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ORIGINAL ARTICLE

Validation of Peripheral Perfusion Index in Predicting Successful Supraclavicular Brachial Plexus Block for Upper Extremity Procedures in Children

Sherif M. Soaida, Manal Elgohary, Mohamed K. Elsayed, Ahmed Hazem, Mohamed Elshazly
Department of Anesthesia, Surgical Intensive Care and Pain Management, Faculty of Medicine, Cairo University, Cairo, Egypt.

Correspondence to *Mohamed K. Elsayed, Department of Anesthesia, Surgical Intensive Care and Pain Management, Faculty of Medicine, Cairo University, Cairo, Egypt.*
E-mail: mohamed.k.elsayed@gmx.com

Background To validate the ability of peripheral perfusion index (PPI) to predict the success of supraclavicular brachial plexus block (SCBPB) in children undergoing upper extremity procedures.

Methods This prospective observational study enrolled 55 pediatric patients aged 3-12 years, ASA class I-II scheduled for elective upper extremity procedures. Patients received general anesthesia and a trained anesthesiologist performed ultrasound guided SCBPB on the ipsilateral side of the procedure.

Results PPI measurements from the blocked limb at 30 minutes were significantly higher than non-blocked limb compared to baseline readings. PPI, delta PPI and PI ratio were higher in blocked limb at 30 minutes than non-blocked limb ($P<0.001$). Skin temperature values from blocked limb were considerably higher at 30-min compared to baseline; however, measurements from non-blocked limb were insignificantly different at 30-min compared to baseline. Skin temperature and delta skin temperature were significantly higher in blocked limb than non-blocked at 30-min ($P= 0.031$). PPI can significantly predict block success ($P<0.001$ and AUC= 0.986) at cut-off ≤0.5 with 100% sensitivity, 98.11% specificity, 50.0% PPV and 98.1% NPV. Temperature can't predict block success ($P= 0.268$ and AUC= 0.642) at cut-off ≤0.8 with 100% sensitivity, 45.28% specificity, 6.5% PPV and 100% NPV. PPI was stronger than temperature in prediction of block success ($P= 0.004$).

Conclusions Perfusion index is a valid measure for predicting the success of SCBPB in children undergoing upper limb surgery after induction of general anesthesia. Skin temperature is a valid measure of block success in adults; however, it is not as reliable as PI in children under general anesthesia.

Keywords Child, Peripheral perfusion index, Supraclavicular brachial plexus block, Ultrasonography, Upper extremity.

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INTRODUCTION

Upper limb surgeries common in the pediatric age group include fixation of upper extremity fractures, implant removals, cross-finger flaps, polydactyly, etc [1].

Sensory blockade of the brachial plexus for perioperative analgesia leads to stable hemodynamics intraoperatively, smoother emergence from general anesthesia, and decreased need for supplemental analgesics or suppositories in the postoperative period. It also helps to avoid unwanted side effects of opioids, such as respiratory depression, postoperative nausea and vomiting [2,3].

In contrast to adult practice, most of the brachial plexus block procedures in children and infants are performed under either deep sedation or general anesthesia [3].

The use of ultrasound guidance allows real-time visualization of anatomical structures and shows the spread of the anesthetic solution injected. This is an attractive option in pediatric patients as most regional anesthetic techniques are administered under general anesthesia [4,5]. A vast body of literature supports the safety and efficacy of performing regional anesthetic techniques in children. It has been shown that combined regional and general anesthesia can decrease hospital stay and improve outcomes in pediatric patients [4].

Yet testing the adequacy of a brachial plexus block performed under general anesthesia remains problematic. Most pediatric anesthetists depend on the effects of sympathetic stimulation resulting from pain sensation (tachycardia, hypertension), and the need for rescue analgesia to diagnose a failed block. Other objective methods are being investigated to predict a successful brachial plexus block such as beat to beat heart rate and blood pressure variability, processed EEG and entropy indices as Bispectral index, skin resistance and skin temperature difference and changes in pupillary size to painful stimulation [6].

Perfusion index (PI) is an assessment of the pulsatile strength at a monitoring site; it is calculated using pulse oximetry by expressing the pulsatile signal as a percentage of the non-pulsatile signal by a specialized probe, both of which are derived from the amount of infrared light absorbed [7,8].

PI can provide useful information about the peripheral perfusion status of the patients and works as an index for sympathetic stimulation. A recent study suggested that PI could be used as an early and sensitive indicator to assess the development of sympathectomy induced by brachial plexus block in conscious adults; it is more sensitive than other parameters such as changes in skin temperature gradients or MAP (mean arterial pressure) [9,10].

Few data are available for the PI as a tool for evaluation of peripheral block success in pediatric patients [11].

The aim of this work was to validate the ability of the peripheral perfusion index (PPI) to predict the success of supraclavicular brachial plexus block (SCBPB) in children undergoing upper extremity procedures.

METHODS

This prospective observational study was conducted between September 2023 and May 2024 after obtaining ethical committee approval of Cairo University Hospitals (Ethical committee approval number: MD-279-2021), with the identifier NCT 05157516. The study was conducted in compliance with the 2013 Helsinki Declaration.

A total of 55 pediatric patients aged from 3 to 12 years old, ASA class I-II scheduled for elective upper extremity procedures were included. Patients received general anesthesia, and a trained anesthesiologist performed ultrasound guided supraclavicular brachial plexus block on the ipsilateral side of the procedure. An informed written consent was obtained from the patients' parents.

Exclusion criteria were apparent infection at site of needle insertion, any coagulation disorder such as hereditary coagulation defects or thrombocytopenia, known neuropathy such as degenerative spinal nerve diseases, or brachial plexus injury. American Society of Anesthesiologists III patients with any cardiac, hepatic, renal or neurological disease were also excluded as well as patients with history of hypersensitivity to local anesthetic and patients undergoing vascular surgery.

All patients were premedicated using oral midazolam, with a dose range of 0.25-1mg/kg, depending on age (younger children may need higher doses) and anxiety level. Five leads ECG, noninvasive ABP, pulse oximetry, capnography monitoring was applied. Inhalational induction of general anesthesia was done with 8% sevoflurane in 80% oxygen/air via facemask. Vascular access was obtained in a non-operated-upon limb. Atracurium at a dose of 0.5mg/kg was given intravenously to facilitate endotracheal intubation, and fentanyl at 1µg/kg was given to abolish the stress response of intubation. Anesthesia was maintained by using 1-1.5% isoflurane in a mixture of oxygen and air (60% O2 and atracurium top-up doses of 0.1mg/kg every 30 minutes.

Blocks were carried out using a linear multi-frequency 6-13 MHz Hockey stick transducer (L25 x 6-13 MHz linear array); SonoSite M Turbo ultrasound (USA) and a short-beveled needle (StimuplexTM, Braun, Germany) with an extension tube (25–22G / 35–50mm). Local anesthetics used was a mixture of Bupivacaine 0.5% and Lidocaine 2% in a ratio of 1:1 and a volume of 0.2-0.3ml/kg, keeping in mind that the maximum allowed dose for lidocaine was 4mg/kg and for bupivacaine was 2mg/kg. Surgical stimulation was started after 30 minutes as it is expected to be the time needed for a successful block.

The ultrasound probe was positioned in the coronal oblique plane, just superior to the upper border of the mid-clavicle. The subclavian artery, which was identified as a hypoechoic and pulsatile structure, lies adjacent to the brachial plexus. The needle was advanced medially towards the brachial plexus, just superior and lateral to the subclavian artery, using an in-plane approach. The potential risk of vascular puncture was minimized by directing the needle in a lateral-to-medial fashion and frequent negative aspiration. The risk of intraneural injection was minimized by continuous visualization of the needle tip.

Measurement tools

Hemodynamic parameters: Baseline Heart rate, blood pressure values were recorded as the patient reaches the OR, another set of values were obtained after induction of general anesthesia, after endotracheal intubation, after performing the block, and every 5 minutes for 30 minutes until surgical stimulation and every 5 minutes for 30 minutes after surgical stimulation.

PPI was measured using Masimo Radical 7 pulse oximetry monitor via a pediatric size probe. For each set of readings, the probe was placed on the thumb of the operated-upon hand and then thumb of the non-operated-upon hand. Baseline PPI set of values were recorded after induction of general anesthesia and every 5 minutes after performing the block until surgical stimulation.

Delta value of PI was calculated as the difference between the baseline value and the PPI value at 30mins after local anesthetic injection.

Skin temperature difference: Upper limb skin temperature was recorded using an infrared thermometer. Infrared thermometers have been validated for measuring skin temperature in children [12]. Every set of values included measuring at the dorsum of the hand, at mid forearm, on both upper limbs. A mean of three consecutive measurements was recorded for every reading. A baseline set measured after induction of general anesthesia, and a final set 30 minutes after performing the block. The block was considered successful if heart rate and blood pressure measurements remain within 20% of the baseline values after surgical stimulation and the patient didn’t need rescue analgesia after emergence. In the PACU and during the postoperative period, the pain score (Face, Legs, Activity, Cry, and Consolability [FLACC] scale) was assessed by the attending anesthetist. When the score exceeded 4/10, rescue analgesia in the form of intravenous paracetamol at a dose of 15mg/kg was administered in the immediate postoperative period for patients weighing ≥10kg, and a dose of 7.5mg/kg for patients weighing <10kg. If the FLACC score remained ≥4 after 30 minutes from paracetamol administration, IV nalbuphine 0.1mg/kg was administered. Another dose of nalbuphine 0.1–0.2mg/kg was administered in the PACU if the score remained ≥4 after 30min, and every 3–4h as needed thereafter, to a maximum daily dose of 2.4mg/kg.

After discharge from the PACU, the analgesic plan was to alternate doses of intravenous paracetamol 15mg/kg for patients weighing ≥10 kg or 7.5mg/kg for patients weighing <10kg and ketorolac 0.5mg/kg every 6h if the FLACC score remained ≥4/10

Primary outcome was sensitivity of PPI to detect successful SCBPB in pediatric patients.

Secondary outcome(s) was hemodynamic measurements. Correlation was done to examine if PPI is more sensitive in detection of a successful block than Hemodynamic measurements as well as skin temperature changes. Block failure was recognized by persistent increase in heart rate and blood pressure with skin incision more than 20% of the baseline that did not subside and needed rescue analgesia. Complications such as pneumothorax, local hematoma, intravascular and intraneural injection were to be recorded as secondary outcomes.

Sample size calculation

Power analysis was performed using Medcalc program (version 18) on the level of sensitivity of PI to detect successful supraclavicular block in pediatric patient using ROC curve because it was the primary outcome variable in this study. Based on the assumption that AUC of 0.9 and null hypothesis with area under receiver operating characteristics (AUROC) 0.5A previous study showed that block failure was about 5% [13], and for a power of 0.8 and an alpha error of 0.05, a minimum sample size of 55 patients was calculated with at least 2 negative cases (failed).

Statistical analysis:

Statistical analysis was done using SPSS v26 (Inc., Chicago, IL, USA). Quantitative variables were presented as mean and standard deviation (SD) and were compared by paired Student's *t*-test for the same group. Qualitative variables were presented as frequency and percentage (%). AUROC was calculated for FLIR scanner and axillary temperature for detecting febrile patients. Hanley McNeil test was used for comparing AUROC. Positive predictive value (PPV), negative predictive value (NPV), and best cut-off values were also calculated. Correlation was tested using either Pearson’s or Spearman’s tests according to data normality. Bland-Altman analysis was conducted to evaluate mean bias and 95% agreement between readings. A two-tailed *P* value <0.05 was considered significant.

RESULTS

The age mean value was 5.09 (±2.62) years. There were 30(54.55%) males and 25(45.45%) females. The weight ranged from 9 to 35kg with a mean of 18.85 (±5.83) kg (Table 1). The block was successful in 53 cases out of 55. For these 53 patients, PPI measurements were significantly higher at blocked limb at 30min and non-blocked limb at 30min compared to baseline (*P*<0.001). PPI, delta of PPI and PI ratio (the ratio between PI baseline reading and PI value at 30mins) were significantly higher in blocked limb at 30min than non-blocked at 30min (*P*<0.001) (Table 2, Figure 1).

Table 1: Demographic data of the studied patients:

		***n*= 55**	
Age (year)	Mean±SD	5.1±2.62	
Sex	Male	30(54.55%)	
	Female	25(45.45%)	
Weight (kg)	Mean±SD	18.9±5.83	
Type of operation		Time of operation	
		Mean (min)	SD
ORIF		49	±13
Syndactyly		128	±24
Polydactyly		56	±10
Osteotomy		67	±11

SD: Standard deviation.

Table 2: Peripheral perfusion index measurements of the studied patients:

		Mean±SD	***P* value**	***P* value between blocked and non-blocked**
Peripheral perfusion index	Baseline	4±0.91		
	Blocked at 30-min	6.4±1.66	<0.001*	<0.001*
	Non-blocked at 30-min	4.5±1.01	<0.001*	
Delta of peripheral perfusion index	Blocked at 30-min	2.4±1.16	<0.001*	
	Non-blocked at 30-min	0.5±0.35		
PI ratio	Blocked at 30-min	2.4±0.99	<0.001*	
	Non-blocked at 30-min	2.8±0.93		

SD: Standard deviation; PI: Perfusion index; *: Significant as *P*<0.05.

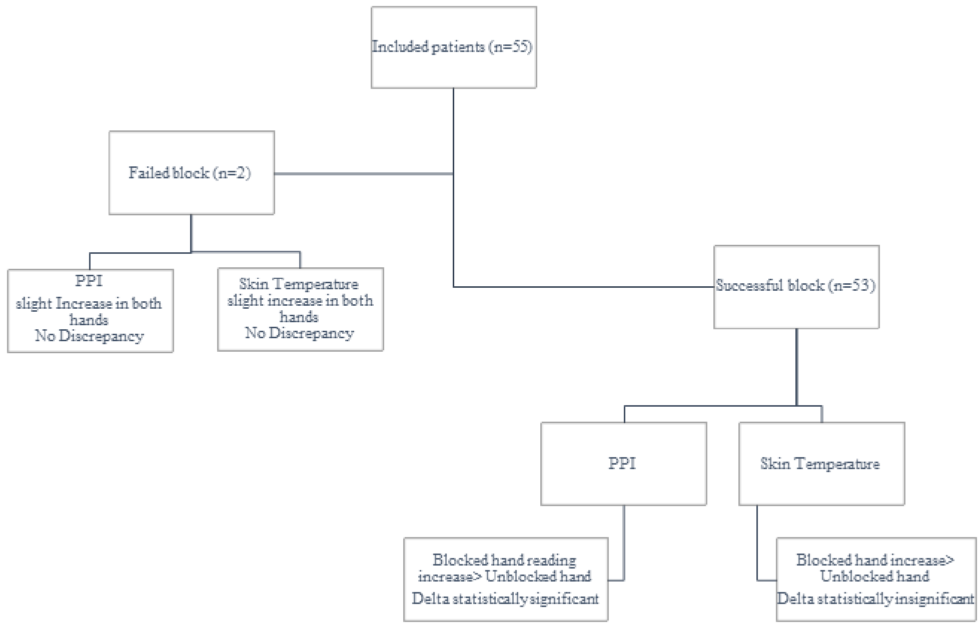

Figure 1: Flow diagram of the study.

Skin temperature measurements were significantly higher at blocked limb at 30min compared to baseline ($P<0.001$) and were insignificantly different at non blocked limb at 30min compared to baseline. Skin temperature and delta of skin temperature was significantly higher in blocked limb at 30min than non-blocked at 30min ($P= 0.031$) (Table 3).

PPI can significantly predict block success ($P<0.001$ and AUC= 0.986) at cut-off ≤0.5 with 100% sensitivity, 98.11% specificity, 50.0% PPV and 98.1% NPV. Temperature can't predict block success ($P= 0.268$ and AUC= 0.642) at cut-off ≤0.8 with 100% sensitivity, 45.28% specificity, 6.5% PPV and 100% NPV (Table 4).

Table 3: Skin temperature (°C) and delta of skin temperature of the studied patients:

		Mean±SD	*P* value	*P* value between blocked and non-blocked
Skin temperature	Baseline	35.2±0.55		
	Blocked at 30-min	36.1±0.47	<0.001*	0.031*
	Non-blocked at 30-min	34.7±4.7	0.426	
Delta of skin temperature	Blocked at 30-min	0.9±0.58	0.031*	
	Non-blocked at 30-min	-0.5±4.76		

SD: Standard deviation; *: Significant as $P<0.05$.

Table 4: Role of delta peripheral perfusion index and delta temperature in prediction of block success:

	Cut-off	Sensitivity	Specificity	PPV	NPV	AUC	*P* value
delta peripheral perfusion index	≤0.5	100%	98.11%	50.0%	98.1%	0.986	<0.001*
delta temperature	≤0.8	100%	45.28%	6.5%	100%	0.642	0.268

PPV: Positive predictive value; NPV: Negative predictive value; AUC: Area under curve; *: Significant as $P<0.05$.

PPI was stronger than temperature in prediction of block success ($P= 0.004$) (Table 5).

Systolic blood pressure measurements were significantly higher at intubation and 5min compared to baseline ($P<0.001$) and were significantly lower at 15min, 25min, skin incision, 35min, 45min, 50min, 55min, 60min and 60min compared to baseline ($P<0.001$). Systolic blood pressure measurements were insignificantly different at 10min and 20min compared to baseline. Diastolic blood pressure measurements were significantly higher at intubation compared to baseline ($P<0.001$) and were significantly lower at 5min, 15min, 20min, 25min, skin incision, 35min, 45min, 55min, 60min and 60min compared to baseline ($P<0.001$). Diastolic blood pressure measurements were insignificantly different at 10min compared to baseline. Heart rate (bpm) measurements were significantly higher at intubation compared to baseline ($P<0.001$) and were significantly lower at 10min, 15min, 20min, 25min, skin incision, 35min, 45min, 50min, 55min and 60min compared to baseline ($P<0.001$). Heart rate (bpm) measurements were insignificantly different at 5min compared to baseline (Table 6).

Among our studied patients two had incidence of failed nerve block. A failed block was recognized by persistent increase in heart rate and blood pressure with skin incision more than 20% of the baseline that did not subside and needed rescue analgesia. PPI readings increased slightly after 30 minutes (from 3.2 to 3.5) for one case and (4.3 to 4.6) for the other. PPI value did not vary between both limbs at 30mins. These two patients were dealt with as per protocol for analgesia under general anesthesia. No adverse events were encountered to any of our 55 studied patients.

Table 5: Role of delta peripheral perfusion index and delta temperature in prediction of block success:

Variable	AUC	95% CI	SE	*P* value
Delta peripheral perfusion index	0.986	0.909 to 1.000	0.016	0.004*
Delta temperature	0.642	0.501 to 0.766	0.128	

AUC: Area under curve; CI: Confidence interval; SE: Standard error; *: Significant as $P<0.05$

Table 6: Systolic blood pressure, diastolic blood pressure and heart rate measurements of the studied patients:

		Mean±SD	Range	*P* value
Systolic blood pressure (mmHg)	Baseline	105.6±10.51	79-126	
	At intubation	122.6±10.79	98-139	<0.001*
	5-min	110.9±13.12	75-128	<0.001*
	10-min	104.3±11.12	76-122	0.184
	15-min	99.1±9.75	78-118	<0.001*
	20-min	97.1±9.75	75-117	<0.001*
	25-min	93.6±8.7	74-108	<0.001*
	Skin incision	96.4±8.55	82-124	<0.001*
	35-min	95.7±9.41	76-128	<0.001*
	40-min	93.9±9.33	78-123	<0.001*
	45-min	92.7±9.16	74-118	<0.001*
	50-min	92.7±9.43	76-119	<0.001*
	55-min	92±8.77	76-118	<0.001*
	60-min	92.4±8.88	79-119	<0.001*
Diastolic blood pressure (mmHg)	Baseline	52.9±6.74	37-67	
	At intubation	63.8±6.11	49-78	<0.001*
	5-min	56.1±8.5	30-74	<0.001*
	10-min	51.1±6.66	34-68	0.056
	15-min	48±5.52	34-60	<0.001*
	20-min	46.3±5.96	32-56	<0.001*
	25-min	45.2±6.72	30-58	<0.001*
	Skin incision	47.6±6.79	34-69	<0.001*
	35-min	46.6±6.89	32-69	<0.001*
	40-min	45.8±6.29	33-66	<0.001*
	45-min	44.9±5.47	34-64	<0.001*
	50-min	44.2±5.08	35-56	<0.001*
	55-min	43.8±5.25	34-56	<0.001*
	60-min	43.7±5.54	34-56	<0.001*
Heart rate (beat/min)	Baseline	119.2±11.69	89-135	
	At intubation	134.7±12.71	99-168	<0.001*
	5-min	118.6±11.85	92-146	0.488
	10-min	109.6±12.85	78-138	<0.001*
	15-min	104.8±12.33	72-128	<0.001*
	20-min	100.3±11.75	65-124	<0.001*
	25-min	98.6±13.62	56-140	<0.001*
	Skin incision	101.8±12.79	70-149	<0.001*
	35-min	99.8±14.34	67-149	<0.001*
	40-min	97.3±13.51	61-137	<0.001*
	45-min	96.1±13.48	59-135	<0.001*
	50-min	95.7±13.62	64-136	<0.001*
	55-min	95.2±13.62	60-137	<0.001*
	60-min	94.5±13.51	62-134	<0.001*

SD: Standard deviation; *: Significant as $P<0.05$.

DISCUSSION

The main findings in our study were that PPI is a valid measure for predicting the success of SCBPB in children undergoing upper limb surgery after induction of general anesthesia; moreover, our study showed that PPI is more sensitive than peripheral skin temperature in predicting block success based on the fluctuation of hemodynamics throughout the operation and lack of the need for rescue analgesia.

Abdelnasser *et al.,* investigated the validity of PPI as an indicator for SCBPB success in a study that included seventy seven awake adult patients undergoing orthopedic upper limb surgery and block success was confirmed by the loss of sensory and motor function supplied by the brachial plexus in the blocked limb. These results were in line with our study results, proving that PPI was a valid indicator of block success [9].

Their methods of assessing block success are invalid in children, as nerve block in children is mostly done under sedation or general anesthesia.

This study was also criticized in an article by D. Paul, where they questioned the direct vasoactive effect of injecting local anesthesia near the feeding artery (subclavian artery in this case) to be a cause of increased PPI reading. The author of the later article proposed that changes in PPI readings and PPI ratio of the blocked limb in a failed block may provide more validity to the study [14]. Thus, we were keen to provide our two failed block cases' numbers, which showed significant difference from successfully blocked cases as lower PPI values and absence of discrepancy between both limbs.

Another study with similar findings by Lal. *et al.,* showed that PPI can be a reliable time saving measure to assess a successful block, however like the prior it was conduct on adult patients; moreover, PPI was not recorded in an unblocked arm and no comparison was made [15]. They had a low number of failed blocks in which they did not supplement these blocks with additional injections. Improvement in PPI readings with supplementation of failed blocks could have further confirmed their results.

Local anesthetic injection in our study was done after induction of general anesthesia. The effects of general anesthesia on PPI value are illustrated in a study by Park *et al.,* where they observed that PPI value increased with Sevoflurane anesthesia [16]. Such finding was taken into account while designing our study, as two sets of PPI readings from both (blocked and unblocked) arms were collected. PPI values (represented as delta PPI) recorded on the blocked side were significantly higher than those of the unblocked one.

Skin temperature is recognized as a valid measure of assessment of nerve block success and it is shown to be superior to pin prick and cold sensation in the study conducted by Galvin *et al.,* [17].

In our study it was observed that PPI is a more sensitive and specific measure than measuring skin temperature for predicting block success in children under general anesthesia. Our findings were matched by the previous study by Ginosar *et al.*; twenty-nine subjects had photoplethysmography signals that met a prior signal quality criterion for analysis. By 20 minutes, PPI increased by 326%, compared with a 10% decrease and a 3% increase in MAP and toe temperature, respectively. For PPI 15/29, 26/29 and 29/29 of the subjects met the sympathectomy criteria at 5, 10 and 20 min, respectively, compared with 4/29, 6/29 and 18/29 for MAP changes and 3/29, 8/29 and 14/29 for toe temperature changes [18].

Another study by D Kim *et al.,* showed that both PPI and skin temperature measurement were of the same sensitivity in predicting block success. Nevertheless, peak PPI values were reached faster (14 min.s) than the peak skin temperature values (17 min.s) [19]. This outcome may be due to a discrepancy in skin blood flow control during the changes in peripheral vasodilation.

Our study faced some limitations as it took place only in one hospital, however; Kasr Alaini is considered a leading teaching hospital in Egypt, and the practice in Kasr Alaini can be a mirror of the standard of care nationwide also, we had to study patients undergoing different types of operations. Neither the operating surgeon nor operating time were standardized, however, we randomly chose those patients while excluding lengthy operations and operations with vascular manipulation. We had a few numbers of unsuccessful block cases; more failed cases may have provided more significant statistical proof to our study.

CONCLUSION

PI is a valid measure for predicting the success of SCBPB in children undergoing upper limb surgery after induction of general anesthesia. Skin temperature is a valid measure of block success in adults; however, it is not as reliable as PI in children under general anesthesia.

CONFLICTS OF INTEREST

There are no conflicts of interest.

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