Journal of Anesthesia (2024) 38:364–370
https://doi.org/10.1007/s00540-024-03317-5

ORIGINAL ARTICLE

Evaluation of pulse oximeter at the nasal septum during general anesthesia: comparison with finger oximeter

Yena Oh[1] · Duk Kyung Kim[2] · Dae Kyun Ryu[2] · Ji Won Choi[2]

Received: 1 December 2023 / Accepted: 4 February 2024 / Published online: 19 March 2024

Abstract

Purpose Though the finger is generally recommended for pulse oxygen saturation (SpO_2) monitoring site, its reliability may be compromised in conditions of poor peripheral perfusion. Therefore, we compared the performance of nasal septum SpO_2 monitoring with finger SpO_2 monitoring relative to simultaneous arterial oxygen saturation (SaO_2) monitoring in generally anesthetized patients.

Methods In 23 adult patients, comparisons of SpO_2 measured at the nasal septum and finger with simultaneous SaO_2 were made at four time points during the 90 min study period. A pulse oximetry monitoring failure was defined as a > 10 s continuous failure of in an adequate SpO_2 data acquisition. Core temperature as well as finger-tip and nasal septum temperatures were simultaneously measured at 10 min intervals.

Results A total of 92 sets of SpO_2 and SaO_2 measurements were obtained in 23 patients. The bias and precision for SpO_2 measured at the nasal septum were -0.8 ± 1.3 (95% confidence interval: -1.1 to -0.6), which was similar to those for SpO_2 measured at the finger (-0.6 ± 1.4; 95% confidence interval: -0.9 to -0.4) ($p = 0.154$). Finger-tip temperatures were consistently lower than other two temperatures at all time points ($p < 0.05$), reaching 33.5 ± 2.3 °C at 90 min after induction of anesthesia. While pulse oximetry monitoring failure did not occur for nasal septum probe, two cases of failure occurred for finger probe.

Conclusions Considering the higher stability to hypothermia with a similar accuracy, nasal septum pulse oximetry may be an attractive alternative to finger pulse oximetry.

Trail registration This study was registered with Clinical Research Information Service (CRIS: https://cris.nih.go.kr/cris/en/; ref: KCT0008352).

Keywords Hypothermia · Oxygen saturation · Oximetry · Skin temperature

Introduction

Pulse oxygen saturation (SpO_2) measured by pulse oximetry is widely used as the fifth vital sign in clinical practice. The most important advantage of pulse oximeters is the capability to provide real-time, non-invasive, and effective monitoring of blood oxygenation at the patient's bedside. Generally, fingers are the recommended sensor sites for pulse oximetry in the operating room. However, the reliability of SpO_2 measured from the fingers may be compromised in conditions of poor peripheral perfusion such as hypotension, hypothermia, and vasoconstriction [1–3]. In addition, finger SpO_2 monitoring is mechanically interfered with shivering, movement, or surgical maneuvers. Especially, its dislodgement during laparoscopic surgery cannot be easily overcome because of the necessity of reposition maneuver under the surgical draping.

Our hypothesis was that the nasal septum was more central and therefore better perfused, allowing for more accurate monitoring despite of poor peripheral perfusion [4, 5]. And the nasal septum could be less interfered with mechanical and surgical conditions and easily repositioned during

✉ Duk Kyung Kim
dikei@hanmail.net

1 Dpartment of Anesthesiology and Pain Medicine, CHA Bundang Medical Center, CHA University, Seongnam, Republic of Korea

2 Department of Anesthesiology and Pain Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, 81 Irwon-Ro, Gangnam-Gu, Seoul 06351, Republic of Korea

various surgeries other than facial surgery or surgery in the prone position. However, little is known about the performance of pulse oximetry when the probe is placed at the nasal septum.

Therefore, we compared the accuracy and precision of nasal septum SpO_2 monitoring using a newly developed probe with finger SpO_2 monitoring relative to simultaneous arterial oxygen saturation (SaO_2) monitoring in generally anesthetized surgical patients. In addition, we compared skin surface temperatures of both sites and evaluated their influence on the performance of pulse oximetry.

Methods

The present study was a prospective, observational, single-center trial conducted from April to June 2023 with the approval of the Institutional Review Board (Ref: SMC 2023–03–021–001, Approval date: March 26, 2023) and the registration of the Clinical Research Information Service (CRIS: https://cris.nih.go.kr/cris/en/; ref: KCT0008352).

After obtaining written informed consent from each participant, we recruited twenty three patients, aged 18–70 years, classified as American Society of Anesthesiologists (ASA) physical status I or II, and scheduled for elective laparoscopic gastrectomy. Exclusion criteria were patients with pre-existing peripheral vascular diseases, those receiving cardiovascular drugs, or those with diseases or conditions known to affect pulse oximeter accuracy (*e.g.*, sickle cell disease, methemoglobinemia, carboxyhemoglobinemia).

The study period was predefined as the first 90 min after the induction of anesthesia, derived from the minimum operating time for laparoscopic gastrectomy at our institution.

Specification of a nasal septum oximeter probe

In this study, a newly developed pulse oximeter probe (OxiFix M, UNIMEDICS, Republic of Korea) was used for affixing the nasal septum. This omega-shaped disposable probe is a clip-type transmittance probe made from low molecular polyethylene, which can be affixed at earlobe, nasal septum, finger, or toe by pinching both sides of them gently (Fig. 1).

Protocols

The operating rooms had controlled laminar air flow at a temperature of 23 °C and a relative humidity of 30–40%. All exposed areas were kept covered with a single cotton blanket and one layer of surgical drape. While all patients received a circulating water mattress (38 °C) intraoperatively, patients with core temperature < 36.0 °C at the end of surgery received a forced-air warming system (Bair Hugger, Augustine Medical, Eden Prairie, MN, United States) postoperatively.

Fig. 1 Features of a novel pulse oximeter probe (OxiFix M probe) used in this study. This transmittance probe can provide pulse oximetric saturation monitoring from the earlobe or nasal septum as well as finger or toe by pinching both sides of them gently

After arrival in the operating room, the heart rate, noninvasive blood pressure, electrocardiogram (ECG), and bispectral index (BIS) were monitored continuously. SpO_2 was monitored via finger pulse oximeter probe (Covidien MAX-NI Nellcor™ Neonatal-Adult SpO_2 sensor, Medtronic, United States) which was placed on the second digit of the right hand.

Without premedication, anesthesia was induced using a standardized anesthetic regimen, and then maintained with sevoflurane and 50% oxygen in air. The depth of anesthesia was controlled by altering the inhaled sevoflurane concentration, based on the hemodynamic response to surgery (maintenance of mean arterial pressure and heart rate within 20% of the baseline values) and BIS values (target values of 40–60) at the discretion of the attending anesthesiologist.

During the induction of anesthesia, an arterial cannula was placed into the right radial artery for blood sampling as well as continuous arterial blood pressure monitoring. After the induction of anesthesia, a skin surface temperature probe (Skin surface temperature reusable probe, Philips, United States) was placed at the inner side of the nasal ala using a malleable plastic holder. Simultaneously, finger-tip skin temperature was monitored at the third digit of the right hand using a skin surface temperature probe (skin surface temperature reusable

probe, Philips, United States), whereas core temperature was monitored via esophageal temperature probe.

The nasal septum SpO_2 was monitored using the OxiFix M probe across the nasal septum. When the probe was affixed at the nasal septum, its light source was placed at the nostril not bearing nasal septal temperature probe to reduce interference with the temperature measurements. To guarantee that any difference displayed were not due to differences in the sensitivities of each machine, each probe was connected to its own pulse oximeter with an identical model (Nellcor PM100N SpO_2 Pulse oximeter, Medtronic, United States).

Outcome measures

The study period began after both pulse oximeter probes were applied. A simultaneous recording was made of both finger and nasal septum SpO_2 at 10 min intervals during the study period. Arterial samples were taken for blood gas analysis and simultaneous paired SpO_2 data collections were carried out with both oximeters at the following four time points:

T1: 5 min after induction of anesthesia,
T2: 5 min after establishment of pneumoperitoneum,
T3: 60 min after establishment of pneumoperitoneum,
T4: 5 min after release of pneumoperitoneum.

A single reading of SpO_2 was taken in individual sensor locations after the pulse oximeters had achieved optimal plethysmography signals and heart rates matching with the ECG monitor. The blood sample was analyzed by blood gas analyzer (RAPIDLab™ 1265 Blood Gas Analyzer, SIEMENS Healthineer, Germany). By following the manufacturer's instruction, the calibration of the blood gas analyzer was checked at a regular interval by technical and quality assurance staff.

Core temperature and two skin surface temperatures (finger-tip and nasal septum) were simultaneously measured immediately after induction of anesthesia (elapsed time zero) and at 10-min intervals during the study period.

A pulse oximetry monitoring failure was defined as a > 10 s continuous failure of in an adequate SpO_2 data acquisition during the study period. This criterion was arbitrarily chosen based on clinical significance. Then, its cause was classified as hypothermia, low cardiac output, or mechanical dislodgement based on the determination of the attending anesthesiologist.

Statistical analyses

The primary outcome of the present study was the levels of measurement agreement between finger SpO_2 and SaO_2 as well as between nasal septum SpO_2 and SaO_2. The SaO_2 was considered the "gold standard". All SaO_2 values were rounded to zero decimal places to match the corresponding SpO_2 measurements.

Comparison of SpO_2 with SaO_2 was reported in terms of bias and precision as described by Bland and Altman [6]. Bias is the difference between the both SpO_2 (finger and nasal septum) and SaO_2 (*i.e.*, SpO_2 minus SaO_2) and precision is the ± 1 standard deviation (SD) of the difference. A low bias in a sensor site implies that the pulse oximeter sensor gives a more accurate reading at that site and vice versa. Precision implies the reproducibility of the measurement. Further, we calculated the intraclass correlation coefficient (ICC) based on absolute agreement; values lower than 0.5, between 0.5 and 0.8, and greater than 0.8 were indicative of poor or weak, good, and excellent reliability, respectively.

Based on a previous similar study [4], we projected the mean and SD of the difference between the accuracies of both probes to be 0.15% and 0.13%, respectively. Power studies suggested a figure of 19 paired sets of data to have a 90% chance of detecting a 0.6% difference with a 95% confidence level. A difference of 0.6% was considered to be clinically significant. Thus, we enrolled 23 patients to compensate for possible dropouts.

A repeated-measures analysis of variance model explored whether there was a difference between the temperatures. Post hoc comparisons between pairs of temperatures were performed with Tukey's adjustment for multiple comparisons.

Statistical analyses were performed using SPSS version 28 (IBM SPSS Statistics., New York, USA) and MedCalc 22.016 (MedCalc Software Ltd, Ostend, Belgium). Statistical significance was set at $p < 0.05$.

Results

None of the enrolled patients was excluded from the study. Patient characteristics are shown in Table 1. With regard to intraoperative use of cardiovascular drugs, only one patient received a single 5 mg intravenous dose of ephedrine.

A comparison of the three temperatures at each time point is presented in Fig. 2. After the induction of anesthesia, core temperatures and two skin surface temperatures decreased significantly throughout the study period ($p < 0.001$). While changes in the nasal septum temperature were not significantly different from those of core temperature, changes in finger-tip temperature were significantly different from those of core and nasal septal temperatures throughout the study period ($p < 0.001$). Finger-tip temperatures were consistently lower than other two temperatures at all time points ($p < 0.05$), reaching 33.5 ± 2.3 °C at 90 min after induction of anesthesia. The median (interquartile range) of core

Table 1 Patient characteristics

	Patients ($n=23$)
Gender; female/male	10/13
Age (years)	59.4 ± 7.5
Weight (kg)	65.8 ± 10.4
Height (cm)	165.5 ± 7.3
BMI (kg/m^2)	24.1 ± 2.7
ASA physical status; I/II	12/11
Intraoperative use of cardiovascular drugs; yes/no	1/22
Duration of surgery (min)	127 ± 32
Duration of anesthesia (min)	165 ± 32
Duration of pneumoperitoneum (min)	98 ± 27
Estimated blood loss (mL)	61 ± 83
Diuresis (mL)	194 ± 92
Infused fluid (mL)	685 ± 241

Data are expressed as the mean ± standard deviation (SD) or number

BMI body mass index, *ASA* American Society of Anesthesiologists

temperature was 35.7 °C (35.2–36.1 °C) at 90 min after induction of anesthesia.

From the total population of 23 patients, those with SpO_2 and SaO_2 measurements at four time points were analyzed. The SpO_2 values measured at the nasal septum and finger probes during the study period were in the healthy adult oxygen saturation range (95–100% and 94–100%, respectively). The absolute median (range) differences from SaO_2 of pulse oximeters were − 1 (− 4 to 1) for nasal septum probe and 0 (− 5 to 1) for finger probe.

Collectively, the bias and precision for SpO_2 measured at the nasal septum were -0.8 ± 1.3 (95% CI − 1.1 to − 0.6), whereas those for SpO_2 measured at the finger were -0.6 ± 1.4 (95% CI − 0.9 to − 0.4) (Table 2). Though nasal septum and finger pulse oximetry showed poor reliabilities (mean [95% CI of ICC: 0.3 [− 0.0 to 0.5] and 0.4 [0.1–0.6], respectively), absolute percentage error of nasal septal oximetry and finger oximetry were identical (median [95% CI]: 1.0% [1.0 to 1.0%]). There was no statistically difference between the deviations of SpO_2 measured at both sites relative to SaO_2 ($p=0.154$). The Bland–Altman plots with mean differences and 95% limits of agreement are shown in Fig. 3.

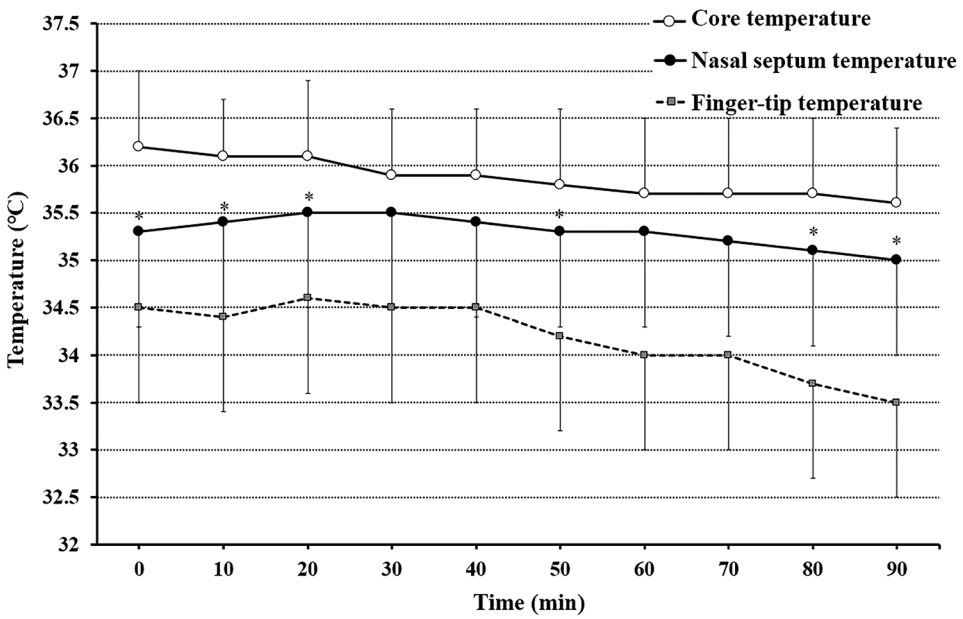

Fig. 2 Changes in core temperature and two skin surface (nasal septum and finger-tip) temperatures for 90 min after induction of anesthesia. Values are expressed as the mean and standard deviation. Finger-tip temperatures were consistently lower than other two temperatures at all time points ($p<0.05$). *Statistically significant between nasal septal and core temperatures ($p<0.05$)

Table 2 Comparison between nasal septum and finger pulse oximetry versus arterial blood gas analysis for the entire cohort (92 paired measurements)

	Difference (mean ± SD)	95% CI	Lower limit (95% CI)	Upper limit (95% CI)	ICC (95% CI)
Nasal septal SpO_2 *vs* SaO_2	− 0.8 ± 1.3	− 1.1 to − 0.6	− 3.3 (− 3.8 to − 2.9)	1.7 (1.2 to 2.1)	0.3 (− 0.0 to 0.5)
Finger SpO_2 vs SaO_2	− 0.6 ± 1.4	− 0.9 to − 0.4	− 3.3 (− 3.8 to − 2.8)	2.0 (1.6 to 2.5)	0.4 (0.1 to 0.6)

Negative numbers indicate that the measured value was below the SaO_2

SD standard deviation, *CI* confidence interval, *ICC* intraclass correlation coefficient, *SpO_2* pulse oximetric saturation, *SaO_2* arterial oxygen saturation

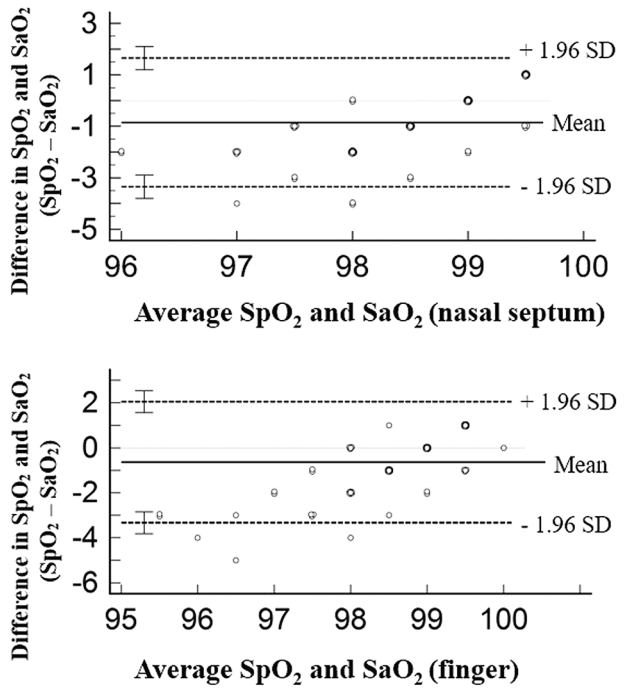

Fig. 3 Bland–Altman plots of the difference between pulse oxygen saturation (SpO_2) measured at nasal septum and finger and arterial oxygen saturation (SaO_2) versus the average of the two readings. *SD* standard deviation

In all cases, nasal septal sensor functioned well continuously, whereas finger sensor failed two or three times in two cases. The causes of pulse oximetry monitoring failure were identically determined as hypothermia in both cases.

There was no skin and soft tissue complication with pulse oximeter probes.

Discussion

This study demonstrated that nasal septum pulse oximeter had a similar degree of accuracy in SpO_2 measurement compared to finger pulse oximeter. And it seemed to provide a better reliability than finger pulse oximeter under the influence of intraoperative hypothermia.

Since the invention of pulse oximetry in 1972, it was proposed as a fifth vital sign and is now well established as a standard of care in anesthesia. However, pulse oximeters placed at the periphery (finger or toe) produce erroneous (or even unobtainable) SpO_2 readings in conditions of poor peripheral perfusion such as hypotension, low cardiac output, hypothermia, and vasoconstriction, in which they may be most necessary [7, 8]. Many attempts have been made to minimize this limitation by the application of sensors on better-perfused areas such as the forehead [9], ear canal [10] and tongue [11].

In this study, the nasal septum was chosen as a suitable alternative site for monitoring. The hypothesis underlying this choice was that the nasal septum, being closer to the trunk with no direct exposure to ambient temperature, would remain adequately perfused during low perfusion states [4, 5]. The nose is a highly vascular structure with multiple anastomoses and redundancy of blood supply. The nasal septum is supplied by the branches of external and internal carotid arteries in which pulsation persists for longer in the presence of intense peripheral vasoconstriction than digital arteries [9].

The digits are under intensive regulation by the autonomic nervous system, and in cases of low surrounding temperature or low cardiac output, their arteries are constricted to reduce heat dissipation or to maintain sufficient blood supply to the critical core organs. Thus, finger or toe skin surface temperatures significantly drop during operation under general anesthesia. In this study, finger-tip temperatures were consistently lower than nasal septum and core temperatures at all time points ($p < 0.05$), reaching 33.5 ± 2.3 °C at 90 min after induction of anesthesia. As a result, two cases of pulse oximetry monitoring failure occurred in the finger pulse oximeter. Skin temperature less than 26.5 °C was already identified as a predictor of pulse oximetry failure with conventional pulse oximeters in adult patients [12].

In contrast with the finger probe, nasal septum probe functioned well continuously in all cases. Though nasal septum temperatures were significantly lower than core temperatures at some time points, they were consistently much higher than finger-tip temperatures ($p < 0.05$). Our results were supported by the study of Lim et al. [13] in which temperature measured at the nasal cavity did not show a large difference to esophageal temperature immediately after anesthetic induction (mean: 0.32 °C, 95% CI 0.27 to 0.37), and such a small difference was maintained for 60 min.

In this study, the bias and precision for SpO_2 measured at the nasal septum were -0.8 ± 1.3 (95% CI -1.1 to -0.6), which was similar degree of reliability to finger pulse oximetry. SpO_2 is defined as the percentage of oxygenated hemoglobin (HbO_2) relative to the sum of HbO_2 and Hb, while SaO_2 is defined as the percentage of HbO_2 relative to the total of four variants of hemoglobin (oxygenated hemoglobin, deoxygenated hemoglobin, methemoglobin, and carboxyhemoglobin). However, because we excluded the patients with known methemoglobinemia or carboxyhemoglobinemia, such an inherent discrepancy between SpO_2 and SaO_2 measurements might similarly influence our study participants. Manufacturers of pulse oximeters generally claim an accuracy of 2%, evaluated by the SD of the differences between SpO_2 and SaO_2, measured simultaneously in healthy subjects [14]. Thus, the level of accuracy observed in this study is certainly within acceptable limits for most clinical situations.

Ezri and colleagues [4] firstly suggested the clinical usefulness of nasal septum SpO_2 monitoring. They compared its performance with finger SpO_2 monitoring in 14 patients using an adhesive, flexible probe and demonstrated a better accuracy and no monitoring failure. However, in that study, finger probe could not obtain the SpO_2 data in 18% of measurements.

In view of immunity to the effects of peripheral vasoconstriction, commercially available forehead pulse oximetry also appears to be an alternative to finger pulse oximetry. However, due to venous pulsation via valveless veins in the head and face, forehead sensor produces intermittent low saturation readings if not properly pressure-fixed with a headband or similar device. Such a phenomenon is more pronounced during mechanical ventilation or in head-down tilt position [15].

Most commercial pulse oximeter probes are designed to be attached to peripheral sites such as the finger or toe. Thus, they would be inadequate for natural anchoring for the sensor to the nasal septum. Thus, we used a novel OxiFix M probe which was an omega-shaped clip-type transmittance probe developed for nasal septum and ear lobe pulse oximetry. Its main technology is a soft pinching power provided by a unique molding process of low density polyethylene for avoiding an excessive pressure to the tissues. It can provide SpO_2 monitoring from finger or toe as well as earlobe or nasal septum by pinching both sides of them gently.

When a transmittance probe is placed at the ear lobe or finger, device-related pressure ulcer has been anecdotally acknowledged [16, 17]. If the pressure exerted by probes exceeds capillary perfusion pressure (12–32 mmHg), pressure ulcer can occur theoretically [17]. However, as pressure ulcers occur from a combination of pressure and time, it takes 1 to 4 h of excessive pressure to cause a pressure ulcer. In this regard, additional studies will be required for OxiFix M probe in long-term use or use for neonate or infant.

Nasal septal monitoring has several other advantages; very easy to apply, less sensitive to motion artifacts, and less interfered with surgical maneuver during most surgeries. In addition, the nasal septum is usually readily accessible to the anesthesiologist, whereas the fingers are often remote or made inaccessible by the surgical drapes or the patient's position (especially in robot-assisted surgery). Though the nasal septal probe is similarly accepted in awake patients compared with the finger probe, it has major disadvantage of interference with mask ventilation. However, this problem can be solved by placing the probe at the earlobe during induction of general anesthesia.

This study has some limitations. The major limitation was that our patients had a SpO_2 range of 94 to 100% during the study period. At low saturation states, pulse oximetry accuracy deteriorates and tends to overestimate the SaO_2 [14]. It was ethically difficult to perform deliberate hypoxic challenges to our patients. Thus, we could not know response time of nasal septum pulse oximeter during desaturation and resaturation period. However, nasal septum probe may respond more quickly than the finger probes, as the nasal septum being closer to the heart than the finger, has less transit time for blood to reach the nasal septum compared to the finger [18]. The other limitation was that we did not evaluate the reliability of nasal septum pulse oximetry under moderate hypothermia due to ethical concern. This can be evaluated in cardiac surgery using moderate-to-deep hypothermia. Lastly, because a novel OxiFix M probe was not technically applied to oximeters providing perfusion index (PI), we could not use its benefit as a marker of peripheral perfusion in the present study. PI represents the ratio of pulsatile light absorption on continuous light absorption (*i.e.*, the alternating current/direct current ratio). As direct current corresponds to light absorption from non-pulsatile capillaries and venous vessels, skin, soft tissues, and bones, absolute PI values vary significantly depending on the measurement sites [19]. Thus, when using PI data for objective assessment of peripheral perfusion, it is reasonable to compare the individual PI ratios obtained at each of the measurement sites rather than their absolute PI values.

In conclusion, our study demonstrated a similar degree of accuracy of nasal septum pulse oximetry to conventional finger pulse oximetry for continuous monitoring of oxygen saturation. When considering that the nasal septum maintains more close temperature to core temperature than the finger, the nasal septum may be a more attractive site than the finger for SpO_2 monitoring in conditions of intense peripheral vasoconstriction due to hypothermia.

Authors contribution All authors contributed to the study conception and design. Material preparation, data collection was performed by YO and DKR. Data curation and statistical analyses were performed by Ji Won Choi. The first draft of the manuscript was written by DKK. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding The authors receive no financial support from any pharmaceutical or medical devices companies.

Data availability The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Falconer RJ, Robinson BJ. Comparison of pulse oximeters: accuracy at low arterial pressure in volunteers. Br J Anaesth. 1990;65:552–7.

2. Lawson D, Norley I, Korbon G, Loeb R, Ellis J. Blood flow limits and pulse oximeter signal detection. Anesthesiology. 1987;67:599–603.
3. Palve H, Vuori A. Accuracy of three pulse oximeters at low cardiac index and peripheral temperature. Crit Care Med. 1991;19:560–2.
4. Ezri T, Lurie S, Konichezky S, Soroker D. Pulse oximetry from the nasal septum. J Clin Anesth. 1991;3:447–50.
5. Clayton DG, Webb RK, Ralston AC, Duthie D, Runciman WB. Pulse oximeter probes. A comparison between finger, nose, ear and forehead probes under conditions of poor perfusion. Anaesthesia. 1991;46:260–5.
6. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;1:307–10.
7. Ralston AC, Webb RK, Runciman WB. Potential errors in pulse oximetry. I. Pulse oximeter evaluation. Anaesthesia. 1991;46:202–6.
8. Evans ML, Geddes LA. An assessment of blood vessel vasoactivity using photoplethysmography. Med Instrum. 1988;22:29–32.
9. Clayton D, Webb R, Ralston A, Duthie D, Runciman W. Pulse oximeter probes- a comparison between finger, nose, ear and forehead probes under conditions of poor perfusion. Anaesthesia. 1991;46:260–5.
10. Budidha K, Kyriacou PA. In vivo investigation of ear canal pulse oximetry during hypothermia. J Clin Monit Comput. 2018;32:97–107.
11. Coté CJ, Daniels AL, Connoll M, Szyfelbein SK, Wickens CD. Tongue oximetry in children with extensive thermal injury: comparison with peripheral oximetry. Can J Anaesth. 1992;39:454–7.
12. Pälve H, Vuori A. Pulse oximetry during low cardiac output and hypothermia states immediately after open heart surgery. Crit Care Med. 1989;17:66–9.
13. Lim HS, Kim BR, Kim DC, Lee SK, Ko SH. A comparison of the temperature difference according to the placement of a nasopharyngeal temperature probe. Korean J Anesthesiol. 2016;69:357–61.
14. Aoyagi T. Pulse oximetry: its invention, theory, and future. J Anesth. 2003;17:259–66.
15. Shelley KH, Tamai D, Jablonka D, Gesquiere M, Stout RG, Silverman DG. The effect of venous pulsation on the forehead pulse oximeter waveform as a possible source of error in Spo2 calculation. Anesth Analg. 2005;100:743–7.
16. Berge KH, Lanier WL, Scanlon PD. Ischemic digital skin necrosis: a complication of the reusable Nelcor pulse oximeter probe. Anesth Analg. 1988;67:712–3.
17. Goodell TT. An in vitro quantification of pressures exerted by earlobe pulse oximeter probes following reports of device-related pressure ulcers in ICU patients. Ostomy Wound Manage. 2012;58:30–4.
18. Severinghaus JW, Naifeh KH. Accuracy of response of six pulse oximeters to profound hypoxia. Anesthesiology. 1987;67:551–8.
19. Desgranges FP, Desebbe O, Ghazouani A, Gilbert K, Keller G, Chiari P, Robin J, Bastien O, Lehot JJ, Cannesson M. Influence of the site of measurement on the ability of plethysmographic variability index to predict fluid responsiveness. Br J Anaesth. 2011;107:329–35.