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New-generation pulse oximetry for the assessment of peripheral perfusion during general anaesthesia — a comparison between propofol and desflurane

Michał Kowalczyk, Anna Fijałkowska, Andrzej Nestorowicz

I[st] Department of Anaesthesiology and Intensive Care, Medical University of Lublin, Poland

Abstract

Background. A pulse oximeter is a standard device for perioperative monitoring. The early detection of tissue hypoxia is of a great importance. Recently, the detection of tissue hypoxia has been made easier due to a new generation of pulse oximetry devices from Masimo. These devices enable the measurements of the peripheral perfusion index (PI) in a real time. Volatile anaesthetics such as sevoflurane and desflurane increase the perfusion index. However, no data are available concerning the perfusion index during propofol/remifentanil total intravenous anaesthesia.

Methods. ASA I and II class women scheduled for elective gynaecological surgery were eligible for inclusion in the study. Patients were divided into two groups: group P received propofol/remifentanil intravenous anaesthesia, and group D received desflurane/fentanyl general anaesthesia. The PI was measured before anaesthesia, after remifentanil/fentanyl injection, after endotracheal intubation, at the beginning of surgery, during the procedure in 10 minute intervals, at the end of procedure, after eye opening, after extubation and before discharge to the ward.

Results. Eighty-three patients were enrolled into the study. In both groups, PI increased significantly from beginning to the end of surgery. There was a significant correlation between the PI and the end-tidal desflurane concentration ($r = 0.807$; $P = 0.001$). No correlation was observed between propofol or remifentanil concentrations and PI.

Conclusion. Both intravenous propofol/remifentanil and desflurane/fentanyl general anaesthesia increase peripheral perfusion. Increased end-tidal desflurane concentrations raise peripheral perfusion.

Key words: monitoring, pulse oximetry; monitoring, peripheral tissue perfusion; monitoring, perfusion index; intravenous anaesthetics, propofol; volatile anaesthetics, desflurane

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One of the canons of current intraoperative monitoring is the measurement of arterial blood oxygen saturation (SpO_2). Since 1983 when the first percutaneous pulse oximeter was introduced, this method has been popularised worldwide [1]. For years, however, producers of pulse oximetry devices have contended with two common clinical situations: poor peripheral perfusion and motion-induced artefacts. Both problems lead to a low signal-to-noise (artefact) ratio resulting in falsely underestimated readings, signal fading or unjustified activation of alarms [2].

Many producers have attempted to solve these problems and introduce new-generation pulse oximeters using modern, innovative algorithms of signal conversion aimed at minimising the adverse effects of external factors on the measurement accuracy [3–5]. Additionally, some of the currently available pulse oximeters can measure the peripheral blood flow expressed as the perfusion index (PI). The PI is defined as the ratio between the range of absorption of a suitably long light wave (infrared, red) by pulsatile blood flow (arterial) versus non-pulsatile blood flow (venous, capillary, tissue, arterial non-pulsating) and is expressed as a numerical value [6].

Abnormal tissue flow can lead to cell hypoxia and subsequent organ failure; therefore, modern monitoring should

be aimed at the earliest possible detection of such disturbances and the institution of appropriate management to protect patients against irreversible consequences. Measurements of peripheral perfusion enable physicians to achieve this goal. Unlike other methods assessing the global haemodynamic status, oxygen supply-consumption imbalance or arterial blood concentrations of lactic acid, measurements of peripheral perfusion are easy to use and non-invasive and are therefore not associated with any adverse side effects [6, 7].

Volatile anaesthetics administered during general anaesthesia increase peripheral perfusion. This correlation has been demonstrated for sevoflurane [8] and desflurane [9]; however, there are no data regarding the effects of total intravenous anaesthesia with propofol on the peripheral tissue flow.

The aim of the present study was to determine the peripheral perfusion index during total intravenous anaesthesia and to compare its changes to the values observed during combined anaesthesia with desflurane.

METHODS

The study was approved by the Bioethics Committee, Medical University of Lublin. Female patients, ASA I and II, scheduled for gynaecological laparotomy procedures were included after obtaining their informed consent for participation.

All patients were premedicated with 10 mg oral diazepam two hours before surgery. In the operating room setting, routine monitoring of vital functions and passive oxygen therapy were initiated; subsequently, patients were randomly assigned to group P (propofol) or D (desflurane).

The group P patients received total intravenous anaesthesia, i.e., 0.5 mg atropine *i.v.* and remifentanil in continuous infusions according to the target controlled infusion (TCI) protocol in a saturating dose to reach the target plasma concentration of 8.5 ng mL^{-1}, followed by propofol infusion to the target plasma concentration of 8 μg mL^{-1}. After the ciliary reflex was abolished and suxamethonium (1 mg kg^{-1}) was administered, the trachea was intubated, and artificial lung ventilation was initiated with the mixture of N_2O and O_2 (F_IO_2 = 0.33). The ventilation parameters were corrected to maintain normocapnia. Muscle relaxation after subsidence of depolarising block was provided with 0.1 mg kg^{-1} cisatracurium. TCI anaesthesia was maintained with the continuous infusion of remifentanil and propofol. The target plasma concentrations of remifentanil and propofol were 3–6 ng mL^{-1} and 2–4 μg mL^{-1}, respectively.

In group D, combined general anaesthesia was administered, which included atropine (0.5 mg *i.v.*) and fentanyl (5 μg kg^{-1}). Anaesthesia was induced with thiopental at a dose of 5 mg kg^{-1}, and muscle relaxation was achieved with 1 mg kg^{-1} suxamethonium. Following endotracheal intubation, artificial lung ventilation was initiated, and normocapnia was maintained. After subsidence of depolarising block, muscle relaxation was obtained with 0.1 mg kg^{-1} cisatracurium (analogically to group P). Anaesthesia was maintained with the mixture of N_2O and O_2 (F_IO_2 = 0.33), desflurane at the concentration of 3–6 vol% and fentanyl in fractionated doses, 1.5 μg kg^{-1} each.

After completion of surgery, neuromuscular blockage was reversed with neostigmine (2.5 mg) proceeded by atropine (0.5 mg) in both groups. Before the end of anaesthesia, 100 mg of ketoprofen was administered. Patients received balanced multi-electrolyte fluid infusions at a dose of 8 mL kg^{-1} h^{-1} throughout the procedure.

Standard monitoring during anaesthesia involved measurements of HR, SAP/DAP/MAP, SpO_2, E_TCO_2 and E_T desflurane. Moreover, predicted plasma concentrations of remifentanil and propofol were recorded in group P. Additionally, PI was monitored using the pulse oximeter Radical 7 (Masimo Corporation, Irvine, USA).

Measurements were recorded at the following time points: 1 — before anaesthesia (baseline values); 2 — after the administration of remifentanil/fentanyl; 3 — after intubation; 4 — after the onset of surgery; 5–9 — every 10 minutes during the procedure; 10 — at completion of the surgery; 11 — at eye opening; 12 — at extubation; and 13 — before transferring the patient to the ward.

Because not all of the data exhibited a normal distribution, results are presented as medians and ranges. The significance of inter-group differences was evaluated with the Mann-Whitney U test. Repeated measurements were assessed with multivariate analysis of variance using the contrast statement. Correlations were tested using the Spearman's rank correlation coefficient. In all tests, $P < 0.05$ was considered statistically significant.

RESULTS

In total, 83 patients were included in the study: 43 in group P and 40 in group D. Groups were comparable with respect to age, body weight, duration of surgery and anaesthesia (Table 1). In group P, a significant increase in PI was observed beginning at intubation and was markedly higher throughout the surgery until its completion ($P < 0.001$). At eye opening, extubation and transfer to the ward, PIs did not significantly differ from baseline values (Fig. 1). Similar changes were recorded in group D; PI significantly increased at the procedure onset and was higher than baseline values until the completion of the procedure ($P < 0.01$). PIs at eye opening, extubation and transfer to the ward were not markedly different from baseline values (Fig. 2).

Table 1. Characteristics of study groups ($\bar{x} \pm SD$)

Group	Age (years)	Weight (kg)	Duration of surgery (min)	Duration of anaesthesia (min)
P (n = 43)	36.0 ± 10.8	70.5 ± 17.3	45.0 ± 20.4	60.1 ± 22.6
D (n = 40)	36.8 ± 14.0	65.5 ± 10.8	47.3 ± 23.0	66.6 ± 23.4
P	0.672	0.278	0.705	0.566

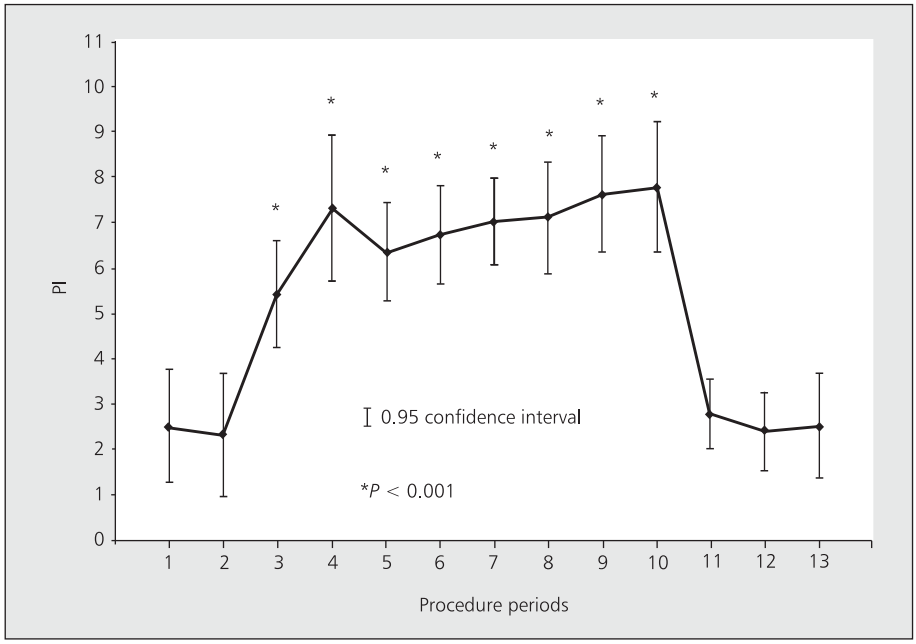

Figure 1. PI at individual procedure periods in group P

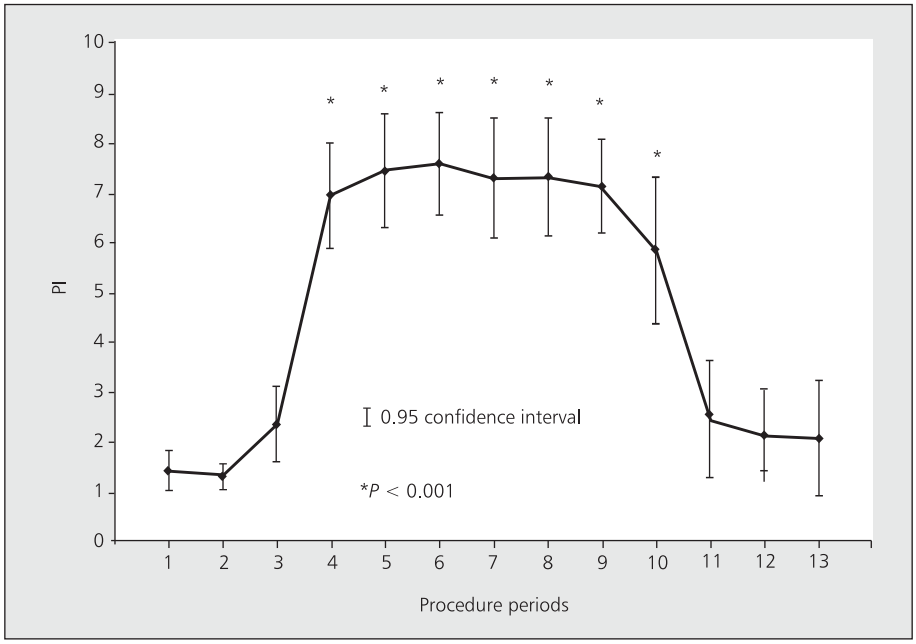

Figure 2. PI at individual procedure periods in group D

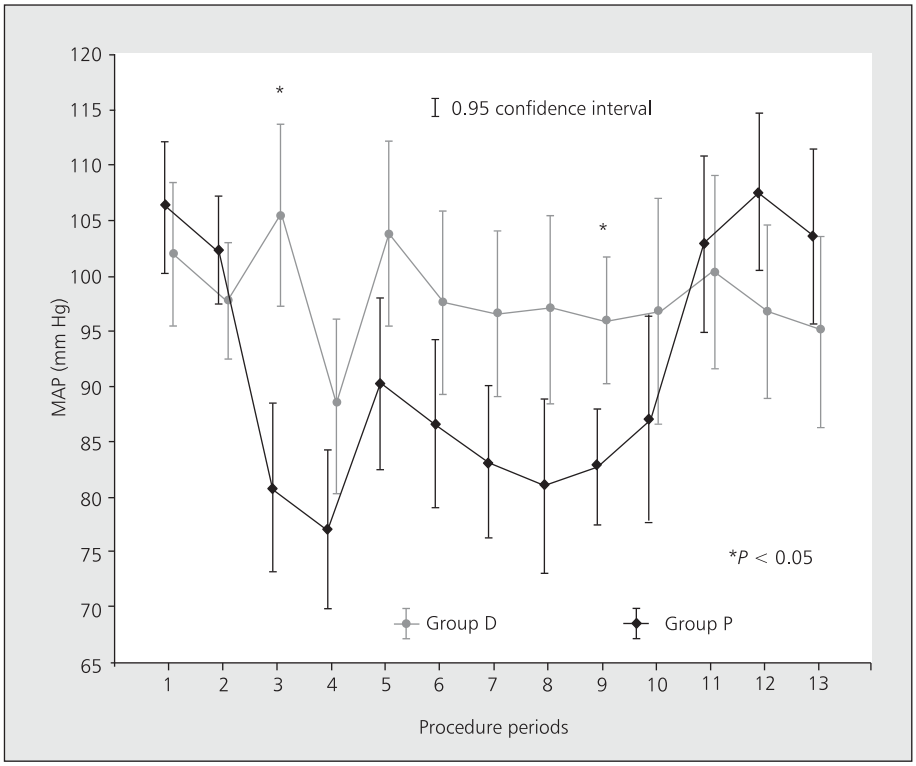

Figure 3. MAP at individual procedure periods

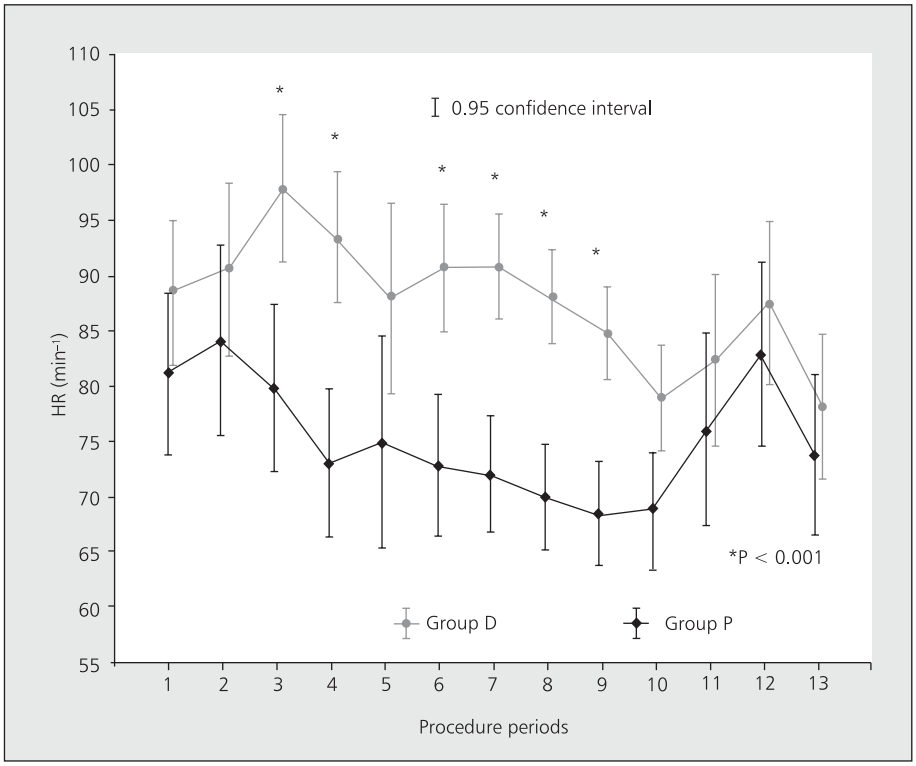

Figure 4. HR at individual procedure periods

Analysis of PI in both groups at individual study stages demonstrated no significant differences between the groups at any time point ($P = 0.240$).

A strong correlation was observed between PI and the end-expiratory concentration of desflurane (r = 0.807; $P = 0.001$). Otherwise, there was no correlation between PI and the predicted plasma concentrations of remifentanil and propofol. Arterial pressure in group D was significantly higher at intubation and the 50th min of the procedure ($P < 0.05$) (Fig. 3). Likewise, HR was found to be significantly higher in group D at the following time points: intubation, onset of the procedure, and at minute 20, 30, 40 and 50 ($P < 0.001$). In the remaining time points, no significant differences were recorded (Fig. 4).

DISCUSSION

Second to electrocardiography, conventional pulse oximetry is the most common method of monitoring of vital functions, particularly in the perioperative period, enabling assessment of arterial blood oxygenation and heart rate [1]. Contrary to appearances, an accurate and continuous measurement of SpO_2 is difficult under clinical conditions. Numerous disturbances, such as excessive ambient light, the electromagnetic field of other devices, patient's movements or poor peripheral perfusion, are likely to lead to improper readings or false alarms [4, 10]. In the intraoperative period, patients are at risk of deteriorated tissue perfusion, mainly due to hypotension and hypothermia. The modern algorithms used in new-generation pulse oximeters (Masimo) whose theoretical assumptions differ from those applied in older devices enable physicians to obtain reliable measurements even under such difficult clinical circumstances using reference signal calculations, the adaptive filter and transformation of a single saturation signal [3–5].

There are several options to non-invasively assess peripheral perfusion. The oldest and simplest, albeit less reliable, modality of tissue flow assessment is clinical evaluation based on skin colour and temperature. However, this method is subjective and thus frequently inaccurate, especially in cases of distribution shock [11]. The other perfusion assessment methods involve gradients of body temperature — peripheral and environmental, central and peripheral, and on the forearm and finger [6]. The above methods have been evaluated in various clinical trials to be capable of estimating the skin blood flow yet are limited by the necessary use of at least two temperature sensors and do not reflect the changeability of flow in real time [12]. Near-infrared spectroscopy (NIRS) seems to be a simple and reliable technique to assess regional blood flow within the tissues. Thanks to its better tissue penetration compared to pulse oximetry, oxygenation in all vascular compartments (arterial, venous, capillary) can be more globally assessed [13]. The limitation of this method is that it requires special electrodes and additional equipment with suitable software for result presentation. Orthogonal polarisation spectra (OPS) imaging using reflected light allows the analysis of microcirculation in real time [14] but is half-quantitative and susceptible to the subjectivity of the user. Laser Doppler flowmetry (LDF) uses the Doppler effect and monochromatic laser light for continuous flow measurements in the microcirculation. However, as a method of non-invasive measurements of peripheral flow, LDF is confined to skin microcirculation. As far as its faults are concerned, the method does not take into account the nonhomogeneity of the blood flow rate and provides an averaged value from the measurement window; moreover, the flow volume depends on the probe location [6].

The easiest method of all peripheral perfusion assessment modalities available on the market seems to be pulse oximetry, which is based on the absorption of light waves of various lengths and the unique algorithm for the identification of a proper signal [3, 4]. Among many such devices, those using Masimo technology provides the best results in laboratory [3] and clinical [5] tests.

Since the introduction of peripheral perfusion measurements using new-generation pulse oximeters, attempts have been made to determine their usefulness in various clinical situations. Decreased PI values in mothers prior to Caesarean section have been identified as a risk factor of increased newborn morbidity and subclinical placentitis [15]. According to another study, reduced PI might be a useful tool for the early detection of left ventricular failure in newborns [16].

The majority of anaesthetics used for the induction and maintenance of anaesthesia are known to exert various effects on the circulatory system, including changes in arterial pressure, cardiac output, and peripheral resistance (pre-capillary) as well as affecting the microcirculation by altering the blood flow. The literature data and our earlier findings confirm the beneficial effect of anaesthesia on tissue flow during both block [17] and general anaesthesia with sevoflurane [8] or desflurane [9]. However, there are no reports on the impact of general anaesthesia with propofol on the peripheral perfusion index measured by spectrophotometry. Our results revealed increased peripheral perfusion compared to baseline values from the onset until the completion of surgery in groups of patients anaesthetised with both propofol and desflurane. The effects of desflurane on the microcirculation in peripheral tissues have not been fully documented**.** The available data have only demonstrated that desflurane increases the visceral flow through the intestines and that the extent of the increase is higher than for isoflurane [18].

To date, the effect of propofol on the peripheral perfusion index has not been determined. In the present study, a significantly increased peripheral flow was observed following the use of this agent; however, the PI did not differ significantly compared with patients anaesthetised with desflurane. On the other hand, a correlation between the peripheral perfusion index and the end-expiratory concentration of desflurane was observed, which is consistent with our findings and literature data [8, 9].

The impact of anaesthetics on the microcirculation is disputed. Bruegger and co-workers [19] studied the effects of sevoflurane and propofol on microcirculation parameters in the lower limbs using plethysmographic measurements. According to their results, the agents in question did not affect the flow, whereas sevoflurane reduced the capillary filtration index, which resulted in lesser losses of fluids to the interstitial space. Moreover, the authors observed reduced venous pressure during anaesthesia maintenance in both groups, which is unsurprising. According to more recent research by De Blasi and colleagues [20] evaluating the effects of propofol and sevoflurane on microcirculation, increased flow in calf muscles was observed only in the group of patients anaesthetised with propofol, which correlated with an increase in oxygenated haemoglobin. In the group anaesthetised with sevoflurane, an increase in the oxygenated haemoglobin concentration did not correlate with the flow, which remained unchanged with reduced oxygen consumption by cells. Furthermore, Koch and co-workers [21], who studied the effect of propofol on the microcirculation using spectra polarisation, reported an anaesthetic-induced reduction in capillary flow and decreased density of capillaries. The above discrepancies may be associated with different methods or with disparities in study groups or various techniques and equipment used for the microcirculation assessment.

Our analysis revealed differences in MAP at two time points; although the result is statistically significant, it seems to be of no significant clinical relevance. Otherwise, differences in HR were found to be significant at many time points, as the use of desflurane was associated with higher heart rate compared with propofol. This finding does not appear to be surprising and is rather consistent with the pharmacological characteristics of desflurane, which can induce tachycardia at its quickly increasing concentrations in the inspiratory mixture.

Despite the discrepancies observed, the recent study results indicate that impaired microcirculation can lead to organ failure [22] and reduced abilities of tissue oxygen extraction [23]. For these reasons, monitoring peripheral perfusion using the presently available non-invasive methods should be recognised as daily routine management in anaesthesiology and intensive therapy.

The limitation of the present study was the use of atropine during anaesthesia; the drug can potentially affect peripheral perfusion. However, atropine was applied in both study groups at identical doses; therefore, its effects on the results should not have been relevant. Another limitation was that the study population consisted only of female patients; nevertheless, no literature data were found implicating any impact of gender on peripheral perfusion index.

CONCLUSIONS

1. Both total intravenous anaesthesia with propofol and combined anaesthesia with desflurane increase peripheral tissue perfusion.
2. Peripheral tissue perfusion is strongly correlated with the end-expiratory concentration of desflurane.

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Corresponding author:
Michał Kowalczyk, MD, PhD
ul. Szwajcarska 10/16, 20–861 Lublin, Poland
tel. 605 397 703, fax: + 48 81 724 45 50
e-mail: michalkowalczyk@vp.pl

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