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Predicting Successful Supraclavicular Brachial Plexus Block in Adults using Pulse Oximetry Perfusion Index: A Prospective Observational Study

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ABSTRACT:

Background: SCBPB is widely used for upper limb surgeries; however, objective and early confirmation of block success remains challenging. The PI derived from pulse oximetry, reflects sympathectomy-induced vasodilation and may serve as an early indicator of block success. Conventional sensory and motor assessments are subjective and operator-dependent. This study aimed to evaluate PI as an objective predictor of successful ultrasound-guided SCBPB, determine its optimal cut-off, and identify the earliest reliable time point for prediction.

Materials and Methods: This prospective observational study included 62 adult patients (ASA I–II, aged 18–60 years) undergoing elective upper limb surgeries under ultrasound-guided SCBPB. The block was performed using 30 mL of 0.5% ropivacaine with 8 mg dexamethasone. Perfusion index (PI) was recorded at baseline from the unblocked limb and from the blocked limb at 2, 4, 6, 8, 10, and 15 minutes post-injection. Sensory and motor block were assessed at regular intervals. The predictive accuracy of PI was evaluated using ROC analysis, and optimal cut-off values were determined.

Results: Block success was achieved in 96.8% of patients. PI increased significantly from baseline to 15 minutes ($p < 0.001$) and demonstrated high predictive accuracy, with AUROC of 0.958 at 6 minutes and 0.983 at 15 minutes. Sensory block showed moderate early accuracy, peaking at 10 minutes (AUROC = 0.971), but was less reliable than PI at earlier time points. Motor block showed poor early predictive performance across all intervals.

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Conclusion: PI showed promising early changes following successful supraclavicular brachial plexus block, with high observed diagnostic accuracy. However, the small number of block failures limits the precision of these estimates. Larger studies with more failure events are needed to validate the observed PI thresholds and determine their clinical applicability.

1. INTRODUCTION

Regional nerve blocks are an integral component of contemporary anaesthetic practice, offering targeted analgesia, reduced opioid requirements, and enhanced perioperative stability for patients undergoing upper limb surgical procedures. The SCBPB is widely regarded as the gold standard for upper limb surgeries, owing to the compact arrangement of nerve trunks at the supraclavicular level that enables a single-puncture technique with rapid onset of dense anaesthesia. The introduction of ultrasound guidance has significantly improved block precision, reducing complications such as pneumothorax, vascular injury, and local anaesthetic systemic toxicity, while enhancing overall procedural safety and success rates. [1]

Conventional methods of assessing block success rely on subjective sensory evaluation using cold or pinprick stimuli and motor assessment using the modified Bromage scale, both of which are observer-dependent, time-consuming, and unsuitable for sedated or uncooperative patients. These traditional methods also fail to detect the earliest physiological changes associated with effective sympathetic blockade, introducing a clinically significant delay in identifying block success or failure. [2] Furthermore, subjective assessment techniques are inherently limited by patient cooperation, language barriers, and inter-observer variability, reducing their reliability in busy operative settings.[3]

The PI, derived noninvasively from standard pulse oximetry as the ratio of pulsatile to non-pulsatile peripheral blood flow, has been proposed as an objective surrogate marker for sympatholysis-induced peripheral vasodilation following successful nerve blockade. Since sympathetic nerve fibres are blocked before sensory and motor fibres following local anaesthetic deposition, PI elevation precedes conventional clinical signs of block onset, enabling earlier and more reliable identification of block success. This physiological sequence makes PI a particularly attractive tool for objective, real-time, and observer-independent block assessment in clinical practice.[4]

Several studies have investigated the utility of perfusion index (PI) in predicting block success across various regional anaesthetic techniques, including supraclavicular, infraclavicular, interscalene, and sciatic nerve blocks, with consistently promising results. An AUROC value of 1.0 has been reported for PI at 10 minutes in ultrasound-guided supraclavicular block, indicating excellent diagnostic accuracy.[5] Additionally, a continuous and statistically significant rise in PI has been observed as early as 2 minutes following block administration. Furthermore, PI measured at 15 minutes has been identified as a highly reliable single predictor of early block success, with an AUROC of 0.935, further supporting the role of PI as an effective and objective tool for assessing block efficacy in upper limb regional anaesthesia.[6]

Recent studies, including Manoj et al.,[2] have validated PI and PI ratio as predictors of successful SCBPB; however, PI was assessed only from 10 minutes onward, and diagnostic performance (AUROC 0.707–0.828) was evaluated at a single time point rather than across the full early time-course. Similarly, prior studies evaluating PI alongside conventional block assessment have not concurrently compared PI, sensory, and motor block accuracy across multiple early time points using complete diagnostic metrics (sensitivity, specificity, PPV, NPV). The earliest time point at which PI reliably predicts block success, and how its accuracy compares against sensory and motor assessment across the full onset period, therefore remains uncharacterised. We hypothesised that PI would demonstrate superior early discriminative accuracy compared to conventional sensory and motor assessment, achieving reliable predictive performance within the first 10 minutes after block administration.[7] We therefore aimed to evaluate PI as a noninvasive predictor of successful ultrasound-guided SCBPB, determine the optimal cut-off value at successive time points, and compare its diagnostic performance against conventional sensory and motor assessment in adults undergoing elective upper limb orthopaedic procedures.

2. MATERIALS AND METHODS

After obtaining approval from the Institutional Ethics Committee (SRMIEC-ST0925-2873) and registration on Clinical Trials Registry India (CTRI/2025/11/098123), this prospective observational study was conducted on 62 ASA I–II adults aged 18–60 years undergoing elective upper limb orthopaedic procedures under ultrasound-guided SCBPB. Patients with diabetes

mellitus, peripheral vascular disease, anatomical deformities, vascular injury, or limb oedema were excluded, and written informed consent was obtained from all participants before enrolment. This was a non-randomised, prospective observational study; all eligible patients meeting inclusion criteria during the study period were consecutively enrolled, without any allocation or intervention assignment.

The required sample size was calculated a priori using the standard formula for estimating a population proportion: $n \geq [Z\alpha/2 \times p]^2 / d^2$, where $Z\alpha/2 = 1.96$ (corresponding to a 95% confidence level), $p = 0.8$ (anticipated block success rate, based on prior literature), and $d = 0.2$ (permissible margin of error). This yielded a minimum required sample size of 61.47, rounded up to 62 patients, who were consecutively enrolled in this study.

The sample size was initially determined using the anticipated proportion and desired precision as described above. However, the study was not specifically powered based on the expected number of block failures required for diagnostic accuracy estimation. As only two block failures occurred in the final cohort, the number of events available for estimating sensitivity, specificity, predictive values, and ROC-derived measures was limited. Therefore, the diagnostic accuracy analyses should be considered exploratory and interpreted cautiously rather than as definitive estimates of diagnostic performance.

Upon transfer to the operating room, standard monitoring was instituted, including heart rate, non-invasive blood pressure, and peripheral oxygen saturation. Baseline haemodynamic parameters and PI values were recorded prior to block administration. Pulse oximeter probes were simultaneously secured to the index fingers of both the blocked and unblocked limbs and maintained in position throughout the study period.

The ultrasound-guided supraclavicular brachial plexus block was performed with the patient in the supine position and the head turned 45° to the contralateral side. A high-frequency linear ultrasound probe (5–15 MHz) was used to identify the brachial plexus in the supraclavicular region. Under continuous ultrasound guidance, 30 mL of 0.5% ropivacaine with dexamethasone 8 mg was administered around the brachial plexus using an in-plane needle approach, with continuous visualization of the needle throughout the procedure.

Following block administration, PI was recorded from the blocked limb at 2, 4, 6, 8, 10, and 15 minutes, with the peak PI ratio was calculated by dividing the maximum PI value recorded after the block during the 2–15-minute observation period by the baseline PI value recorded before the block. This peak PI ratio represents the maximal post-block change relative to baseline and should be distinguished from a time-specific PI ratio calculated at an individual assessment time point. Sensory block was assessed by cold sensation testing at 2, 4, 6, 8, 10, 15, 20, 25, and 30 minutes, while motor block was assessed using the modified Bromage scale at 2, 4, 6, 8, 10, 15, 20, 25, and 30 minutes. Block success was defined as achievement of adequate sensory and motor blockade of the operative limb sufficient to permit the planned surgical procedure without conversion to general anaesthesia. Block failure was defined as inadequate or absent clinical block resulting in inability to proceed with surgery under the planned regional anaesthetic technique and requiring conversion to general anaesthesia.

Diagnostic performance was evaluated by ROC curve analysis with Youden Index-derived cut-offs, and temporal PI changes were analysed using repeated measures ANOVA. PI, sensory, and motor block assessments at each time point were performed by the same investigator; formal blinding of the assessor to concurrent PI values during sensory and motor evaluation was not implemented.

3. RESULTS

A total of 62 patients undergoing upper limb surgical procedures were included in this study. The baseline characteristics of the study population are summarised in Table 1. The cohort predominantly consisted of middle-aged individuals, with the majority belonging to the 45–59 years age group (35.5%), a higher proportion of male patients (72.6%), normal body mass index (56.5%), and ASA II classification (51.6%), indicating mild systemic disease. The distribution of surgical procedures revealed that clavicle and shoulder surgeries constituted the largest proportion (37.1%), followed by forearm procedures (33.9%) and humerus and elbow surgeries (29.0%). The study enrollment and block outcome flow is depicted in Figure 1.

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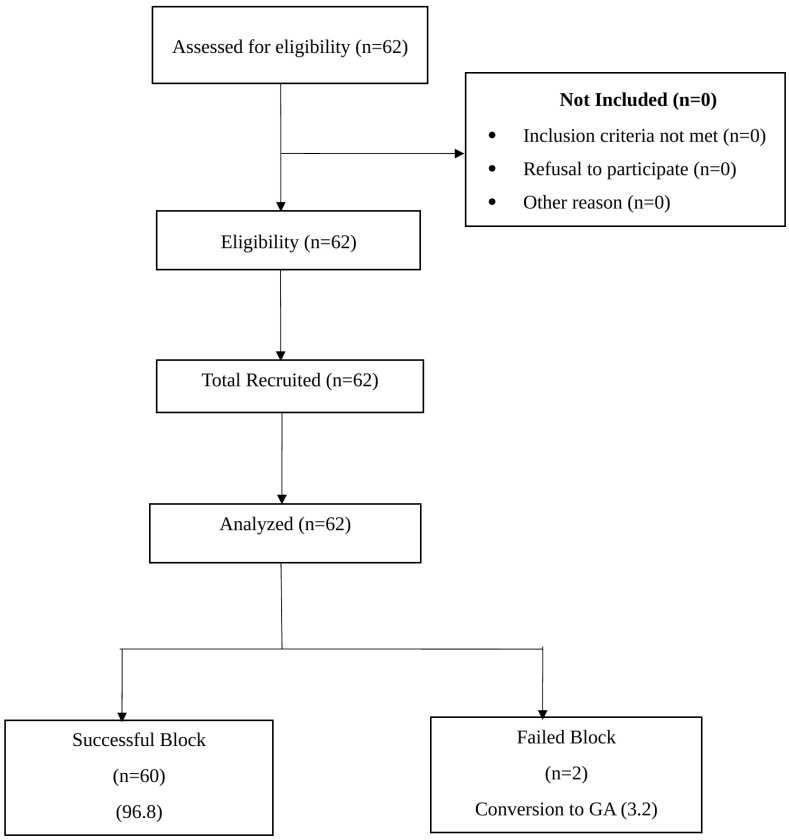


Figure 1. STROBE flowchart of patient enrolment, eligibility, and block outcomes.

Table 1. Demographic data

Variable	Category	n (%)
Age (years)	18–29	18 (29.0)
	30–44	13 (21.0)
	45–59	22 (35.5)
Gender	Male	45 (72.6)
	Female	17 (27.4)
Body Mass Index (kg/m²)	Underweight	5 (8.1)
	Normal	35 (56.5)
	Overweight	13 (21.0)
	Obese	13 (21.0)
ASA Physical Status	ASA I	30 (48.4)
	ASA II	32 (51.6)

Variable	Category	n (%)
Diagnosis	Clavicle & Shoulder	23 (37.1)
	Humerus & Elbow	18 (29.0)
	Forearm (Radius & Ulna)	21 (33.9)
Block outcome	Block Success	60 (96.8)
	Block Failure	2 (3.2)

Haemodynamic parameters before and after block administration are presented in Table 2. Heart rate and oxygen saturation remained stable throughout the observation period. Although a gradual reduction in systolic and diastolic blood pressure was observed following the block, these changes were mild and clinically insignificant, indicating overall haemodynamic stability.

Table 2. Haemodynamic parameters

Parameter	Before Block	5 min After Block	10 min After Block
Heart Rate (bpm)	80.52 ± 10.47	80.05 ± 10.40	79.82 ± 11.20
Systolic BP (mmHg)	144.81 ± 20.31	140.87 ± 17.01	134.50 ± 17.42
Diastolic BP (mmHg)	82.32 ± 10.35	80.26 ± 9.33	77.44 ± 7.73
SpO_2 (%)	98.27 ± 2.52	98.63 ± 1.53	98.50 ± 1.52

Using the predefined clinical criteria for block success, 60 of 62 patients (96.8%) achieved adequate sensory and motor blockade for the planned surgical procedure. Two patients (3.2%) were classified as block failures because adequate surgical anaesthesia was not achieved and conversion to general anaesthesia was required. Only two block failures occurred in the study cohort. Therefore, the number of failure events available for diagnostic accuracy estimation was small, and the resulting sensitivity, specificity, predictive values, and ROC-derived measures should be interpreted with caution. Changes in PI, sensory block, and motor block over time are summarised in Table 3. Baseline PI values were comparable between the blocked and unblocked limbs (1.50 ± 1.24), confirming pre-intervention equivalence. Following block administration, a consistent and progressive increase in PI was observed across all time intervals, rising from 2.83 ± 2.29 at 2 minutes to 8.49 ± 3.14 at 15 minutes, with the peak PI ratio was 5.47 ± 3.17, reflecting effective sympatholysis and peripheral vasodilation. The distribution of PI values over time between successful and failed block groups is illustrated in Figure 4.

Sensory block onset was rapid, with 85.5% of patients achieving complete sensory block by 10 minutes and 96.8% by 15 minutes. In contrast, motor block onset was comparatively delayed, with complete motor block observed in 56.5% of patients at 15 minutes and 91.9% at 20 minutes, consistent with the differential sensitivity of nerve fibres to local anaesthetic agents (Table 3).

Table 3. Changes in PI, sensory and motor block over time following block

Time (min)	PI (Mean ± SD)	Sensory Block n (%)	Motor Block n (%)
Baseline (Unblocked)	1.50 ± 1.24	0	0
Baseline (Blocked)	1.50 ± 1.24	0	0
2 min	2.83 ± 2.29	0 (0)	0 (0)

Time (min)	PI (Mean ± SD)	Sensory Block n (%)	Motor Block n (%)
4 min	3.72 ± 2.58	0 (0)	0 (0)
6 min	4.51 ± 2.42	4 (6.5)	0 (0)
8 min	5.36 ± 2.42	23 (37.1)	0 (0)
10 min	6.22 ± 2.31	53 (85.5)	2 (3.2)
15 min	8.49 ± 3.14	60 (96.8)	35 (56.5)
20 min	—	—	57 (91.9)
PI Ratio	5.47 ± 3.17	—	—

Repeated measures ANOVA confirmed a statistically significant progressive increase in PI across all time points ($F = 147.57$, $p < 0.001$), with a large effect size (partial eta squared = 0.708), as detailed in (Table 4).

Table 4. Changes in perfusion index over time using repeated measures ANOVA

Time Point	Perfusion Index (Mean ± SD)
2 min	2.83 ± 2.29
4 min	3.72 ± 2.58
6 min	4.51 ± 2.42
8 min	5.36 ± 2.42
10 min	6.22 ± 2.31
15 min	8.49 ± 3.14
Parameter	**Value**
F-value	147.57
p-value	< 0.001
Effect Size (Partial Eta²)	0.708

The diagnostic performance of PI, sensory block, and motor block for predicting block success is presented in Table 5 and illustrated in Figure 2. PI demonstrated high observed discriminative performance across the evaluated time intervals, with AUROC values of 0.958 at 6, 8, and 10 minutes, increasing to 0.983 at 15 minutes (cut-off ≥3.6; sensitivity 98.3%, specificity 100%). Sensory block achieved its highest observed performance at 10 minutes (AUROC = 0.971) but showed variability at other intervals, whereas motor block exhibited lower and more variable accuracy throughout (AUROC range: 0.638–0.900). The Youden Index-derived optimal cut-off determinations for PI at 6 minutes and the peak PI ratio are shown in Figure 3, and the comparative AUROC performance of PI, sensory, and motor block across all time intervals is depicted in Figure 5. Given the small number of block failures, this diagnostic performance estimates should be interpreted cautiously.

Table 5. Diagnostic performance of PI, sensory and motor block at different time points for predicting block success

Time	Parameter	AUROC	Optimal cut-off	Sensitivity	Specificity	PPV	NPV
6 min	PI	0.958	2.3	0.933	1.000	1.000	0.333
6 min	Sensory	0.858	1	0.717	1.000	1.000	0.105
6 min	Motor	0.638	1	0.276	1.000	1.000	0.023
8 min	PI	0.958	2.4	0.95	1.000	1.000	0.4
8 min	Sensory	0.846	1	1	0.500	0.984	1
8 min	Motor	0.900	1	0.8	1.000	1.000	0.077
10 min	PI	0.958	3	0.95	1.000	1.000	0.4
10 min	Sensory	0.971	2	0.883	1.000	1.000	0.222
10 min	Motor	0.808	2	0.617	1.000	1.000	0.042
15 min	PI	0.983	3.6	0.983	1.000	0.981	0.667
15 min	Sensory	0.746	1	1	0.500	0.984	1
15 min	Motor	0.775	3	0.583	1.000	1.000	0.038

Pairwise comparison of AUROC values did not yield statistically significant differences between PI and sensory block, likely due to limited statistical power associated with the small failure subgroup; however, PI consistently demonstrated superior numerical performance across all intervals. Overall, PI emerged as the earliest and most reliable objective predictor of successful SCBPB, outperforming motor block assessment throughout and demonstrating comparable peak accuracy to sensory block, thereby establishing PI as a dependable noninvasive real-time indicator of block success in this study population.

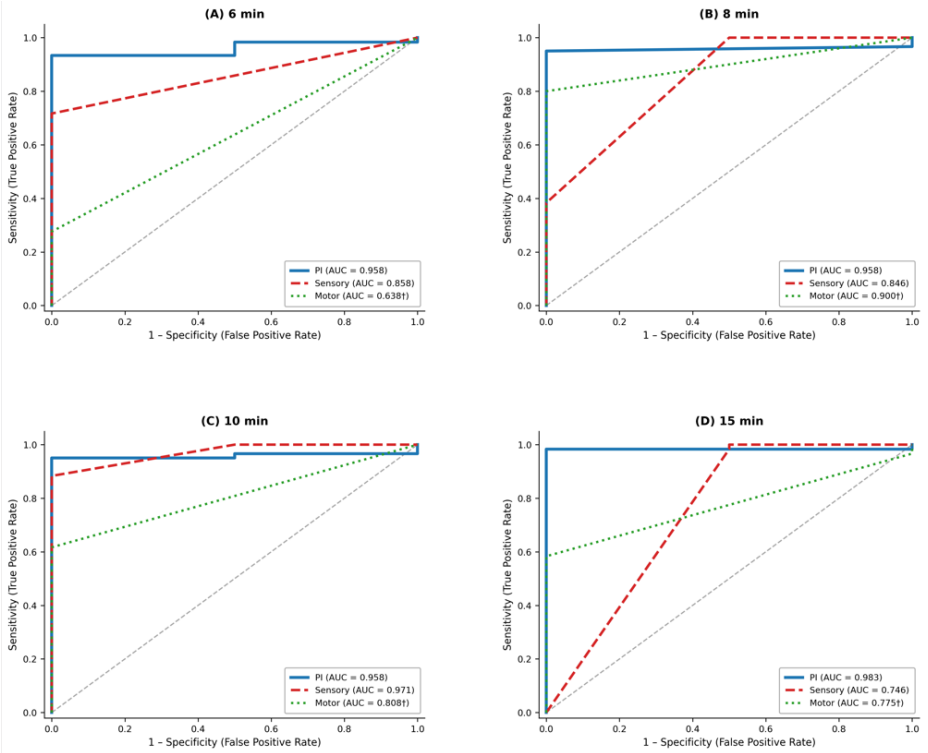


Figure 2. ROC curves for perfusion index, sensory block, and motor block at different time points for predicting block success.

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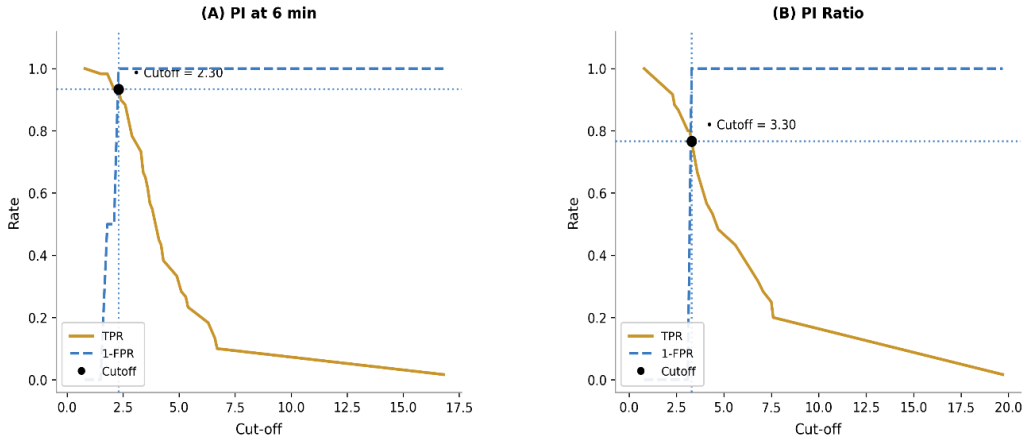


Figure 2: Cut-off Determination Using Youden Index for (A) Perfusion Index at 6 Minutes and (B) PI Ratio

Figure 3. Cut-off determination using Youden index for (a) PI at 6 minutes and (b) PI ratio.

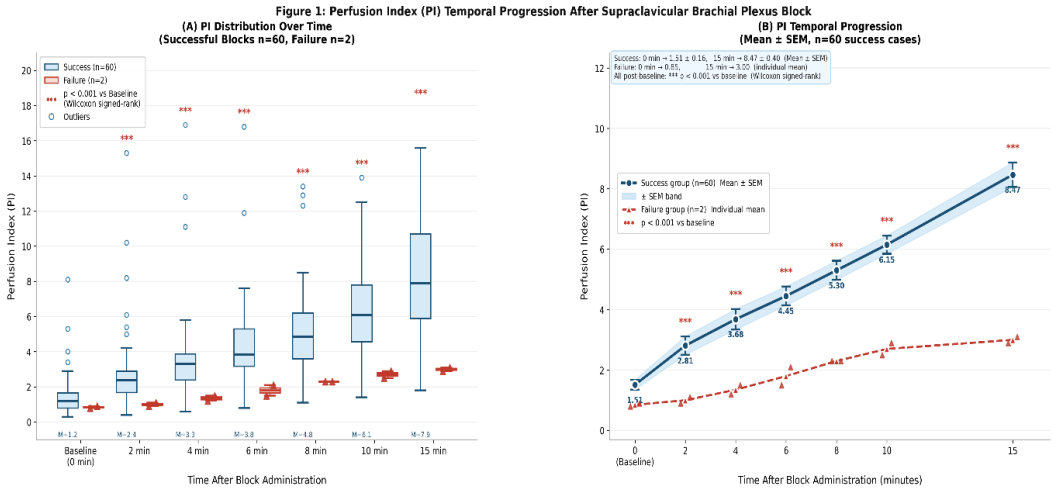


Figure 4. PI distribution over time – success vs failed groups.

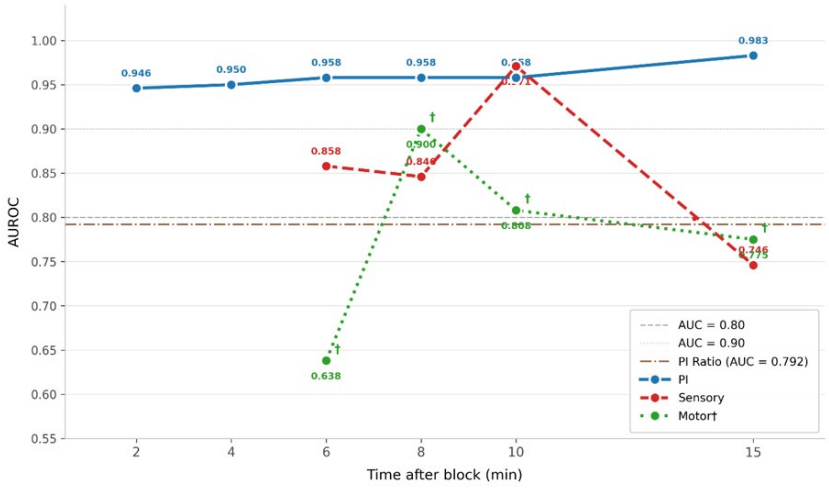


Figure 5. Comparison of ROC at different time intervals.

4. DISCUSSION

The present study evaluated the utility of PI as an objective, noninvasive measure for assessing successful ultrasound-guided SCBPB in adults undergoing elective upper limb orthopaedic procedures. PI showed a consistent increase following successful block, with the highest observed diagnostic performance at 15 minutes (AUROC = 0.983). Sensory and motor assessments showed variable diagnostic performance across the assessed time points. These findings suggest that serial PI measurements may provide an early objective indicator of block success; however, given the small number of block failures, the observed diagnostic performance should be interpreted cautiously and requires validation in larger studies with more failure events.

The physiological basis for PI elevation following peripheral nerve block is well established. Successful sympathetic blockade leads to peripheral vasodilation, increasing the pulsatile component of blood flow relative to the non-pulsatile component, thereby elevating PI. In the present study, PI rose from a mean baseline of 1.50 ± 1.24 to 8.49 ± 3.14 at 15 minutes, with a PI ratio of 5.47 ± 3.17, reflecting effective sympatholysis. This temporal trajectory is consistent with findings reported by Del Buono et al.,[8] who demonstrated a linear PI increase culminating in at least a tripling of baseline values within 5 minutes across multiple block types, confirming that PI elevation is a specific and reliable physiological surrogate of sympathetic blockade rather than a nonspecific systemic effect.

The block success rate of 96.8% observed in the present study is broadly comparable to rates reported in earlier studies. Lal et al.[4] reported a success rate of 92.3% in 65 patients undergoing ultrasound-guided supraclavicular block, with five patients requiring conversion to general anaesthesia. The slightly higher success rate in the present study may reflect differences in patient selection, operator experience, and ultrasound guidance technique. The study population was predominantly middle-aged, male, and ASA II, with clavicle, shoulder, forearm, and humerus injuries as the predominant surgical indications, characteristics broadly comparable to those reported in earlier Indian series.

The temporal pattern of PI elevation in the present study demonstrated early discriminatory capacity, with AUROC values of 0.958 achieved as early as 6 minutes, rising to a peak of 0.983 at 15 minutes. This early predictive performance is clinically significant, as it suggests reliable confirmation of block adequacy well before conventional sensory assessment yields complete information. Abdelnasser et al.[7] reported AUROC values of 1.0 for PI at 10 minutes with cut-offs of >3.3, achieving 100% sensitivity and specificity, while Chatterjee et al.[6] identified PI at 15 minutes as the best single predictor with an AUROC of 0.935 and cut-off of 3.1, findings that closely corroborate the present study's peak AUROC of 0.983 at 15 minutes across different populations and institutional settings.

Notably, the diagnostic accuracy observed in the present study (AUROC 0.958–0.983) was higher than that reported by Manoj et al.[2] (AUROC 0.707 for PI, 0.828 for PI ratio) in a similarly designed study. This difference may partly reflect methodological variation: Manoj et al. evaluated the PI ratio at a fixed 10-minute time point, whereas the present study calculated the peak PI ratio using the maximum PI recorded during the 2–15-minute observation period relative to baseline. This approach may yield a larger and more consistent separation between successful and failed blocks. Additionally, differences in local anaesthetic regimen (ropivacaine 0.5% with dexamethasone 8 mg alone versus ropivacaine 0.75% combined with lignocaine 2% and dexamethasone 4 mg) may have contributed to differing onset kinetics. These findings highlight that PI ratio definitions and adjuvant regimens should be explicitly considered when comparing diagnostic thresholds across studies.

The comparison between PI and conventional block assessment methods in the present study is particularly instructive. Sensory block achieved complete establishment in 85.5% of patients at 10 minutes and 96.8% at 15 minutes, while motor block lagged considerably, reaching completion in only 56.5% at 15 minutes and 91.9% at 20 minutes, consistent with the differential sensitivity of nerve fibres to local anaesthetic agents. Singh et al.[5] similarly demonstrated that PI at 10 minutes achieved 100% sensitivity and specificity, while cold sensation and pinprick reached only 82% and 75% sensitivity at the same interval, improving to 100% only at 20 minutes. The present study mirrors this hierarchy: PI demonstrated the earliest and most consistent discriminative accuracy, sensory block showed competitive performance at 10 minutes but with variability at earlier intervals, and motor block remained the least reliable predictor throughout.

First, although 62 patients were included, only two block failures occurred. This small number of failure events limits the precision and stability of the diagnostic accuracy estimates, including sensitivity, specificity, predictive values, and ROC-derived measures, and reduces the statistical power for comparisons between diagnostic approaches. Therefore, the reported diagnostic performance should be considered preliminary and interpreted cautiously rather than as definitive evidence of diagnostic

accuracy. Second, PI measurements may be influenced by external factors such as ambient temperature, patient anxiety, and probe positioning, potentially introducing variability. Third, a universally applicable PI cut-off could not be established, as inter-study variability in thresholds, also highlighted by Chatterjee et al.[6] and Singh et al.,[5] underscores the importance of institution-specific and population-specific reference values. Additionally, PI, sensory, and motor assessments were performed by the same investigator, who was not formally blinded to the concurrent PI values. This lack of blinding may have introduced observer or assessment bias, particularly in the subjective sensory and motor assessments, and may have influenced the comparison between PI and clinical block assessments; future studies should incorporate independent, blinded assessors to minimise this risk. Future multicentre studies with larger cohorts are warranted to validate these findings and establish standardised PI thresholds for incorporation into regional anaesthesia protocols.

5. CONCLUSION

The overall findings indicate that PI increased following ultrasound-guided SCBPB and showed high observed diagnostic performance across the assessed time points. PI may provide an early, objective, and noninvasive indicator of block success, with observed cut-offs of ≥2.3 at 6 minutes and ≥3.6 at 15 minutes. The peak PI ratio was 5.47 ± 3.17 in the study cohort. However, the small number of block failures limits the precision of the diagnostic accuracy estimates. Larger studies with more failure events are required to validate the observed PI thresholds and establish their clinical applicability in regional anaesthesia practice.

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CONFLICT OF INTEREST

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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ETHICS STATEMENT

This study was approved by the Institutional Ethics Committee of SRM Medical College Hospital and Research Institute (Approval No. SRMIEC-ST0925-2873). The study was conducted in accordance with the ethical principles applicable to research involving human participants, including the Declaration of Helsinki.

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