Correlation between Perfusion Index and Left Ventricular Output in Healthy Late Preterm Infants

Nilay Hakan (nhakan@hotmail.com)
Sıtkı Koçman University https://orcid.org/0000-0002-6575-7640
Ayça Aytekin
Muğla Sıtkı Koçman Üniversitesi: Mugla Sitki Kocman Universitesi
Özkan İlhan
Muğla Sıtkı Koçman Üniversitesi: Mugla Sitki Kocman Universitesi
Mustafa Aydin
Firat University School of Medicine: Firat Universitesi Tip Fakultesi
Haşim Olgun
Muğla Sıtkı Koçman Üniversitesi: Mugla Sitki Kocman Universitesi

Research Article

Keywords: Perfusion index, left ventricular output, late preterm infants, echocardiography

Posted Date: May 14th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-519041/v1

Abstract

The perfusion index (PI) is a noninvasive marker derived from photoelectric plethysmographic signals in pulse oximetry in the evaluation of peripheral perfusion. This study was aimed to determine the correlation between PI and left ventricular output (LVO) in healthy late preterm infants at 48th hour of life. With new generation pulse oximeter [MASIMO Rad 7 Oximeter] pre- and post-ductal PI values were recorded from healthy late preterm babies at the 48th hour of life. PI was determined simultaneously with LVO as measured by transthoracic echocardiography. A total of 50 late preterm babies were included in the study. The mean gestational age of the cases was 35.4 ± 0.7 weeks and the birth weight was 2586 ± 362 g. Mean pre- and post-ductal PI values at the postnatal 48th hour of babies' life were found to be 2.0 ± 0.9 and 1.7 ± 1.1. The mean LVO value was 438 ± 124, LVO/kg 175 ± 50. When the LVO value was normalized according to the babies' body weight, there was no statistically significant correlation between the pre- and post-ductal PI and the LVO / kg value ($r < 0.2$, $p > 0.05$ in both comparisons).

Conclusion: There was no correlation between pre- and post-ductal PI and LVO values in healthy late preterm infants. This may be due to the failure of the LVO, a systemic hemodynamic parameter, to accurately reflect microvascular blood flow due to incomplete maturation of the sympathetic nervous system involved in the regulation of peripheral tissue perfusion in preterm babies.

What Is Known?

- Peripheral perfusion index (PI) derived from photoelectric plethysmographic signals in a new generation pulse oximeter has been reported to show real-time changes in peripheral blood flow.
- Changes in PI are thought to be related to changes in peripheral vascular tone and cardiac output.
- It is suggested that PI may be a possible marker for screening critical congenital heart diseases with low left ventricular output (LVO).

What Is New?

- There is no correlation between pre- and post-ductal PI and LVO values in healthy late preterm infants.
- LVO cannot adequately reflect peripheral microvascular blood flow due to incomplete maturation of the sympathetic nervous system in preterm infants

Introduction

Congenital heart diseases (CHD) are the most common birth defects, with a prevalence of approximately 1 percent of births. About 25 percent of these babies have a critical CHD that requires catheter-based intervention or surgery in the first year of life, and late diagnosis is associated with higher mortality and morbidity [1]. Therefore, peripheral capillary oxygen saturation (SpO_2) should be determined by pulse oximeter from pre - and post-ductal regions in infants who are about 48 hours old for early diagnosis of

critical CHD as a universal neonatal screening strategy in line with the recommendations of the American Academy of Pediatrics, the American Heart Association, and the American College of Cardiology [2, 3]. A major disadvantage of this screening method is that it cannot detect CHD even if it is at a critical level in patients with low left ventricular output (LVO) [4]. To detect these cases, it is recommended that SpO_2 measurement be supplemented with perfusion index (PI) during screening [5].

PI is an easy-to- apply, inexpensive and noninvasive method used in clinical practice to evaluate peripheral perfusion of critical patients [6]. Peripheral PI derived from photoelectric plethysmographic signals in a new generation pulse oximeter has been reported to show real-time changes in peripheral blood flow, and is a numerical value that occurs when infrared signals at the monitored location are reflected relative to different tissue components [7, 8]. It is achieved by the ratio of variable light absorption (AC) due to pulsatile arterial blood flow to constant light absorption (DC) due to non-pulsatile blood flow in venous blood, connective tissue, skin, bone and other tissues [7]. Changes in PI are thought to be related to changes in peripheral vascular tone and cardiac output [9]. It is suggested that PI may be a possible marker for screening critical CHD with low LVO [5]. But it is not known whether there is a correlation between PI and LVO in late preterm infants. A literature review showed that there was only one study in term infants on this topic [10], but no study in late preterm infants.

The aim of this study is to determine whether there is a correlation between PI and LVO in healthy late preterm infants.

Materials And Methods

This study included clinically and hemodynamically stable late preterm infants ($34^{0/7}$ and $36^{6/7}$ weeks gestational age) born in a university hospital between August 2019 and February 2020. Study was approved by xx University Ethics Committee (date: May 02, 2019 and decision no: 08 / II). The babies were considered hemodynamically stable according to the following criteria: normal skin color, respiratory pattern and cry, normal posture, muscle tone and movements, and no need for fraction of inspired oxygen (FiO_2) $\geq$ 0.25, heart rate (HR) 100–160 beats/min, respiratory rate 40–60 breaths/min, absence of > 20 sec apnea episodes. During the first 12 h after birth, the clinical and laboratory evaluations were carried out to assessment for Score for Neonatal Acute Physiology - Perinatal Extension (SNAPPE-II) [11]. Neonates with a SNAPPE-II score of > 18 were excluded from the present study. In addition, exclusion criteria were as follows: maternal gestational diabetes, pregnancy hypertensive disorders, premature rupture of membranes, Apgar score < 6 at 1 min, FiO_2 requirement $\geq$ %25 and need for mechanical ventilation, and invasive procedures at birth, intra-cardiac shunt with the exception of patent foramen ovale and non-hemodynamically significant ductus arteriosus, intrauterine growth restriction, and congenital malformations (congenital diaphragmatic hernia, neural tube defect etc.).

Along with demographic and clinical information of infants, PI, SpO_2, HR, body temperature, blood pressure (BP) and cardiac output (CO) values measured at the 48th hour of life were recorded into previously prepared forms. The pre-ductal (right hand) and the post-ductal (foot) PI, SpO_2, and HR were

measured by Masimo Radical 7 pulse oxymetry (Masimo Corp., Irvine, CA, USA). The PI value was recorded during the echocardiographic examination after a period in which the signal was stable and artifact-free with an average time setting of 3 min. The median PI for each measurement was obtained from the average of PI values recorded signal at 10-s intervals. Transthoracic echocardiographic (TTE) examination was performed by a single pediatric cardiologist using Philips EPIQ7C Ultrasound System (Philips Healthcare, Best, The Netherlands), with 12S transducer (S12-4 Sector Array Transducer), and CO value was calculated with “pulse wave” Doppler echocardiography. Simultaneously measured PI value was not reported to the pediatric cardiologist. Right ventricular output (RVO), LVO, superior vena cava (SVC) flow, right and left ventricular outflow tract velocity time integral (VTI) values were measured by two-dimensional and pulsed-wave Doppler echocardiography. LVO was evaluated, using the following formula as previously reported by European Society of Pediatric Cardiology [12]: LVO (mL/min) = LVO velocity time integral (VTI) (cm) × π × (LVO diameter/2)^2 (cm^2) × HR (bpm).

LVO diameter was measured just below the aortic valve during 5 consecutive systole in a cardiac long axis view with 2d mode TTE, and averaged. LVO VTI was measured with “pulse wave” Doppler echocardiography tracing in a five-chamber apical view with the box positioned inside the LVO tract and with an angle < 15°.

RVO was evaluated in agreement with van Vonderen et al [13] using the following formula: RVO (mL/min) = RVO VTI (cm) × π × (RVO diameter/2)^2 (cm^2) × HR (bpm). By the same method, the RVO diameter was measured from the adhesion site of the pulmonary valves during 5 consecutive systoles in a cardiac transthoracic short axis and averaged. RVO VTI was measured with pulse Doppler tracing in a cardiac view with the box positioned inside the RVO tract and with an angle < 15°.

The superior vena cava flow (SVCf) was evaluated in agreement with Kluckow et al [14] using the following formula: SVCf (mL/min) = (mean SVC VTI × π × (mean SVC diameter^2/4) (cm^2) × HR (bpm). In subcostal view, the maximum and minimum SVC inner diameter was measured from the right atrium - SVC connection area during 3 consecutive cycles with 2d mode TTE and averaged. SVC VTI was measured with pulse Doppler tracing in the box positioned at the junction of the SVC and the right atrium with an angle < 15° (14). The mean velocity of SVCf was averaged from five consecutive cardiac cycles with "pulsed wave" Doppler echocardiography.

LVO, RVO and SVCf values were standardized by proportioning the baby’s weight at the time of operation. LVO, RVO, SVCf values were standardized by proportioning the baby's weight at the time of study. (LVO/kg, RVO/kg, and SVCf/kg).

Statistical analysis

SPSS 22.0 (SPSS, Chicago, IL, USA) was used for the statistical analysis. The data was expressed as mean (standard deviation, SD) or median (interquartile range [IQR]), frequency, percentage, minimum, maximum as appropriate. The suitability of quantitative data for normal distribution was tested by the

Shapiro-Wilk test and graphical assessment. Differences between two groups were tested by using Student's t -test or Mann-Whitney U-test. Pearson Chi-Square test and Fisher's exact test were used to compare qualitative data. Spearman correlation analysis and Pearson correlation analysis were used to evaluate the relationships between quantitative variables. A two-tailed p value of < 0.05 was accepted as significant.

Results

Overall 50 late preterm babies with negative CHD screening was studied, and the clinical characteristics of these babies were shown in Table 1. Of these babies, 14% (n: 7) were at 34th week of gestation, 24% (n: 12) at 35th week of gestation, and 62% (n: 31) at 36th week of gestation. Among them, 17 (34%) were hospitalized infants with a SNAPPE-II score of ≥ 18. None of them showed any evidence of cardiac pathologies and/or required blood transfusions or pharmacological treatments.

Table 1
Demographic and clinical characteristics of cases

Variables	**n = 50**
Gestational age (weeks, [mean ± SD])	35.4 ± 0.7
Birth weight (g, [mean ± SD])	2586 ± 362
Cesarean section (n, %)	40 (80)
Female / Male (n, %)	27 (54) / 23 (46)
Apgar score at 5th min. (median, range)	9 (8–10)
SD, Standard deviation	

Table 2 shows PI, SpO_2, HR, BP and body temperature mean ± (SD) or median (IQR) values of cases at the 48th hour of life. All infants had normal echocardiographic findings, none had hemodynamically significant patent ductus arteriosus (PDA). LVO, RVO, SVC diameter and VTI values measured by echocardiography are shown in Table 3. Mean values of LVO, RVO, and SVCf were 4438 ± 124, 626 ± 213 and 343 ± 139 mL/min, respectively. Mean values of LVO/kg, RVO/kg, and SVCf/kg were 175 ± 50, 250 ± 83 and 136 ± 52 mL/kg/min, respectively.

Table 2
PI, SpO_2, heart rate, blood pressure and body temperature of cases

Variables	n = 50
PI	
Preductal (mean ± SD)	2.0 ± 0.9
Postductal (mean ± SD)	1.7 ± 1.1
SpO_2	
Preductal (%, range)	97 (90–100)
Postductal (%, range)	97 (91–100)
HR (median, IQR)	137 (102–170)
Body temperature (°C, [median, IQR])	36.6 (36.4–36.9)
Systolic BP (mmHg, [median, IQR])	78 (63–108)
Diastolic BP (mmHg, [median, IQR])	47 (28–80)
Mean BP (mmHg, [median, IQR])	56 (32–85)
PI, Perfusion index; *SpO_2*, Oxygen saturation; *HR*, Heart rate; *BP*, Blood pressure;	
SD, Standard deviation; *IQR*, Interquartile range	

Pre-ductal PI was not significantly correlated LVO, LVO/kg, SVCf and SVCf/kg ($r < 0.2$ and $p > 0.05$ for all comparisons). A statistically weak correlation was found between pre-ductal PI values and RVO, RVO/kg values ($r < 0.3$ and $p < 0.05$ for all comparisons). No significantly correlation was found between post-ductal PI and LVO, LVO/kg, RVO, RVO/kg, SVCf, SVCf/kg ($r < 0.2$ and $p > 0.05$ for all comparisons; Table 4).

There was no significant correlation among pre- / post-ductal PI and HR, SpO_2, BP (systolic / diastolic / mean), body temperature of babies at the 48th hour of life ($r < 0.2$ and $p > 0.05$ for all comparisons). No association was found between Pre- / post-ductal PI and heart rate, SpO_2, body temperature, and blood pressure (systolic, diastolic, and mean blood pressure).

Discussion

In this study, the relationship between LVO and PI derived from a new generation pulse oximeters in healthy late preterm infants was investigated for the first time. It is believed that PI may be a direct predictor of peripheral perfusion, as well as a useful and practical method for determining critical patients in NICU and evaluating the effect of treatment on peripheral perfusion [15, 16]. Normal values of PI were

evaluated during the postnatal transition period and early neonatal period in healthy term infants [17, 18]. Cresi et al [19] was investigated the PI reference values in clinically and hemodynamically stable preterm infants during the first week of life. They reported average PI values measured from the feet of infants at 28 to 36 gestational weeks (mean 32.5 weeks) as 0.90 on the postnatal 1st day, 1.22 on the 3rd day and 1.36 on the 7th day. Although they found a significant difference in PI values between 1st day and 3rd day, there wasn't a significant difference between 3rd day and 7th day. They suggested that this trend of changes in peripheral PI values reflects physiological changes in peripheral microvascular blood flow that begin immediately after birth and may be associated with intrinsic hemodynamic adaptation that occurs on the first day of life. A study of systemic blood flow in preterm infants reported that perfusion is achieved even in the presence of low blood flow and high vascular resistance within the first 24 hours of life. In the following days, it was noted that vascular resistance decreased due to vasodilation and blood flow returned to normal [20]. In our study, the median PI value measured from the preterm babies' feet at the 48th hour of life was higher than the PI values from the study of Cresi et al [19]. This may have been caused by the fact that the gestation age of preterm infants in our study was higher than that of infants in the study of Cresi et al, and the completion of physiological changes in peripheral microvascular blood flow within the first 24 hours in our cases.

In a study conducted by Granelli et al [5], pre - and post-ductal PI reference values were investigated in 10.000 healthy newborns whose postnatal ages ranged from 1 to 120 hours. In this study, the measured PI 5th percentile value of both the right hand and foot was reported as 0.7. It is noted that a PI value of < 0.7 can be a critical CHD indicator. They suggested that only pre-and post-ductal arterial oxygen saturation screening can miss the diagnosis of infants with left ventricular obstruction, and that this screening method may be insufficient in the diagnosis of critical CHD associated with low systemic perfusion. But as far as we know, there is only one study in the English literature that evaluates the correlation between PI and LVO in the newborn. Corsini et al [10] showed for the first time that there is a correlation between PI and LVO in healthy term infants. In their study on 49 healthy term infants at the 2nd day of life, when postnatal transition circulation was completed, the average PI value of both pre-ductal and post-ductal was 1.9. In our study, the pre-ductal PI value was similar to the Corsini et al study, but the post-ductal PI value was lower. Corsini et al [10] reported the LVO/kg, RVO/ kg and SVCf/kg as 139, 160 and 132 mL/kg/min, respectively. In our study, both LVO/kg, RVO/kg and SVC/kg values were higher than those reported by Corsini et al [10]. They reported that there was a positive correlation between pre- / post-ductal PI and LVO in term infants, and also the correlation between PI and LVO/kg continued when LVO was normalized according to body weight (LVO/kg). Therefore, they noted that PI may have a role in detecting critical CHD with low perfusion. Contrary to the findings of Corsini et al [10], our study found no correlation between pre- / post-ductal PI and LVO in healthy late preterm infants. There was also no correlation between PI and LVO/kg when LVO was normalized according to body weight (LVO/kg). These data suggested that LVO, as a hemodynamic parameter, in healthy late preterm infants was not sufficiently sensitive to reflect peripheral microvascular blood flow. It has been thought that this difference between term and preterm infants may be due to the fact that the maturation of the sympathetic nervous system, which plays a role in the regulation of peripheral perfusion, in preterm

infants is not yet complete. Although studies in adult patients on this topic are limited, a study conducted by Lima et al [8] in adult patients reported no association between changes in cardiac output and peripheral PI or clinical signs of poor peripheral perfusion.

In our study, there was no correlation between pre- / post-ductal PI and RVO or RVO/kg, similar to the study of Corsini et al [10]. This may be because the foramen ovale has not yet closed. Similar to the results of Corsini et al (10), there was no association between pre- / post-ductal PI and SVCf or SVCf/kg in our study. Takahaski et al [21] reported that they found a correlation between PI and SVC flow in their cohort of preterm infants. They noted that SVC flow reflects systemic blood flow, especially in small preterm infants with PDA. In our study, there was a moderate correlation between SVC flow and LVO/kg. The reason why our study result differs with the findings of Takahaski et al [21] may be that our study population does not cover very low birth weight babies with PDA.

As a result of observations, it has been reported that PI shows circadian rhythm, and can be affected by nutrition, intravenous therapy, jaundice, sleep-awake status and sleep position [11, 22]. A study conducted by Sahni et al [22] in low birth weight infants reported that the PI value measured in the supine sleep position was higher than in the supine position. In our study, peripheral perfusion in all infants was evaluated after feeding, in supine position and while awake. Although the infants with physiological jaundice were included in the study, the infants with hyperbilirubinemia requiring phototherapy were not included in the study. In our study, circadian rhythm was not taken into account in the time period during which the measurement was performed, due to the fact that babies had different birth times. It has been reported that PI measurement is not affected by physiological variables such as heart rate, SpO_2, oxygen consumption, blood pressure, and body temperature [23]. Similarly, no association between PI and heart rate, SpO_2, body temperature, and blood pressure (systolic, diastolic, and mean blood pressure) was found in our study.

Our study had some limitations: i) the number of babies included in the study was small, and ii) we did not examine whether there was a relationship between PI and LVO in infants with CHD.

In conclusion, a correlation between pre- / post-ductal PI and LVO in healthy late preterm infants wasn't found in our study. We believe that a systemic hemodynamic parameter such as LVO cannot adequately reflect peripheral microvascular blood flow due to incomplete maturation of the sympathetic nervous system in preterm infants, which is involved in regulating peripheral perfusion. New studies with larger populations are needed to determine the actual role of the synergistic effect of SPO_2 with PI in screening for critical CHD, especially in preterm infants.

List Of Abbreviations

CHD: Congenital heart diseases

SpO_2: Blood oxygen saturation

LVO: Left ventricular output

PI: Perfusion index

AC: Variable light absorption

DC: Constant light absorption

FiO_2: Fraction of inspired oxygen

HR: Heart rate

SNAPPE-II: Score for Neonatal Acute Physiology - Perinatal Extension II

BP: Blood pressure

CO: Cardiac output

TTE: Transthoracic echocardiographic

RVO: Right ventricular output

SVC: Superior vena cava

VTI: Velocity time integral

SVCf: Superior vena cava flow

SD: Standard deviation

IQR: Interquartile range

PDA: Patent ductus arteriosus

Declarations

- *Funding:* The authors declare that this study has not received any financial support.

- *Conflicts of interest/Competing interests:* The authors have no conflicts of interest to declare.

- *Availability of data and material:* N/A

- *Code availability:* N/A

- *Authors' contributions:* Concept - N.H., H.O.; Design - N.H., A.A.; Supervision - M.A., H.O.; Materials - Ö.İ., A.A.; Data Collection and/or Processing - A.A., Ö.İ., H.O.; Literature Review – A.A., Ö.İ., M.A.; Writing - A.A., N.H., Ö.İ; Echocardiographic evaluation: H.O.; Critical Review – N.H., M.A., H.O.

- *Ethics approval:* The study was approved by our faculty ethics committee (date: May 02, 2019 and decision no: 08 / II).

- *Consent to participate:* Formal and written consents were obtained from the study subjects' parent.

- *Consent for publication:* All authors would like to publish their manuscript in *European Journal of Pediatrics*.

References

1. Frank LH, Bradshaw E, Beekman R, Mahle WT, Martin GR (2013) Critical congenital heart disease screening using pulse oximetry. J Pediatr 162: 445–453
2. Kemper AR, Mahle WT, Martin GR, Cooley WC, Kumar P, Morrow WR, Kelm K, Pearson GD, Glidewell J, Grosse SD, Howell RR (2011) Strategies for implementing screening for critical congenital heart disease. Pediatrics 128: e1259-1267
3. Mahle WT, Martin GR, Beekman RH **3rd**, Morrow WR; **Section on Cardiology and Cardiac Surgery Executive Committee (**2012**)**. **Endorsement of Health and Human Services recommendation for pulse oximetry screening for critical congenital heart disease**. **Pediatrics 129**: **190–192**
4. Mellander M, Sunnegårdh J (2006) Failure to diagnose critical heart malformations in newborns before discharge–an increasing problem? Acta Paediatr 95: 407–413
5. Ad G, Ostman-Smith I (2007) Noninvasive peripheral perfusion index as a possible tool for screening for critical left heart obstruction. Acta Paediatr 96: 1455–1459
6. Riede FT, Wörner C, Dähnert I, Möckel A, Kostelka M, Schneider P (2010) Effectiveness of neonatal pulse oximetry screening for detection of critical congenital heart disease in daily clinical routine–results from a prospective multicenter study. Eur J Pediatr 169: 975–981
7. Lima A, Bakker J (2005) Noninvasive monitoring of peripheral perfusion. Intensive Care Med 31: 1316–1326
8. Lima AP, Beelen P, Bakker J (2002) Use of a peripheral perfusion index derived from the pulse oximetry signal as a noninvasive indicator of perfusion. Crit Care Med 30: 1210–1213
9. Piasek CZ, Van Bel F, Sola A (2014) Perfusion index in newborn infants: a noninvasive tool for neonatal monitoring. Acta Paediatr 103: 468–473
10. Corsini I, Cecchi A, Coviello C, Dani C (2017) Perfusion index and left ventricular output correlation in healthy term infants. Eur J Pediatr 176: 1013–1018
11. Richardson DK, Corcoran JD, Escobar GJ, Lee SK (2001) SNAP-II and SNAPPE-II: Simplified newborn illness severity and mortality risk scores. J Pediatr 138: 92–100
12. Mertens L, Seri I, Marek J, Arlettaz R, Barker P, McNamara P, Moon-Grady AJ, Coon PD, Noori S, Simpson J, Lai WW; **Writing Group of the American Society of Echocardiography (ASE)**; **European Association of Echocardiography** (**EAE**); **Association for European Pediatric Cardiologists** (**AEPC**)

(2011). **Targeted neonatal echocardiography in the neonatal intensive care unit: practice guidelines and recommendations for training**: **Eur J Echocardiogr 12**: **715–736**

13. **van** Vonderen JJ, **te** Pas AB, Kolster-Bijdevaate C, **van** Lith JM, Blom NA, Hooper SB, Roest AA (2014). **Non-invasive measurements of ductus arteriosus flow directly after birth**. **Arch Dis Child Fetal Neonatal Ed 99**: **408–412**
14. Kluckow M, Evans N (2000). **Superior vena cava flow in newborn infants: a novel marker of systemic blood flow**. **Arch Dis Child Fetal Neonatal Ed 82**: **182–187**
15. De Felice C, Latini G, Vacca P, Kopotic RJ (2002) The pulse oximeter perfusion index as a predictor for high illness severity in neonates. Eur J Pediatr 161: 561–562
16. Zaramella P, Freato F, Quaresima V, Ferrari M, Vianello A, Giongo D, Conte L, Chiandetti L (2005) Foot pulse oximeter perfusion index correlates with calf muscle perfusion measured by near-infrared spectroscopy in healthy neonates. J Perinatol 25:417–422
17. Unal S, Ergenekon E, Aktas S, Beken S, Altuntas N, Kazanci E, Kulali F, Hirfanoglu IM, Onal E, Turkyilmaz C, Koc E, Atalay Y (2016) Perfusion index assessment during transition period of newborns: an observational study. BMC Pediatr 16: 164
18. Hakan N, Dilli D, Zenciroglu A, Aydin M, Okumus N (2014) Reference values of perfusion indices in hemodynamically stable newborns during the early neonatal period. Eur J Pediatr 173: 597–602
19. Cresi F, Pelle E, Calabrese R, Costa L, Farinasso D, Silvestro L (2010) Perfusion index variations in clinically and hemodynamically stable preterm newborns in the first week of life. Ital J Pediatr 36: 6
20. Evans N (2006) Assessment and support of the preterm circulation. Early Hum Dev 82: 803–810
21. Takahashi S, Kakiuchi S, Nanba Y, Tsukamoto K, Nakamura T, Ito Y (2010) The perfusion index derived from a pulse oximeter for predicting low superior vena cava flow in very low birth weight infants. J Perinatol 30: 265–269
22. Sahni R, Schulze KF, Ohira-Kist K, Kashyap S, Myers MM, Fifer WP (2010) Interactions among peripheral perfusion, cardiac activity, oxygen saturation, thermal profile and body position in growing low birth weight infants. Acta Paediatr 99: 135–139
23. Hales JR, Stephens FR, Fawcett AA, Daniel K, Sheahan J, Westerman RA, James SB 1989 Observations on a new non-invasive monitor of skin blood flow. Clin Exp Pharmacol Physiol 16: 403–415