Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/d86ysr08

ANATOMICAL VARIATIONS OF THE BRACHIAL PLEXUS AND THEIR PHARMACOLOGICAL IMPLICATIONS IN REGIONAL ANESTHESIA: A CLINICAL OBSERVATIONAL STUDY

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ABSTRACT

Background: Understanding anatomical variations of the brachial plexus is essential for effective administration of regional anesthesia. Variations in nerve branching patterns can influence the spread and efficacy of local anesthetic drugs, potentially leading to failed blocks or complications. Pharmacological considerations such as dose adjustment and choice of anesthetic agents must be tailored to the anatomical findings.

Methodology: A total of 100 adult patients undergoing upper limb surgeries requiring brachial plexus block were included in this observational study. Pre-procedural ultrasonography was performed to assess anatomical variations in nerve branching, fascicular arrangement, and surrounding structures. Standardized doses of bupivacaine and lidocaine were administered, and block success rate, onset time, duration of analgesia, and complications were recorded. Data were analyzed using descriptive statistics and chi-square test for associations between anatomical variations and pharmacological outcomes.

Results: Out of 100 patients, 28% demonstrated anatomical variations of the brachial plexus, including atypical branching and aberrant fascicular patterns. These variations were significantly associated with delayed onset of anesthesia ($p < 0.05$) and increased requirement of supplemental doses. Patients with typical anatomy showed higher block success rates (95%) compared to those with variations (78%). No major complications were reported, though minor vascular punctures occurred in 6% of cases.

Conclusion: Anatomical variations of the brachial plexus significantly affect the pharmacological efficacy of regional anesthesia. Incorporating ultrasonographic evaluation prior to block administration enhances drug delivery precision, reduces complications, and optimizes clinical outcomes. A combined anatomical and pharmacological approach is crucial for safe and effective anesthesia practice.

Keywords: Anatomy, Pharmacology, Brachial Plexus, Regional Anesthesia, Ultrasonography

INTRODUCTION

Regional anesthesia of the brachial plexus is one of the most frequently employed techniques for upper limb surgeries.[1] It provides excellent analgesia, minimizes systemic drug exposure, and allows for faster postoperative recovery compared to general anesthesia.[2] The success of brachial plexus blocks, however, largely depends on the clinician's knowledge of the anatomical organization of the plexus and its variations.[3]

The brachial plexus arises from the anterior rami of C5–T1 spinal nerves, forming trunks, divisions, cords, and branches.[4] Despite this classical arrangement, numerous anatomical variations have been reported, including atypical contributions (e.g., from C4 or T2), abnormal branching patterns, and aberrant fascicular arrangements.[5] Such variations may alter the spread of local anesthetics and result in incomplete or failed nerve blocks.

From a pharmacological perspective, the efficacy of local anesthetic drugs such as bupivacaine and lidocaine is influenced by the site of deposition, tissue diffusion, and proximity to target nerves.[6] Anatomical deviations can lead to uneven distribution of the anesthetic solution, requiring higher doses or supplemental injections, thereby increasing the risk of systemic toxicity or complications.[7] Furthermore, delayed onset, shorter duration of analgesia, and inconsistent block quality may occur in patients with atypical anatomy.

With the advent of ultrasonography, anesthesiologists can now visualize the brachial plexus in real-time, detect anatomical variations, and tailor drug administration accordingly.[8] This combined anatomical and pharmacological approach enhances the precision, safety, and effectiveness of regional anesthesia.

This study aimed to observe the prevalence of anatomical variations of the brachial plexus in patients undergoing upper limb surgeries, and to evaluate their pharmacological implications in terms of block success, onset, duration, and complication rates.

METHODOLOGY

A clinical observational study was carried out over a 12-month period in the Department of Anesthesiology, including 100 adult patients aged 18–65 years who were scheduled for elective upper limb surgeries under brachial plexus block. All enrolled patients were classified as ASA physical status I–III and underwent surgeries involving the shoulder, arm, forearm, or hand requiring regional anesthesia. Patients with a history of allergy to local anesthetics, coagulopathy, infection at the injection site, previous brachial plexus surgery, or severe cervical spine deformity were excluded. Pre-procedural ultrasonography was performed in each case to assess brachial plexus anatomy, branching patterns, fascicular arrangement, and adjacent vascular structures. Blocks were administered under ultrasound guidance using standardized volumes of bupivacaine 0.5% (15 ml) and lidocaine 2% (10 ml). The parameters recorded included anatomical findings (typical versus variations), onset time of sensory and motor block, duration of analgesia, success rate (defined as complete block without the need for supplementation), and any complications such as vascular puncture, local anesthetic toxicity, or incomplete block.

Statistical Analysis

Data were analyzed using SPSS v25. Descriptive statistics summarized baseline data. The chi-square test was applied to assess associations between anatomical variations and block outcomes. A p-value < 0.05 was considered statistically significant.

RESULTS

The study included 100 patients with a mean age of 42.8 ± 11.5 years, consisting of 62 males and 38 females. ASA status distribution showed most patients in Class II (45%), followed by Class I (40%) and Class III (15%).

Demographic Data

Parameter	Mean ± SD / n (%)
Age (years)	42.8 ± 11.5
Gender (Male/Female)	62 / 38
ASA I / II / III	40 / 45 / 15

Typical branching was found in 72% of cases, while 28% showed variations, including atypical branching (15%), aberrant fascicular arrangement (10%), and additional contributions from C4/T2 (3%). This highlights a considerable frequency of anatomical diversity.

Anatomical Variations Observed

Anatomical Pattern	n (%)
Typical branching	72 (72%)
Atypical branching	15 (15%)
Aberrant fascicular arrangement	10 (10%)
Additional contributions (C4/T2)	3 (3%)

Patients with typical anatomy had significantly higher block success rates (95% vs. 78%), shorter onset times, and longer analgesia duration compared to those with variations. Supplemental dosing was also more frequently required in patients with variations, indicating a clear impact on block efficacy.

Block Characteristics

Parameter	Typical Anatomy (n=72)	Variations (n=28)	p-value
Block success rate	95% (68/72)	78% (22/28)	<0.05*
Mean onset time (min)	8.5 ± 2.1	12.4 ± 3.3	<0.05*
Duration of analgesia (hours)	6.8 ± 1.5	5.6 ± 1.2	<0.05*
Supplemental dose required	5% (4/72)	32% (9/28)	<0.05*

Minor vascular puncture occurred in 6% of patients, while no cases of local anesthetic toxicity or major neurological complications were reported. This indicates the safety of ultrasound-guided blocks despite anatomical differences.

Complications

Complication	n (%)
Minor vascular puncture	6 (6%)
Local anesthetic toxicity	0 (0%)
Major neurological complications	0 (0%)

*Statistically significant

DISCUSSION

This study demonstrated that 28% of patients exhibited anatomical variations of the brachial plexus, a finding consistent with previously reported ranges of 20–30%. These variations had a significant impact on the pharmacological outcomes of regional anesthesia. Patients with such variations experienced delayed onset of anesthesia, likely due to uneven drug spread or increased distance from nerve fascicles, as well as a reduced block success rate, which often necessitated supplemental dosing. Furthermore, the duration of analgesia was shorter, suggesting less effective anesthetic distribution. These findings highlight the clinical importance of pre-procedural ultrasonography, which allows anesthesiologists to identify anatomical variations, adapt injection techniques, adjust drug dosages, and thereby minimize complications. From a pharmacological perspective, although standardized doses of bupivacaine and lidocaine were used, patients with variations frequently required additional supplementation, raising concerns about potential toxicity if repeated doses are administered without anatomical guidance.

In our study, anatomical variations of the brachial plexus were observed in 28% of patients and were significantly associated with delayed block onset, reduced success rates, and increased supplemental dosing requirements. These findings are consistent with cadaveric and ultrasonographic studies reporting high variability in brachial plexus anatomy, including atypical branching, prefixed or postfixed plexuses, and aberrant fascicular patterns, with prevalence ranging from 20% to 40% in different populations.[9,10] Clinical studies have shown that such variations adversely affect the pharmacological efficacy of local anesthetics by altering drug spread, leading to incomplete or failed blocks.[11,12] The use of ultrasonography has been shown to improve block success, shorten onset time, and reduce complications by allowing real-time visualization of neural and vascular structures.[13,14,15] Thus, a combined anatomical and pharmacological approach incorporating ultrasound is essential to optimize safety and outcomes in regional anesthesia.

CONCLUSION

This study demonstrates that anatomical variations of the brachial plexus are relatively common and have a significant impact on the pharmacological efficacy of regional anesthesia. Patients with such variations experienced delayed onset, shorter duration of analgesia, reduced block success, and higher requirements for supplemental anesthetic doses. Incorporating ultrasonographic evaluation into routine practice allows early identification of these variations, enabling more precise drug delivery and minimizing complications. Therefore, a combined anatomical–pharmacological approach is essential for optimizing the safety, reliability, and effectiveness of brachial plexus blocks in clinical anesthesia.

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