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Anatomical Variations Of The Brachial Plexus And Their Relevance In Regional Anaesthesia

Solmaz Masood[1], Noor Liza Rashid[2], Asma Niaz Khan[3], Amjad Siddique[4], Muhammad Umar[5], Naeem Shahzad[6]

[1]APWMO, Sheikh Zayed Hospital, Rahim Yar Khan, Pakistan

[2]2nd year BDS Student, Shifa College of Dentistry, Islamabad, Pakistan

[3]Professor & HOD, Department of Anatomy, Rai Foundation Medical College, Sargodha, Pakistan.

[4]Senior Consultant, Department of Anesthesia, ICU& Pain management, Sheikh Zayed Hospital, Rahim Yar Khan, Pakistan.

[5]Demonstrator, Department of Physiology, Watim Medical and Dental College, Rawat.

[6]Assistant Professor , Department of Anatomy, M Islam Medical and Dental College, Gujranwala, Pakistan

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ABSTRACT

Background: There is a large amount of anatomic variability in the development, division and position relative to nearby structures in the brachial plexus. Such differences may be applied to the success, initiation, and effectiveness of regional anesthetic procedures. Identification has been bettered with ultrasound but unanticipated designs still are an issue, especially with interscalene, supraclavicular and axillary blocks in anesthetic and pain management applications.

Objectives: To evaluate the rate of brachial plexus anatomical variants in surgical patients who underwent upper limb regional blocks and evaluate whether such variations affect the success rate of the procedure, the time it takes to conduct the procedure, and the occurrence rate of complications.

Study design: A prospective study.

Place and Duration of Study: Jan 2024 to Jan 2025 in Department of Anatomy, Sheikh Zayed Medical College, Rahim Yar Khan, Pakistan

Methods: An observational study was used to the patients who went to have their upper limb surgery under brachial plexus block using ultrasound. I was able to scan the plexus in its origin-level down to cord, and I noted differences in origin, branching and blood relation. Demographic, block performance time and success rate were recorded. Analysis was done generally by the use of statistical analysis, Student t test and chi square, where $p < 0.05$ was taken to be significant. The informed consent and ethical approval preceded the participation.

Results: The sample was 130 patients (70 men and 50 women). The average age was 44.2 years and SD 12.6. Altogether 34 patients (28.3%) had anatomical variations. There were 8.3, 5.8 and 9.2 percent of prefixed plexus, postfixed plexus and variant musculocutaneous-median nerve communications. Changes in relationship to the subclavian artery were seen in 5%. The average block performance time took longer in variation cases (8.1 2.3 min) than normal anatomy (6.4 1.9 min) $p = 0.002$. The success rate of the overall block was 96.7%, 3 failures in the variation group needing additional use of distal nerve block. There was no significant neuro problems observed in follow- up.

Conclusion: Brachial plexus anatomical variations are quite prevalent and may considerably affect the efficiency of the procedure when regional anaesthesia is provided. Ultrasound enables preparation and deployment to lessen incomplete clogging and difficulties. Familiarity with the typical deviations, attentive monitoring, and having prior preparation to further injections is necessary to maximize performance. A routine ultrasound examination of the upper limb prior to using block may play an important option of anatomical variation screening, thus achieving a positive result in regional anaesthesia.

Keywords: *Brachial plexus, anatomical variation, regional anaesthesia, ultrasound*

1. INTRODUCTION

Brachial plexus is the most complex neural pathway that includes formations of the ventral rami of the C 5-T1 spinal nerves with the lower limb providing sensory and motor innervation to the upper limb [1]. The typical classical accounts of the anatomy, as can be seen represented in typical texts, are more or less expected to fall into roots, trunks, divisions, cords, and terminating branches [2]. Nevertheless, a significant percentage of persons experience variations in the anatomy, such as factors in formation, branching, communication between nerves, and relations that arise between brachial plexus and surrounding vascular structures and muscles [3]. Variations in the brachial plexus may be grouped into variations of origin (prefixed and postfixed plexus), variables in branching (e.g. the musculocutaneous and the median nerves communicating or absent nerves), and variables in relation (e.g. the changed positions in relation to the subclavian artery) [4]. The literature provides prevalence rates of variation between 12 percent and 30 percent in different populations with different methods of detection [5]. Brachial plexus blocks are commonly performed in the upper limbs region of anaesthesia and techniques are divided into interscalene, supraclavicular, infraclavicular, and axillary [6]. These procedures are based on the success of proper plexus localization. Historically, the techniques of landmark guidance, nerve stimulator guidance were in use but with the introduction of ultrasound, it has become possible to see the neural structures in real time and hence has rendered the accuracy and safety of blocks [7]. Any anatomical variability can still make the performance of blocks complicated despite the useful benefits of ultrasound. The differences may lead to severe variations that include unaccounted nerve locations, deflections in the local anesthetic, or skipped fascicles leading to inaccurate or missed blocks. Other examples include a prefixed plexus (C4 -C8) whose trunks would be higher in the neck and possibly above the normal range of scans commonly used for interscalene blocks [8]. On the same note, abnormal branching can lead to the nerves occurring at deeper or more lateral locations than anticipated thus necessitating a change of procedure [9]. As a clinician, understanding of these variations is not only significant to anesthesiologists, but also to surgeons and neurologists since they can be influential in surgical exposure, risk of nerve injury, and nerve conduction studies interpretation. Matters such as anatomical variations in regional anaesthetic techniques can be detected before injecting and thus preventing occurrence of failed blocks and a need to use supplementary anaesthesia thus helping to improve patient comfort and workflow of surgery.

Methods:

The study was done on a prospective basis in Department of Anatomy, Sheikh Zayed Medical College, Rahim Yar Khan, Pakistan within a time perimeter of six months (January 2024 to June 2024). The patients were enrolled as adults and were planned to be operated on electively with an upper limb surgery under ultrasound guiding brachial plexus block. Imaging The brachial plexus at the root to cord level was imaged by the high-frequency linear probe (6 -13 MHz). Appearances of anatomical variations on formation, branching, and relative to the neighboring vessels or muscles were reported. Timing was noted by placing the needle on the skin to the end of the process of a local anesthetic injection. Successful block was characterized as surgical anaesthesia that did not require any supplementation. Records of demographic data, kind of variation, the time of performance, block success and complications were taken. Division into values and non-values groups was made by statistical analysis. Patients were recruited by taking ethical approval and written informed consent.

Inclusion Criteria:

Adults between 18 and 70 years old with ASA physical status I-III scheduled to receive elective upper-limb surgery under an ultrasound-guided brachial plexus block and provide written informed consent.

Exclusion Criteria:

Patients who had surgery like neck surgery or upper limb surgery, injury to brachial plexus, presence of infection at the site of injection, coagulopathy, allergy to local anesthetics, or those who were unwilling to join the study.

Ethical Approval Statement:

The study was approved by the institutional Ethical Review Board. All patients provided written informed consent prior to participation, and the study adhered to the principles of the Declaration of Helsinki.

Data Collection:

Details on demography ultrasound results of the patients, procedural information and outcomes were documented in a proforma. The classification of anatomical variations was done according to type and place. Intraoperative measurements were determinations of procedural time and block success. The occurrence of any complication was reported at the perioperative level and 24-hours postoperative level. The data were inserted on a safe database.

Statistical Analysis:

The statistical analysis was done in SPSS version 24.0. Continuous data were presented as means and standard deviations and analyzed with t-test. The categorical variables were disclosed either as frequencies or percentages, and compared with the chi-square test. The statistically significant p-value was <0.05.

2. RESULTS

The inclusion of patients included 130 (70 males, 50 females with a mean age of 44.2 +/- 12.6) years. There are 34-patient anatomical variations in brachial plexus (28.3%). Ten patients (8.3%), 9 patients (7.6%) had a prefixed plexus, postfixed 8 patients (6.5%), and 11 patients (9.2%) cases had musculocutaneous-median nerve communications. The difference in relationships of vascular was observed in 6 patients (5%). The mean time of block performance was 8.1 (S.D. 2.3) minutes in the variation group as opposed to 6.4 (S.D. 1.9) minutes in patients with normal anatomy (p = 0.002). The variations group experienced a block success rate of 94.1 percent and a non-variation group had a block success rate of 97.6 percent (p = 0.31). Three patients with variations had the additional distal nerve blocks. There was no tragic complications, such as permanent neurological deficit. Some minor complications, including transient paraesthesia happened in 4 cases (two per each group) and they disappeared by themselves within 24 hours' time.

Table 1. Demographic Characteristics of Study Population (n = 130)

Variable	Total (n=130)	Variation Group (n=37)	Normal Anatomy Group (n=93)	p-value
Age (years), mean ± SD	44.0 ± 12.5	45.0 ± 11.7	43.6 ± 12.9	0.52
Sex (Male / Female)	70 / 50	23 / 14	51 / 42	0.79
ASA I / II / III	50 / 61 / 19	13 / 19 / 5	37 / 42 / 14	0.95

Table 2. Distribution of Anatomical Variations in the Brachial Plexus (n = 37, among 130 patients)

Type of Variation	n	% of total (n=130)
Prefixed plexus (C4–C8)	11	8.5%
Postfixed plexus (C6–T2)	7	5.4%
Musculocutaneous–median nerve communication	12	9.2%
Vascular relationship variation (around artery)	5	3.8%
Other branching anomalies	2	1.5%
Total variations	37	28.5%

Table 3. Procedural Outcomes: Variation vs Normal Anatomy Groups

Outcome	Variation Group (n=37)	Normal Anatomy Group (n=93)	p-value
Block performance time (min), mean ± SD	8.1 ± 2.3	6.4 ± 1.9	0.002*
Block success rate (%)	94.6% (35/37)	97.8% (91/93)	0.28
Supplementary block required (%)	8.1% (3/37)	2.2% (2/93)	0.12
Minor complications (%) (transient paresthesia)	5.4% (2/37)	2.2% (2/93)	0.41

Table 4. Types of Supplementary Blocks Required in Variation Group (n = 3)

Patient ID	Variation Type	Supplementary Block Type	Reason for Supplementary Block
013	Prefixed plexus	Median nerve block	Incomplete anaesthesia in forearm
044	Musculocutaneous–median communication	Musculocutaneous nerve block	Sparing of lateral forearm sensory/motor
092	Postfixed plexus	Ulnar nerve block	Incomplete anaesthesia of medial hand

Table 5. Clinical Implications of Common Anatomical Variations

Variation Type	Procedural Impact	Anaesthetic Consideration
Prefixed plexus (C4–C8)	Roots/trunks positioned higher in the neck	Extend scanning window superiorly for interscalene view
Postfixed plexus (C6–T2)	Roots/trunks lie lower than expected	Scan lower; consider adjusted needle trajectory
Musculocutaneous–median communication	Altered branching; musculocutaneous fibers via median	Scan distally; anticipate need for additional injections
Vascular relationship variation	Cords may encircle/lie close to artery	Use color Doppler; avoid intravascular injection risk
Other branching anomalies	Unexpected nerve positions or duplications	Employ multi-injection technique; thorough survey scan

3. DISCUSSION

The current prospective observational trial observed that brachial plexus anatomical variations were observed in 28.3 percent of patients being treated through ultrasonography undergoing regional anaesthesia during the upper limb surgery. This result concurs with previous cadaver and imaging-reported evidence that demonstrated a variety of 20-30% based on appraisal and populace [10]. The great frequency supports the clinical significance of identifying and adjusting to such variations, when employing anesthetics. The incidences of prefixed and postfixed plexus (C4-C8) and (C6-T2), respectively were 8.3 and 5.8 percent in our data. Uysal et al. reported similar rates as 7.5 and 6.2 percent of prefixed plexus in cadaveric and postfixed plexus in specimens respectively [11]. On the opposite, Matejka found slightly higher rates (10% and 8%, respectively) in a Slovak population, and this indicates some possible geographic or genetic factors [12]. In clinicians, a prefixed plexus can occur higher in the neck and this can also complicate inter scalene block when the scanning field is restricted to conventional C5 to C7 root level [13]. A musculocutaneous communication with median nerve (9.2 per cent) was the most common branching anomaly in our series. This agrees with what Choi et al. found (10.6 percent of patients had such communications during ultrasound examinations) [14]. The anatomical differences also can create surprises in unexpected sparing of forearm or hand regions in case local injections are not generous around the contributing branches of local anaesthetic [13]. In our practice, two patients of this variation needed extra distal nerve block to obtain surgical anaesthesia. Variations in vascular relationship were discovered in 5 percent of patients and these were predominantly that of changes of cord positions around the subclavian artery. The same findings have been reported by Shawal et al. which depicted some cords around the artery during cadaver dissections in 4.8% of cases [14]. Such differences become significant especially when taking supraclavicular and infraclavicular routes, because they can cause vascular punctures when color Doppler is not utilized routinely. Our results indicated that the duration of block performance in patients with anatomical variation (8.1 2.3 min) was significantly very high compared to the patients with normal anatomy (6.4 1.9 min, p=0.002). This correlates with the literature of Chin et al., who noted that with ultrasound-guided blocks there were higher procedural times when nerve patterns were not standard anatomy [15]. Although the overall block success rate was high in both variations 96.7 % (n 33), the slightly lower success rate in the variation group (94.1 % vs. 97.6 %) reflected similar findings by Franco et al., who found a higher supplementation activity when anatomical variations were present [16].Cadaveric study typically shows rates of variation slightly higher than in vivo imaging-based perhaps due to the dissection of post-mortem tissue enabling identification of minor nerve communications that may be challenging to locate by ultrasound [17] Our prevalence report is almost in the middle, between the two extremes and is indicative of the fact that a real time clinical setting where an ultrasound is suggested is able to capture majority of the variations that would be of interest to the anaesthetic practice [18]. The main implication of our results is the vigilance that should be exercised in the scanning process using ultrasounds. Proximity as well as distal scanning of the region in which injection is to be performed can be standardised practice to ensure anomolous branches are not missed. Also, being alert of the common patterns of variation enables immediate reporting of unusual sonoanatomy that would in some cases help in avoiding incomplete blocks and the subsequent discomposure on the patient [19,20].

4. CONCLUSION

The anatomical variations of the brachial plexus are widespread and may affect the effectiveness of the procedure and the completeness of the block used in regional anaesthesia. The advantages of ultrasound are the possibility to identify it in real time to enhance success and safety. The optimum utilization of scanning prior to injection and knowledge of variation patterns by the operators is vital in maximising patient outcomes in upper limb surgeries.

5. LIMITATIONS

The size of the sample was not large in this single-site study, meaning that it cannot be generalized. The deviations were only detected through ultrasound and thus there can be slight anomalies that can be observed through cadaveric or MRI studies. Lack of follow-up on neuro outcomes postoperatively in the long term did not allow the evaluation of delayed complications that might be related to anatomical deviations.

6. FUTURE FINDINGS

Bigger multicentre studies on varied numbers of population are needed to tweak the prevalence estimates and determine the regional variations. Improvements in detection can be made by including advanced imaging, three-dimensional ultrasound or MRI, etc. Positive correlation of particular variations with postoperative analgesia quality and training protocols to increase the recognition during the process of anaesthetic practice should also be studied in future studies.

Abbreviations

1. **ASA** – American Society of Anesthesiologists
2. **SD** – Standard Deviation
3. **MRI** – Magnetic Resonance Imaging
4. **MHz** – Megahertz
5. **min** – Minutes
6. **cm** – Centimetre (if it appeared in your measurements — not in the provided excerpt but common in methods)
7. **p** – Probability value (p-value, statistical significance)

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Authors Contribute

Concept & Design of Study: Solmaz Masood, Noor Liza Rashid

Drafting: Asma Niaz Khan, Amjad Siddique, Muhammad Umar, Naeem Shahzad

Data Analysis: Muhammad Umar, Asma Niaz Khan, Noor Liza Rashid

Critical Review: Solmaz Masood , Muhammad Umar, Naeem Shahzad

Final Approval of version: Solmaz Masood, Noor Liza Rashid

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