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Comparative Study of Ultrasound-Guided versus Landmark-Based Techniques in Regional Anesthesia

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Abstract

Background: The integration of ultrasound technology in regional anesthesia has transformed procedural approaches, yet comprehensive comparisons with traditional landmark-based techniques remain essential for evidence-based practice.

Methods: This prospective, randomized controlled trial compared ultrasound-guided versus landmark-based techniques for regional anesthesia in 240 patients (120 per group) undergoing upper and lower limb surgery. Primary outcomes included block success rates and complications.

Results: Block success rates were significantly higher in the ultrasound-guided group (95.0% vs 81.7%, $p<0.001$). Procedure duration was shorter with ultrasound guidance (8.4 ± 2.3 vs 12.7 ± 3.6 minutes, $p<0.001$), requiring fewer needle passes (median 1 vs 3, $p<0.001$). Local anesthetic volume requirements were reduced (22.4 ± 3.2 vs 28.6 ± 4.1 mL, $p<0.001$). Complications were significantly lower in the ultrasound group, including vascular puncture (1.7% vs 6.7%, $p=0.032$) and neurological symptoms (1.7% vs 5.8%, $p=0.038$).

Conclusions: Ultrasound guidance significantly improves the success rate and safety profile of regional anesthesia procedures while reducing procedure time and local anesthetic requirements.

Keywords: Regional anesthesia; Ultrasound guidance; Nerve block; Landmark technique; Block success rate; Complications; Local anesthetic; Procedural efficiency

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

Introduction

Regional anesthesia has undergone a remarkable transformation over the past few decades, evolving from a purely landmark-based approach to incorporating advanced imaging technologies that enhance precision and safety [1]. Among these technological advances, ultrasound guidance has emerged as a revolutionary tool in the field of regional anesthesia, offering real-time visualization of anatomical structures, needle trajectory, and local anesthetic spread [2]. This development has sparked considerable interest in comparing traditional landmark-based techniques with ultrasound-guided approaches to determine their relative efficacy, safety profiles, and clinical outcomes.

The practice of regional anesthesia traditionally relied on surface anatomical landmarks, nerve stimulation, and the operator's tactile feedback to locate target nerve structures [3]. While these conventional methods have served the medical community for many decades, they present inherent limitations, including variable success rates, potential complications, and a steep learning curve for practitioners [4]. The landmark-based technique's reliability is particularly challenged in patients with anatomical variations, obesity, or previous surgical interventions that may alter the typical anatomical relationships.

The introduction of ultrasound technology in regional anesthesia practice has provided anesthesiologists with unprecedented visual guidance, potentially addressing many limitations of the traditional approach [5]. Real-time imaging allows practitioners to identify anatomical variations, visualize vascular structures, and ensure precise needle placement, potentially reducing the risk of complications such as intravascular injection or nerve injury [6]. Furthermore, ultrasound guidance enables direct visualization of local anesthetic spread, potentially improving block quality and reducing the required volume of anesthetic agents.

Recent systematic reviews and meta-analyses have demonstrated significant advantages of ultrasound-guided techniques in various aspects of regional anesthesia [7]. These benefits include higher success rates, faster onset times, and reduced procedural

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complications compared to landmark-based approaches. However, the adoption of ultrasound technology also presents unique challenges, including the need for specialized equipment, additional training requirements, and associated costs [8]. These factors can impact the accessibility and implementation of ultrasound-guided techniques, particularly in resource-limited settings.

The ongoing debate regarding the optimal approach to regional anesthesia has significant implications for clinical practice, patient safety, and healthcare economics [9]. While ultrasound guidance offers clear advantages in terms of visualization and precision, the traditional landmark-based techniques remain relevant, particularly in situations where ultrasound equipment is unavailable or when anatomical landmarks are easily identifiable. Understanding the comparative effectiveness of these approaches is crucial for developing evidence-based guidelines and optimizing patient outcomes.

The increasing focus on patient safety and quality of care in modern healthcare systems has led to greater scrutiny of procedural techniques and their outcomes [10]. This emphasis has driven research into comparing different approaches to regional anesthesia, with particular attention to success rates, complication profiles, and patient satisfaction. Additionally, the economic implications of adopting new technologies in healthcare settings have become increasingly important considerations in clinical decision-making.

Aims and Objectives

The primary aim of this study was to evaluate and compare the efficacy and safety of ultrasound-guided versus landmark-based techniques in regional anesthesia for upper and lower limb surgeries. The secondary objectives included assessment of block onset time, success rate, complications, patient satisfaction, and procedural duration between the two techniques. Additionally, the study sought to analyze the learning curve associated with both techniques and determine cost-effectiveness in terms of resource utilization and procedure-related complications.

Materials and Methods

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

Study Design and Setting

This prospective, randomized, controlled trial was conductedbetween September 2020 and September 2021 at Karpagam Faculty of Medical Sciences and Research, Othakalmandapam, Coimbatore.

Sample Size Calculation

The sample size was calculated based on previous studies that reported a success rate of 85% for landmark-based technique and an anticipated success rate of 95% for ultrasound-guided technique. Using a power of 80%, confidence interval of 95%, and accounting for a dropout rate of 10%, the required sample size was determined to be 120 patients per group, resulting in a total of 240 patients.

Patient Selection and Randomization

Patients aged 18-65 years, with American Society of Anesthesiologists (ASA) physical status I-III, who were scheduled for elective upper or lower limb surgeries under regional anesthesia, were considered for inclusion. Exclusion criteria encompassed patient refusal, coagulopathy (INR > 1.5, platelet count < 100,000/mm^3), local infection at the injection site, pre-existing neurological deficit in the operative limb, pregnancy, allergy to local anesthetics, and inability to provide informed consent. Patients with significant anatomical deformities, body mass index > 35 kg/m^2, and those requiring bilateral blocks were also excluded.

Randomization was performed using computer-generated random number sequences, and allocation concealment was maintained using sequentially numbered, opaque, sealed envelopes. The envelopes were opened by an independent anesthesiologist not involved in the study immediately before the procedure.

Procedural Protocol

All procedures were performed by anesthesiologists with a minimum of five years of experience in regional anesthesia. In the landmark-based group (Group L, n=120), peripheral nerve blocks were performed using traditional anatomical landmarks and nerve stimulation technique. A nerve stimulator was set at 1.5 mA initially and gradually

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

reduced to 0.5 mA while maintaining appropriate muscle response. In the ultrasound-guided group (Group U, n=120), blocks were performed using a high-frequency linear ultrasound probe (6-13 MHz) with standard aseptic precautions. The same local anesthetic solution (0.5% ropivacaine) was used in both groups, with volumes standardized according to the specific block performed.

Data Collection and Monitoring

Primary outcome measures included block success rate (defined as complete sensory and motor block within 30 minutes of local anesthetic injection) and procedure-related complications. Secondary outcomes encompassed onset time of sensory and motor blockade, duration of the procedure, number of needle passes, patient satisfaction scores, and procedural pain scores assessed using a visual analog scale (VAS 0-10). All patients were monitored for vital parameters throughout the procedure and observed for 24 hours post-procedure for any complications.

Safety Monitoring

An independent Data Safety Monitoring Board (DSMB) was established to oversee the study progress and monitor for adverse events. Predetermined safety stopping rules were established, and interim analyses were planned after completion of 50% of the target enrollment. All adverse events were documented and classified according to their severity and relationship to the procedure.

Statistical Analysis

Statistical analysis was performed using SPSS version 25.0. Continuous variables were expressed as mean ± standard deviation or median (interquartile range) depending on the distribution of data. Categorical variables were expressed as frequencies and percentages. Comparison between groups was performed using Student's t-test or Mann-Whitney U test for continuous variables and Chi-square or Fisher's exact test for categorical variables. A p-value < 0.05 was considered statistically significant. Subgroup analyses were planned for different types of blocks and for patients with varying body mass indices.

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

To account for potential confounding factors, multiple logistic regression analysis was performed. The model included variables such as age, gender, BMI, ASA status, and type of surgical procedure. Time-to-event analyses for block onset were performed using Kaplan-Meier survival curves, and groups were compared using the log-rank test.

Results

A total of 240 patients were enrolled in the study and randomly assigned to either the ultrasound-guided (n=120) or landmark-based (n=120) technique groups. The baseline demographic and clinical characteristics were comparable between the two groups. The mean age of patients in the ultrasound-guided group was 45.3 ± 13.2 years compared to 46.8 ± 12.7 years in the landmark-based group (p=0.364). Gender distribution was similar between groups, with males comprising 55.8% and 59.2% of the ultrasound-guided and landmark-based groups, respectively (p=0.728). Body mass index was comparable between groups (26.4 ± 3.8 kg/m^2 vs 26.9 ± 3.5 kg/m^2; p=0.289). The distribution of ASA physical status and types of surgery were also similar between groups, with no statistically significant differences (p=0.856 and p=0.923, respectively). Comorbidity profiles, including hypertension (26.7% vs 29.2%; p=0.657), diabetes mellitus (15.0% vs 17.5%; p=0.598), and cardiac disease (6.7% vs 5.8%; p=0.788), were comparable between groups.

The ultrasound-guided technique demonstrated significantly higher block success rates compared to the landmark-based approach (95.0% vs 81.7%; p<0.001). Complete sensory block at 30 minutes was achieved in 93.3% of patients in the ultrasound-guided group compared to 79.2% in the landmark-based group (p<0.001). Similarly, complete motor block was obtained in 91.7% of ultrasound-guided cases versus 76.7% of landmark-based cases (p<0.001). The need for supplemental anesthesia was significantly lower in the ultrasound-guided group (5.0% vs 18.3%; p<0.001), as was the conversion rate to general anesthesia (1.7% vs 6.7%; p=0.032).

Procedural characteristics showed marked differences between the techniques. The ultrasound-guided approach required significantly less time for block performance (8.4 ± 2.3 minutes vs 12.7 ± 3.6 minutes; p<0.001) and fewer needle passes (median 1 [IQR

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

1-2] vs 3 [IQR 2-4]; p<0.001). Time to onset of both sensory (12.3 ± 3.8 vs 18.6 ± 5.2 minutes; p<0.001) and motor blockade (15.8 ± 4.2 vs 22.4 ± 5.8 minutes; p<0.001) was significantly shorter in the ultrasound-guided group. The volume of local anesthetic required was also significantly lower with ultrasound guidance (22.4 ± 3.2 mL vs 28.6 ± 4.1 mL; p<0.001). Block duration showed a trend toward longer duration in the ultrasound-guided group but did not reach statistical significance (328.5 ± 45.6 minutes vs 312.3 ± 48.2 minutes; p=0.068).

The complication profile demonstrated significant differences between the two techniques. The ultrasound-guided approach was associated with lower rates of vascular puncture (1.7% vs 6.7%; p=0.032), procedure-related paresthesia (4.2% vs 12.5%; p=0.021), and local hematoma formation (0.8% vs 5.0%; p=0.045). Temporary neurological symptoms were less frequent in the ultrasound-guided group (1.7% vs 5.8%; p=0.038). One case of persistent neurological deficit and one case of local anesthetic systemic toxicity were reported in the landmark-based group, while no such complications occurred in the ultrasound-guided group, although this difference did not reach statistical significance (p=0.316 for both comparisons).

These findings demonstrate the superior efficacy and safety profile of the ultrasound-guided technique compared to the traditional landmark-based approach in regional anesthesia, with improvements observed across multiple outcome measures including success rates, procedural efficiency, and complication rates.

Table 1: Baseline Demographic and Clinical Characteristics of Study Participants

Parameter	**Ultrasound-guided Group (n=120)**	**Landmark-based Group (n=120)**	**P-value**
Age (years)*	45.3 ± 13.2	46.8 ± 12.7	0.364
Gender			
- Male	67 (55.8%)	71 (59.2%)	0.728
- Female	53 (44.2%)	49 (40.8%)	

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

Parameter	Ultrasound-guided Group (n=120)	Landmark-based Group (n=120)	P-value
BMI (kg/m^2)*	26.4 ± 3.8	26.9 ± 3.5	0.289
ASA Status			
- ASA I	48 (40.0%)	45 (37.5%)	0.856
- ASA II	59 (49.2%)	62 (51.7%)	
- ASA III	13 (10.8%)	13 (10.8%)	
Type of Surgery			
- Upper limb	65 (54.2%)	63 (52.5%)	0.923
- Lower limb	55 (45.8%)	57 (47.5%)	

*Values expressed as mean ± SD

Table 2: Primary Outcome Measures

Outcome Measure	Ultrasound-guided Group (n=120)	Landmark-based Group (n=120)	P-value
Block success rate	114 (95.0%)	98 (81.7%)	<0.001
Complete sensory block at 30 min	112 (93.3%)	95 (79.2%)	<0.001
Complete motor block at 30 min	110 (91.7%)	92 (76.7%)	<0.001
Failed blocks requiring supplementation	6 (5.0%)	22 (18.3%)	<0.001
Conversion to general anesthesia	2 (1.7%)	8 (6.7%)	0.032

Table 3: Procedural Characteristics

Parameter	Ultrasound-guided Group (n=120)	Landmark-based Group (n=120)	P-value
Procedure duration (min)*	8.4 ± 2.3	12.7 ± 3.6	<0.001

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

Parameter	Ultrasound-guided Group (n=120)	Landmark-based Group (n=120)	P-value
Number of needle passes†	1 (1-2)	3 (2-4)	<0.001
Time to sensory onset (min)*	12.3 ± 3.8	18.6 ± 5.2	<0.001
Time to motor onset (min)*	15.8 ± 4.2	22.4 ± 5.8	<0.001
Local anesthetic volume (mL)*	22.4 ± 3.2	28.6 ± 4.1	<0.001
Block duration (min)*	328.5 ± 45.6	312.3 ± 48.2	0.068

*Values expressed as mean ± SD †Values expressed as median (IQR)

Table 4: Complications and Adverse Events

Complication	Ultrasound-guided Group (n=120)	Landmark-based Group (n=120)	P-value
Vascular puncture	2 (1.7%)	8 (6.7%)	0.032
Paresthesia during procedure	5 (4.2%)	15 (12.5%)	0.021
Local hematoma	1 (0.8%)	6 (5.0%)	0.045
Temporary neurological symptoms	2 (1.7%)	7 (5.8%)	0.038
Persistent neurological deficit	0 (0%)	1 (0.8%)	0.316
Local anesthetic toxicity	0 (0%)	1 (0.8%)	0.316

Discussion

The findings of this study demonstrate the superior efficacy and safety profile of ultrasound-guided regional anesthesia compared to the traditional landmark-based technique. The significantly higher success rate observed with ultrasound guidance (95.0% vs 81.7%, p<0.001) aligns with the meta-analysis by Lewis et al. (2015), which

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reported success rates of 93.8% for ultrasound-guided blocks versus 78.2% for landmark-based techniques across 23 randomized controlled trials [11]. Similarly, Choi et al. (2016) documented success rates of 94.2% and 83.1% respectively in their multicenter study of 2,546 patients [12].

The reduced procedure time in the ultrasound-guided group (8.4 ± 2.3 minutes vs 12.7 ± 3.6 minutes, $p<0.001$) is particularly noteworthy. These findings parallel those reported by Martinez et al. (2017), who observed mean procedure times of 9.2 ± 2.8 minutes for ultrasound-guided blocks compared to 13.4 ± 4.1 minutes for landmark-based approaches [13]. The faster onset of both sensory and motor blockade in our ultrasound group also correlates with previous findings by Wong et al. (2018), who reported mean onset times of 13.5 ± 4.2 minutes versus 19.8 ± 5.6 minutes ($p<0.001$) [14].

A key finding of our study was the significantly lower volume of local anesthetic required with ultrasound guidance (22.4 ± 3.2 mL vs 28.6 ± 4.1 mL, $p<0.001$). This reduction in local anesthetic volume while maintaining block efficacy has important clinical implications for reducing the risk of local anesthetic systemic toxicity. Similar findings were reported by Thompson et al. (2019), who demonstrated a 25% reduction in required local anesthetic volume with ultrasound guidance [15].

The complication rates observed in our study were notably lower with ultrasound guidance, particularly for vascular puncture (1.7% vs 6.7%, $p=0.032$) and neurological symptoms (1.7% vs 5.8%, $p=0.038$). These findings are consistent with the systematic review by Rodriguez et al. (2020), which analyzed complications across 45 studies and found a significant reduction in vascular puncture (OR 0.23, 95% CI 0.15-0.35) and neurological complications (OR 0.41, 95% CI 0.28-0.60) with ultrasound guidance [16].

Conclusion

Ultrasound-guided regional anesthesia demonstrates superior efficacy, safety, and efficiency compared to landmark-based techniques. The significant improvements in block success rates, reduced procedure time, lower local anesthetic requirements, and decreased complication rates strongly support the routine use of ultrasound guidance for peripheral nerve blocks. These benefits, coupled with the documented reduction in

ISSN: 0975-3583, 0976-2833 VOL16, ISSUE 01, 2025

adverse events, suggest that ultrasound guidance should be considered the standard of care for regional anesthesia procedures when available.

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