foetus showed bilateral pre-fix type variation [Table/Fig-3,4].

Gender	Side of the body	No. of variation in brachial plexus	
Female	Left	1	Pre-fix type
		1	Middle & lower trunk fused
	Right	1	Pre-fix type
		1	Intercommunication between C6 &C7
	Both side	4 (2 left + 2 right)	Pre-fix type
Male	Left	2	Pre-fix type
	Right	1	Post-fix
	Both side	0	--
Total		11	

[Table/Fig-2]: The distribution of plexuses according to gender and the side of the body.

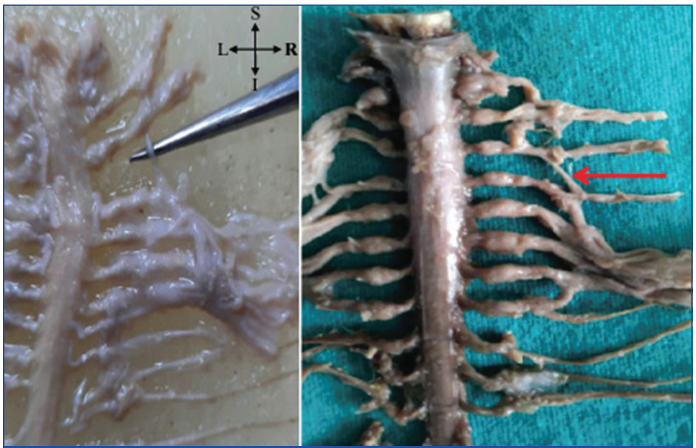
Gestational age	Side of the body	No. of variation in brachial plexus	
28-31st weeks	Right-side	0	--
	Left-side	0	--
	Both side	2 (1 Left +1 Right)	Pre-fix Type
32-35th weeks	Right-side	0	--
	Left-side	1	Pre-fix Type
		1	Middle & lower trunk fused
	Both side	2 (1 left +1 right)	Pre-fix Type
36-40th weeks	Right-side	1	Intercommunication between C6 &C7
		1	Pre-fix Type
		1	Post-fix Type
	Left-side	2	Pre-fix Type
	Both side	0	--
Total		11	

[Table/Fig-3]: The distribution of plexuses according to gestational age and the side of the body.

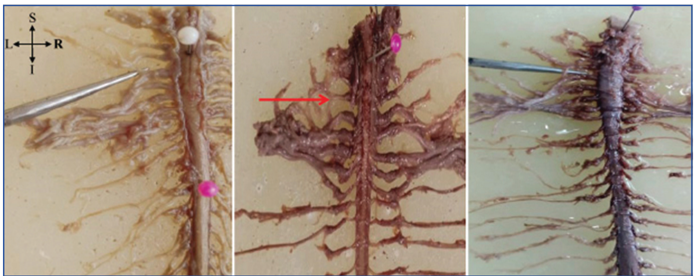


[Table/Fig-4]: Bilateral pre-fix type brachial plexus (pointed with tip of forcep and red arrow).

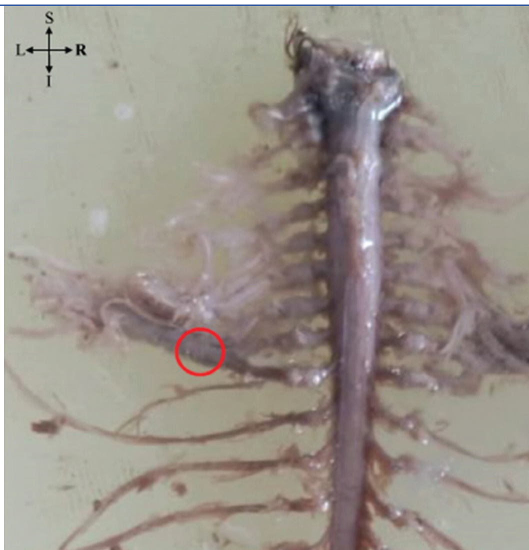
In eight foetuses (13.3%), the brachial plexuses were of the pre-fix type, where the upper trunk was formed by C5 and C6 roots, contributed by the C4 root additionally, with inter-branch communication between C6 and C7 in one (1.7%). The middle and lower trunk united by the C7, C8, and T1 roots formed the lower trunk in another (1.7%), and lastly, the post-fix type in one (1.7%). The present study noted that in female foetuses, six showed the pre-fix type [Table/Fig-5,6], one foetus had a middle and lower trunk fused [Table/Fig-7], and one foetus showed intercommunication between the C6 and C7 levels [Table/Fig-8]. While in male foetuses, two had the pre-fix type, and one had the post-fix type of variation in the brachial plexus [Table/Fig-9].



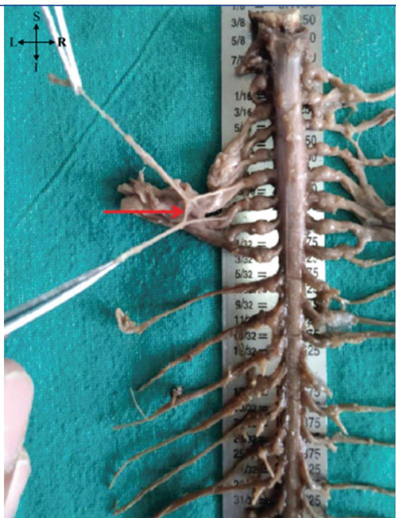
[Table/Fig-5]: Unilateral right-side pre-fix type brachial plexus (pointed with tip of forcep and red arrow).



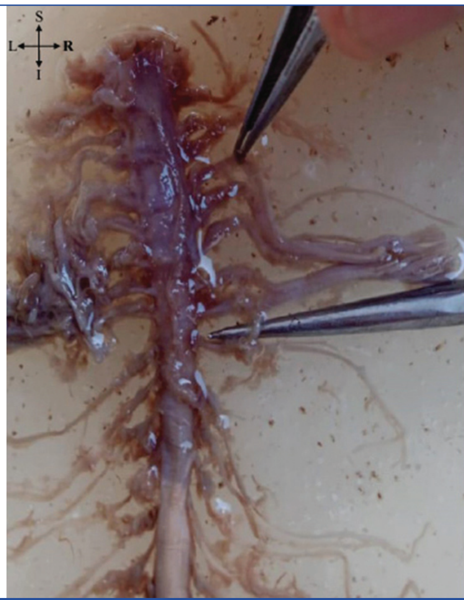
[Table/Fig-6]: Unilateral left-side pre-fix type brachial plexus (pointed with tip of forcep and red arrow).



[Table/Fig-7]: Fig with red circle showing union of middle and lower trunk.



[Table/Fig-8]: Left-side pre-fix type brachial plexus with intercommunication between C6 & C7 (pointed with red arrow).



[Table/Fig-9]: Unilateral right-side post-fix type brachial plexus (pointed with tip of lower forcep).

DISCUSSION

Part of the brachial plexus is located in the axilla and neck, making it a significant and sizable plexus. Small supports may emanate from the ventral rami of C4 or T2, even though the plexus is generally designed from the ventral rami of C5-C8 and T1. Unusual formations in the development of trunks, divisions, or cords may cause variations in the plexus layout. The brachial plexus exhibits more frequent alterations in its gross form, which occur at points where its components separate or converge. Avoid incorrect branch dispersal, which frequently came with no changes made to the branch's segmental foundation [9]. The anterior ventral roots of the brachial plexus have different union types, although being almost the same size. The middle trunk is formed by a single C7 root, the lower trunk is formed by the union of the C8 and T1 roots, and the upper trunk is formed by the union of the C5 and C6 roots along the lateral border of the middle scalene muscle [10,11].

Risk factors include dystocia, a condition where the foetus's shoulder becomes jammed against the mother's pubic symphysis, potentially causing strain along the upper section of the foetal brachial plexus [12]. The newborn's weight may also be related to this dystocia [13]. There are a number of additional factors that could contribute to NBPP, including obesity, idiopathic causes, pelvic births with the newborn's cervical hyperextension, macrosomic foetuses, and gestational or pre-gestational diabetes [14]. Perinatal asphyxia causes hypotonia, predisposing the plexus to injuries from stretching [2]. It is unclear if the use of forceps is a risk, and whether Caesarean sections are safer, although this mode of delivery does not completely remove risk of NBPP [13,15].

The plexus may sustain primary damage from trauma or illnesses that affect the axillary contents (e.g., abnormal lymph nodes or axillary fibroses) or secondary damage from adjacent structures like bone, muscle, breast, or lung. Primary damage can also result from traction injuries, internal jugular vein cannulation, car or motorcycle accidents, gunshot wounds, and occult fractures of the first or second ribs [16].

Physical examination findings, such as the affected limb's painful and passive movement, lack of active movement, loss of flexor pattern, flaccid paralysis, and skin trophic alterations, are used to make the diagnosis [17]. Heise CO et al., and others conducted electroneuromyography tests in unilateral obstetric brachial plexopathy in infants and found it to be a very useful prognostic tool for determining surgical indications [3,18].

The present study noted that 11 (18.33%) plexuses presented variations in trunk formation. Khan GA et al., reported variations in trunk formation in 23.4% of plexuses [19]. Aggarwal A reported connections from C4 to C5 (30.8%) [6]. These variations were all in the prefix type of brachial plexuses. They did not observe any connections from T2 to T1. Aragão JA et al., reported variations in trunk formation of the brachial plexus occurred in 7.50% of cases [20]. In a study conducted by Uysal II et al., in 1.0% of cases, the upper trunk was formed by C4 and C5 [16].

According to the present analysis, one (1.7%) showed interbranch contact between C6 and C7. In the same foetus, on the left and right-sides, the anterior ventral roots of C5, C6, and C7 united to produce the upper trunk. Several authors have also discovered this variant [20,21]. According to Shetty SD et al., this sort of creation of the brachial plexus's upper trunk by the C5, C6, and C7 roots is considered extremely unusual and is frequently linked to the physical lack of the middle trunk or the union of the upper and middle trunks [22]. There were variations observed between two and four trunks. Two trunks, namely the upper trunk formed by the fusion of C5, C6, and C7 roots and the lower trunk formed by C8 and T1, were observed by Prakash S et al., Shetty SD et al., and Nayak S et al., [21-23].

This study noted that eleven (18.34%) plexuses presented variations in trunk formation. In eight foetuses (13.3%), the brachial plexuses were of the pre-fix type, where the upper trunk was formed by the C5 & C6 roots, with contributions from the C4 root additionally. Inter-branch communication between C6 and C7 was observed in one (1.7%); the middle & lower trunk united by the C7, C8, and T1 roots formed the lower trunk in another (1.7%), and lastly, the post-fix type was observed in one (1.7%). Similar to these findings, Aragão JA et al., reported that in 2.5% of cases, there was the formation of four trunks on the left-side of the foetus, which were cranio-caudally numbered as I-IV [20]. The second, third, and fourth trunks were a continuation of the C7, C8, and T1 roots, respectively. A similar finding was also described by Chaudhary P et al., although differing with regard to the divisions for the formation of lateral, medial, and the posterior cords [24].

Vascular anomalies frequently accompany variations in the brachial plexus. The axillary artery supplies blood to the human upper extremities and is linked to the division of the cords. Originating from the seventh segmental artery during development, this artery often travels between the medial and lateral cords. It may, however, pass inferior to the medial chord if it comes from the ninth segmental artery. Therefore, the presence of an improperly situated axillary artery would modify the division of the cords if it had abnormal links to the brachial plexus [9]. In this study, no apparent vascular variations were demonstrated in the path of the axillary artery.

In cases such as surgical exploration of the arm and axilla, correction of cervical rib (which can cause thoracic outlet syndrome), anaesthetic block via cervical or axillary approach, internal fixation of humeral fracture from a common anterior approach, and even during orthopaedic and neurosurgical procedures on the cervical spine and prosthetic implant placements, a thorough understanding of variations in the brachial plexus is mandatory [5].

Lesions in the brachial plexus may result from trauma, nerve compression, shoulder dislocation, iatrogenic injury, traumatic birth in babies, or improper patient placement during anaesthesia [7]. The axillary artery, its branches, and the brachial plexus have complex and intimate neurovascular relationships. It is well recognised that angiographic examinations can be used to identify the normal and abnormal locations of arteries and veins prior to surgery; however, these studies are unable to identify abnormalities related to nerves. Such variations are only presented to the surgeon during the surgical procedure [5]. The knowledge of these variations can help anatomists, neurologists, traumatologists, and surgeons.

Damage may result from compression or stretching (neuropraxia), rupture of the nerve (neurotmesis), avulsion of the nerve roots from the spinal cord, or a neuroma formed by scar tissue during the regeneration of an injured nerve. All of these result in varied degrees of paresis, paralysis, or paraesthesia, which can impair movement and muscle function, hinder activities of the affected limb, and alter physical appearance, as in the cases of Klumpke's palsy and Erb-Duchenne's palsy, among others. This justifies the correct emphasis on the significance of using skilled medical professionals to treat brachial plexus injuries [5].

The brachial plexus might be more susceptible to damage from treatments like radical neck dissections, surgical interventions for the treatment of breast cancer, and nerve problems from anaesthetic injections if it has anatomical changes. Therefore, a wide range of specialists, including anatomists, radiologists, anaesthesiologists, neurosurgeons, and orthopaedic surgeons, find it extremely helpful to understand changes in the creation of the brachial plexus [25].

Limitation(s)

This study was conducted at a single center, and foetuses were collected from the anatomy museum, with some also collected from the obstetrics and gynaecology operation theatre, so the cause of death of the majority of foetuses cannot be ascertained. In this study, the authors enrolled foetuses in the 28-40 weeks gestational age group. This study lacks information about foetuses in the <28 weeks gestational age group.

CONCLUSION(S)

Morphological knowledge of variations in brachial plexus formation in the cervical and axillary regions is imperative for neurosurgeons who accomplish surgical procedures in this area. Anatomic variations are clinically important, but many have been unsatisfactorily described or documented. An awareness of the complete arrangement facilitates localisation, which is important for diagnosis and formulation of a suitable treatment plan. The uncommon anatomic variations of the brachial plexus, which can lead to injuries due to neural complications with anaesthetic injections or surgical interventions, must be constantly advised.

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