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Original Article

Perfusion Index As A Predictor of Successful Spinal Anesthesia: A Time-Dependent Receiver Operating Characteristics Curve Analysis

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ABSTRACT

Objective: The aim of this study was to evaluate the changes in perfusion index (PI), skin temperature, and mean arterial pressure (MAP) during spinal anesthesia and to determine the success of spinal anesthesia using the PI values.

Methods: A total of 128 patients belonging to American Society of Anesthesiologists' physical status I-II undergoing elective surgery under spinal anesthesia at the T10 level were included in this study. MAP, heart rate, body temperature, PI, and spinal anesthesia level, determined with the pinprick test, were recorded from baseline to 30 min following anesthesia induction. Repeated measures ANOVA test was used to evaluate changes after spinal block and linear mixed models were created. Time-dependent receiver operating characteristics (ROC) curves, using post-anesthetic 2nd min PI measurements and time to T10 spinal anesthesia level, were estimated to predict further successful spinal blockade. In addition, standard ROC curve analysis was performed for the PI ratios.

Results: There was a significant linear increase in PI values (β=0.14, standard error = 0.01, p<0.001). Time-dependent ROC curves became significant for the post-anesthetic 6th min and after. Specificity was 100% after the 15th min. The cutoff value of post-anesthetic 2nd min PI was 2.4 (Area under the ROC curve-AUC: 0.71, 95% confidence interval: 0.59–0.83, sensitivity: 47%, specificity: 100%) to predict successful spinal blockage for the 15th min. In standard ROC curve analysis, only the 2nd min ROC curve revealed a significant AUC.

Conclusion: All of the patients whose PI measurement at the 2nd min after the induction of anesthesia was above 2.4, reached the T10 spinal block level at the 15th min after induction. This finding must be supported by the increasing trend in PI individually. Adaptation of the study findings to the operation room practice may be considered for the patients with limited compliance to the pinprick test.

INTRODUCTION

Spinal anesthesia is a regional anesthesia technique, defined as temporarily blocking nerve conduction by injecting a local anesthetic (LA) agent into the cerebrospinal fluid. In this way, ideal operating conditions are achieved by disrupting the afferent transmission of painful stimuli and eliminating the efferent stimuli responsible for skeletal muscle tone.[1–3]

In patients who undergo regional blockade, the efficacy of anesthesia is evaluated by temperature (cold/heat) test and/or loss of pain sensation and motor block test.[2] It has been reported that these traditional methods of regional block success assessment are subjective and time-consuming, and depend on the patient's cooperation.[3] An objective and fast technique for anesthesia efficacy assessment in a regional block increases not only the patient-doctor trust but also the operating room availability.[4]

The perfusion index (PI) automatically calculated by the pulse oximetry is an indicator of peripheral blood flow and reflects changes in the vasomotor tone. The vasomotor tone is influenced by patient-related factors such as sympathetic tonus, pain, and heat.[5] PI is an assessment of the pulsatile strength at a specific monitoring site (e.g., the hand, finger, or foot). It is calculated by means of pulse oximetry by expressing the pulsatile signal (during arterial inflow) as a percentage of the non-pulsatile signal, both of which are derived from the amount of infrared light absorbed.[6] The PI is the ratio of the pulsatile component of pulse oximetry plethysmography to the non-pulsatile component and provides a non-invasive demonstration of the changes in the finger blood flow.[7] The PI is used to identify the sympathetic vascular tone and changes in blood volume.[8] A relative increase in pulsatile flow in states of vasodilation leads to an increase in PI. After a successful regional block with LA, increases are observed in the local vasodilation, local blood flow, and skin temperature depending on the block of sympathetic nerve fibers.[4,9] Changes in the PI may be due to changes in blood volume and pulsation, the flexibility of the vessel wall and intravascular pulse pressure.[6] A special probe is required to measure the PI. Although this probe is more expensive than conventional pulse oximetry probes, its use as an indicator of peripheral perfusion[10] and as an index for sympathetic stimulation[11] is increasing.

The wide range in baseline PI values[4,7] and the tendency to dynamic increase in PI values after LA injection make it difficult to evaluate the predictive value of PI for the successful block in comparison to classic neurological methods. PI and PI ratio (PI at a given time after LA injection divided by baseline PI) was studied in supraclavicular brachial plexus block,[3] but no studies about PI and spinal block efficacy were found in the literature.

The aim of this study was to predict the success of spinal blockage using PI in comparison to the conventional pinprick method.

MATERIALS AND METHODS

This study was initiated after obtaining approval from the ethical committee (Protocol No: 1602-GOA, Date: 24.07.2014) of the Medical Faculty Hospital at Dokuz Eylul University. Written informed consents of all participants were obtained before the study. This prospective, observational study included 128 American Society of Anesthesiologists' physical status (ASA-PS) I-II patients aged 18–65 years who were scheduled for elective surgery, requiring a T10-level block under spinal anesthesia. Patients with ASA III or higher, patients using antihypertensive drugs (such as α- and β-blockers), patients who had a history of diabetes mellitus, peripheral vascular disease, or peripheral neuropathy were excluded from the study.

The patients were not informed about the drug or the combination of drugs. Before the block procedure, the patients received 5 ml/kg 0.9% NaCl intravenously with an 18-gauge intravenous catheter. All patients underwent sensory evaluation before anesthesia. Routine monitoring (non-invasive arterial blood pressure measurement, electrocardiogram, and peripheral oxygen saturation measurement) was performed (HP Viridia Component Monitoring System, USA). The pulse oximetry probe (LNCS adult adhesive sensor connected to Masimo SET_ Radical- 7TM Pulse CO-Oximeter; Masimo Corporation, Irvine, CA, USA) was placed on the 2nd finger of the patient's lower extremity, which would not be operated on. During the study, this probe was used to monitor the PI and record the data obtained. The skin temperature was monitored with a skin temperature probe (Draeger Medical Systems, 4329889C2) placed on the dorsum of the foot and recorded in Celsius. The foot was covered to minimize the impact of the surrounding sources of light on the PI value.

The patients were pre-medicated with 0.02 mg/kg midazolam (Dormicum; Roche, Basel, Switzerland). Optimal physical conditions for surgery were ensured under sterile conditions with patients placed in a sitting position before spinal anesthesia. Then, the spinal puncture was performed on the midline at the L3-4 or L4-5 levels. 10–15 mg of hyperbaric bupivacaine (Buvasin %0.5, VEM Pharmaceutical Industry and Trade Corporation, Ankara, Turkey) was administered as a LA agent for spinal anesthesia. Twenty micrograms of fentanyl were added to the LA, and no other adjuvants were added. To not compromise the accurate measurement of the PI, the ambient temperature was kept constant at 22°C, and all patients had spinal anesthesia with a 25 gauge Quincke type spinal needle (Egemen International, Medical Materials Industry and Trade Corporation, Izmir, Turkey) in a sitting position.

The moment when the needle was removed from the skin after spinal anesthesia administration was assumed to be the baseline. PI, mean arterial pressure (MAP), skin temperature (t), heart rate (HR), and patient responses to the pinprick test in different dermatomes, as well as motor block (Bromage scale), were recorded at post-anesthetic 2nd, 4th, 6th, 8th, 10th, 15th, 20th, 25th, and 30th min. The pinprick examination was performed with a 22-gauge needle along the midclavicular line. Surgical intervention was permitted when a sensory block developed at the T10 level. General anesthesia was performed on patients who had failed spinal anesthesia.

Statistical analysis

The data were analyzed using R version 3.5.1 (a language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org) using the open-source packages "ez," "survival," "survminer," "lmerTest," and "timeROC." The sample size was calculated as 119 in ANOVA design; considering the effect size of 0.1, correlation among repeated measurements of 0.5, a minimum 95% power, and 5% alfa error probability for ten repeated measures in one group (G*Power version 3.1.9.2).

Descriptive statistics were displayed as mean ± standard deviation and numbers with percentages unless stated otherwise. Repeated measures ANOVA with Post hoc Bonferroni test was conducted to test the difference between baseline and post-anesthetic 2nd, 4th, 8th, 15th, and 30th min PI, MAP, HR, and t measurements. Linear mixed models were employed to analyze individual changes over time, allowing random intercept and random variation of growth rates between the individuals. As we are interested in the earliest measurement of PI after LA injection, taking into account the time management in the operation room, optimal cutoffs of post-anesthetic 2nd min PI measurements were selected to predict the T10 spinal block for further minutes up to the 30th min. We conducted a time-dependent receiver operating characteristics (ROC) curve analysis with inverse probability of censoring weighting estimation as described elsewhere.[12,13] In addition, standard ROC curve analysis was performed for the PI ratios to predict the T10 spinal block for each post-anesthetic 2nd, 4th, 6th, 8th, 10th, 15th, 20th, 25th, and 30th min, separately. The optimal cutoffs were determined using Youden Index [YI(c) = maxc (sensitivity(c) + specificity(c)-1]. Significance was defined at the double-sided p<0.05.

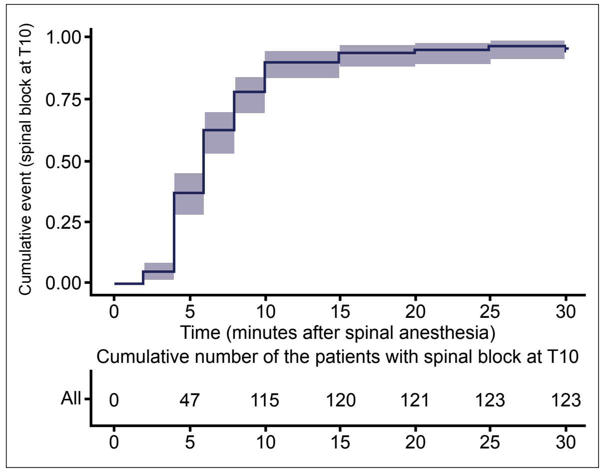

Figure 1. Cumulative number of events for post-anesthetic 30 min.

RESULTS

Of the 128 patients (mean age: 54.02±16.4; males: 74.2%), spinal anesthesia failed in 5 (3.9%) patients; therefore, they were converted to general anesthesia. Demographics of the patients are presented in Table 1. Surgical procedures were due to coxarthrosis, hip fracture, inguinal hernia, transurethral resection of the prostate, and vaginal hysterectomy. 115 (93%) of the patients were at the T10 spinal blockage level at the 10th min (Fig. 1).

There was a statistically significant difference between pre- and post-anesthetic measurements of PI, MAP, t, and HR (p<0.001) (Table 2). The baseline PI measurements started to differ at 2nd min. Post-hoc tests with Bonferroni adjustments revealed a significant difference in all possible pairwise comparisons of PI measurements and temperature. For MAP, there was a significant difference in pairwise comparisons (p<0.001), except the measurements between 8th–15th, 8th–30th, and 15th–30th min (p=1, p=0.09, and p=0.30, respectively). Significant changes in HR measurements were observed for all possible comparisons with the 15th and 30th min.

Table 1. Baseline characteristics of the patients

	Results
Gender, n (%)	
Male	95 (74.2)
Female	33 (25.8)
Age (years)	54.02±16.4
BMI (kg/m^2), mean±SD	25.8±2.5
ASA, n (%)	
I	21 (16.4)
II	107 (83.6)
Baseline PI (min-max)	0.1–10

SD: Standard deviation; BMI: Body mass index; ASA: American Society of Anesthesiologists; PI: Perfusion index.

Table 3 shows that the initial status and linear growth rates of all measurements were not constant over time. There was a significant linear increase in PI (β=0.14, SE=0.01, p<0.001) and t (β=0.17, SE=0.01, p<0.001), while there was a significant linear decrease in MAP (β=−0.42, SE=0.04, p<0.001) and HR (β=−0.31, SE=0.03, p<0.001).

The results of the estimated time-dependent ROC curves of 2nd min PI measurements for predicting T10 spinal blockage at 4th, 6th, 8th, 10th, 15th, 20th, and 25th min are summarized in Table 4. ROC curve for post-anesthetic 4th min was not significant (Area under the ROC curve-AUC: 0.60, 95% confidence interval [CI]: 0.38–0.81). ROC curves became significant at the beginning of the 6th min after the spinal anesthesia. Specificity and the positive predictive value (PPV) was 100% after the 15th min. The maximum AUC was for the 25th min's time-dependent ROC curve (AUC: 0.73, 95% CI: 0.61). Cutoff values of 2nd min PI measurements, predicting successful spinal block for 15th min and 25th min were 2.40 and 2.61, respectively.

Table 2. Comparison of the baseline and post-anesthetic 2nd, 4th, 8th, 15th, and 30th min measurements of PI, MAP, HR, and t

	Baseline	2nd	4th	8th	15th	30th	p
PI	1.7±1.6	2.5±2.1	3.6±2.6	4.9±3.2	5.8±3.8	6.4±4.2	<0.001*
MAP (mm Hg)	100.7±15.5	96.3±15.6	91.9±14.9	87.5±14.2	87.1±14.2	85.3±15	<0.001*
HR (beats per min)	76.5±13.6	75.9±14.9	76.8±14.7	75.6±14.9	73±14.3	67.7±13	<0.001*
t (°C)	29.1±1.9	29.5±2.1	29.7±2	30.6±2.3	32.1±2.4	34±1.8	<0.001*

Data were presented as mean±standart deviation. PI: Perfusion index; MAP: Mean arterial pressure; HR: Heart rate; t (°C): Temperature (degree Celcius), *p<0.05.

Table 3. Results of linear mixed models for PI, MAP, HR, and t

Variable	Estimate	Std. error	t	p
PI				
Intercept	2.91	0.20	14.76	<0.001*
Time (min)	0.14	0.01	12.53	<0.001*
MAP (mmHg)				
Intercept	95.45	1.22	78.19	<0.001*
Time (min)	−0.42	0.04	−11.57	<0.001*
HR (beats/minute)				
Intercept	77.19	1.25	61.66	<0.001*
Time (min)	−0.31	0.03	−10.76	<0.001*
t (°C)				
Intercept	29.11	0.19	151.8	<0.001*
Time (min)	0.17	0.01	27.5	<0.001*

PI: Perfusion index; MAP: Mean arterial pressure; HR: Heart rate; t (°C): Temperature (degree Celcius); Std.Error: Standard error of the estimate, *p<0.05.

Standard ROC curve analysis for PI ratios for the 2nd min revealed a significant AUC (AUC: 0.72, 95% CI: 0.56–0.89). Cutoff of PI ratio was 1.67 with 83% sensitivity and 65% specificity (PPV: 70%, negative predictive value: 79%). The remaining ROC curves of PI ratios for 4th, 6th, 8th, 10th, 15th, 20th, and 25th min were not statistically significant.

DISCUSSION

Recently, the PI has been used in many studies to evaluate block efficacy in neonates[14] and adults.[3,4,7,9,15] To the best of our knowledge, this study is the first to evaluate the spinal block success with PI. In this study, 2nd-min measurements of PI predicted no false positives (PPV: 100%) for the post-anesthetic 15th min and after. It is estimated that there would be no patient with a 2nd min PI measurement above 2.40 but had not reached the T10 spinal anesthesia at the 15th min.

The PI value itself would be an important indicator of the effectiveness of spinal blockage when compared to conventional methods. Conventional methods like pinprick are subjective and more challenging to administer to older patients who are sedated or who have neurocognitive disorders, children, patients with neuropsychiatric disorders, or patients with a speech impediment. As the research on more quantitative methods to detect successful block goes on, different procedures such as thermographic temperature measurement,[4] Doppler perfusion imaging including laser,[16] and skin electrical resistance[17] were studied. However, these objective procedures are time-consuming, often requiring expensive, and sophisticated equipment. PI is a simple, fast, objective, non-invasive, and cost-effective technique.

A significant increase in PI and t and a significant decrease in MAP and t was observed in our study. PI, t, and MAP were started to differ at the 2nd min when they were compared to the baseline. Ginosar et al.[8] reported that these sympathectomy findings after epidural anesthesia were detected earlier and more accurately by PI measurement compared with skin temperature and arterial pressure. The lumbar sympathetic block was associated with sympathectomy-related vasodilation, changes in skin temperature,[4,18] and blood pressure changes.[19]

In our study, 115 (96.1%) patients reached the T10 spinal block level in the 10th min. The spinal failure rate ranges between <1% and 17% in the literature.[20] The level of anesthesia will necessarily increase with time if spinal anesthesia has been successfully applied. As the successful spinal block develops quickly, an increasing trend in PI can be combined with the statistically significant time-dependent cutoff values of 2nd min PI. Clinical reflection of this subject would be to keep the anesthesiology team from the repeated examination of the anesthesia level before the 15th min. In addition, the surgery team may be informed that the procedure can be started after 15 min. Although it is not a routine in our institution and the 15-min time may be a long waiting-time for pending surgeries; the com-

Table 4. Time-dependent ROC curves of 2nd min PI measurements to predict the T10 spinal blockage for the 4th, 6th, 8th, 10th, 15th, 20th, and 25th min, showing cutoff values of 2nd min PI, AUC (95% CI), sensitivity, specificity, positive, and negative predictive values for the defined time (min)

Defined time (min)	The cut-off value of 2nd min PI measurements	AUC (95% CI)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
4th	NA	0.60 (0.38–0.81)*	NA	NA	NA	NA
6th	2.60	0.62 (0.51–0.74)	66	65	65	66
8th	2.61	0.63 (0.51–0.75)	62	69	67	65
10th	2.61	0.65 (0.51–0.80)	59	77	72	65
15th	2.40	0.71 (0.59–0.83)	47	100	100	65
20th	2.40	0.67 (0.55–0.79)	47	100	100	65
25th	2.61	0.73 (0.61–0.84)	55	100	100	69

PI: Perfusion index; AUC (95% CI): Area under the ROC curve (95% confidence interval); PPV: Positive predictive value; NPV: Negative predictive value; NA: Not applicable. *The confidence interval of the area under the curve cut the random classification line; therefore, the cut-off of 2nd min PI, sensitivity, and specificity for the 4th min were not determined.

bination of PI cutoffs and an increasing trend of PI may be considered for the patients with limited compliance to the pinprick test.

Baseline PI values vary from person to person due to changes in vasomotor tone caused by sympathetic activity, pain, and temperature.[3] Diseases such as diabetes and neuropathic injuries can change the degree of vasodilation that occurs after a successful block procedure. We excluded the patients who had a history of diabetes mellitus, peripheral vascular disease, or peripheral neuropathy, so there may have been a relative increase in PI values in this study. It should be noted, however, that in a previous study there was no significant difference between baseline PI values in subjects with or without vascular diseases (diabetes and hypertension) or between smokers and non-smokers.[7]

Due to the high variability of individual baseline PI values, the studies reported that it is more helpful to use PI ratio.[7] To overcome the varying time to reach successful spinal anesthesia level (T10) and varying baseline PI's among the patients, we used time-dependent ROC curves with the indicator itself as well as standard ROC curves with PI ratio. The only statistically significant standard ROC curve of PI ratio was estimated for the 2nd min (cutoff value: 1.67, 83% sensitivity, and 65% specificity). Abdelnasser et al.[3] found that the cutoff value for PI was >3.3 at the 10th min, whereas the cutoff value for the PI ratio was >1.4 and Galvin et al.[4] found that it was 1.55. The similarity of PI ratio cutoff values in these studies despite methodological differences (supraclavicular nerve block vs. axillary and sciatic; ultrasound vs. nerve stimulator; and bupivacaine and lidocaine vs. mepivacaine) is important tips for reaching a definitive cutoff value for PI ratio.

Our study has few limitations. First is the presence of a group of patients undergoing different operations. Second is the individual variation of the basal PI, MAP, HR, and t. All may affect the standardization of the repeated calculations.

CONCLUSION

PI was found to be a useful tool for evaluating the success of spinal block procedures compared with the pinprick test. The cutoff values must be individually combined with the increasing trend in PI. Adaptation of the study findings to the operation room practice may be considered for the patients with limited compliance to the pinprick test.

Ethics Committee Approval

This study approved by the Dokuz Eylul University Faculty of Medicine Ethics Committee (Date: 24.07.2014, Protocol No: 1602-GOA).

Informed Consent

Prospective study.

Peer-review

Internally peer-reviewed.

Authorship Contributions

Concept: N.B., S.O., A.K., M.A., C.A.M., A.N.E.; Design: N.B., S.O., A.K., M.A., C.A.M., A.N.E.; Supervision: N.B., S.O., A.K., M.A., C.A.M., A.N.E.; Fundings: M.A.; Data: S.O., N.B., C.A.M., D.O.A.; Analysis: N.B., A.N.E.; Literature search: N.B., A.N.E., A.K.; Writing: N.B., A.N.E.; Critical revision: N.B., A.K., S.O.

Conflict of Interest

None declared.

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Başarılı Spinal Anestezinin Belirleyicisi Olarak Perfüzyon İndeksi: Zamana Bağlı ROC Eğrisi Analizi

Amaç: Bu çalışmanın amacı spinal anestezi sırasında perfüzyon indeksi, cilt sıcaklığı ve ortalama arter basıncı değişikliklerini değerlendirmek ve perfüzyon indeksi değerlerini kullanarak spinal anestezinin başarısını belirlemektir.

Gereç ve Yöntem: Çalışmaya torakal 10 (T10) seviyesinde spinal anestezi altında elektif cerrahi geçiren, American Society of Anesthesiologists (ASA) fiziksel durumu I–II olan toplam 128 hasta dahil edildi. Ortalama arter basıncı, kalp atım hızı, vücut sıcaklığı, perfüzyon indeksi ve pinprick testi ile belirlenen spinal anestezi seviyesi; anestezi indüksiyonunu takiben 30 dakika boyunca kaydedildi. Spinal blok sonrası değişiklikleri değerlendirmek için tekrarlı ölçümler ANOVA testi kullanıldı ve doğrusal karma modeller oluşturuldu. Anestezi sonrası 2. dakikadaki perfüzyon indeksi ölçümleri için zamana bağlı ROC eğrileri oluşturularak T10 spinal anestezi seviyesine ulaşmayı öngörecek kesim noktaları belirlendi. Ek olarak, perfüzyon indeksi oranları için standart ROC eğrileri oluşturuldu.

Bulgular: Perfüzyon indeksi değerlerinde anlamlı bir doğrusal artış vardı (β=0.14, standart hata = 0.01, $p<0.001$). İstatistiksel olarak anlamlı zamana bağlı ROC eğrileri, anestezi sonrası 6. dakika ve sonrası için elde edildi. Onbeşinci dakikadan sonra spesifisite %100 idi. Anestezi sonrası 15. dakikadaki T10 spinal blokaj oluşumu için, 2. dakikadaki perfüzyon indeksi ölçümlerinin kesim noktası 2.40 idi (Eğri altında kalan alan-EAA: 0.71, %95 güven aralığı-GA: 0.59–0.83, sensitivite: %47, spesifisite: %100) idi. Standart ROC analizinde ise yalnızca 2. dakikadaki perfüzyon indeksi oranları için eğri altında kalan alan istatistiksel olarak anlamlıydı.

Sonuç: Anestezi indüksiyonu sonrası 2. dakikadaki perfuzyon indeksi ölçümü 2.4'ün üzerinde olan hastaların hepsi, indüksiyon sonrası 15. dakikada T10 spinal blok seviyesine ulaşmıştı. Bu bulgunun tekrarlayan perfüzyon indeksi ölçümlerindeki artış eğilimi ile desteklenmesi gerekmektedir. Pinprick testine uyumu kısıtlı hastalar için, çalışmanın bulgularının ameliyathane pratiğine adaptasyonu düşünülebilir.

Anahtar Sözcükler: Perfusion index; rejyonal anestezi; spinal anestezi.