Measurement of exhaled breath temperature in patients under general anesthesia: A feasibility study

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Received September 14, 2022; Accepted January 9, 2023

DOI: 10.3892/br.2023.1600

Abstract. The aim of the present study was to investigate the respiratory parameters that influence the exhaled breath temperature (EBT) and the feasibility of using the latter to monitor the core temperature under general endotracheal anesthesia. A total of 20 patients undergoing abdominal surgery were included in the present study. At the first stage of the experiment, the respiratory rate was adjusted, while the other respiratory parameters [tidal volume, inspiratory and expiratory time ratio (TI:TE), and positive end expiratory pressure (PEEP)] were maintained at a constant level. At the second stage, the tidal volume was adjusted, while the other respiratory parameters were maintained at a constant level. At the third stage, the TI:TE was adjusted, while the other parameters were maintained at a constant level. At the fourth stage, PEEP was adjusted, while the other parameters were maintained at a constant level. In each experiment, the EBT, the maximum temperature of exhaled air in each min, the inhaled air temperature and the nasopharyngeal temperature (T nose) were recorded every min. During the first stage of the experiment, no significant difference was noted in the EBT at different levels of respiratory rate. During the second, third and fourth stage, no significant difference was noted in the EBT at different tidal volumes, TI:TE and PEEP, respectively. The EBT was significantly correlated with the T nose. Overall, the present study demonstrated that the EBT of patients undergoing abdominal surgery under general endotracheal anesthesia was not affected by the examined respiratory parameters and that it could be considered a feasible method of monitoring core temperature.

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Key words: temperature, anesthesia, general, breathing, feasibility study

Introduction

Body temperature is one of the basic human vital signs; therefore, temperature monitoring is essential during anesthesia (1,2). Body temperature measurements include peripheral compartment temperature and core temperature measurements (3,4). The muscle or skin-surface temperatures can reflect the peripheral compartment temperature (5), whereas the pulmonary artery blood temperature is considered the gold standard for the core temperature (6-10); the ear, esophageal, nasopharyngeal and rectal temperatures are considered approximated core temperatures (11,12). However, when a temperature probe is placed in the aforementioned positions, a risk of tissue or organ damage is possible (3). Several approaches have been developed for the non-invasive estimation of core temperature; for example, a method known as zero heat flux developed by Fox *et al* (13) and an unobtrusive passive heat flow sensor invented by Atallah *et al* (14). Flouris and Cheung (15) demonstrated that under spontaneous breathing, a positive correlation was possible between the exhaled breath temperature and the rectal temperature, which suggests a new method of non-invasive temperature measurement. Logie *et al* (16) reported that room temperature and slow vital capacity (SVC) significantly influenced exhaled breath temperature (EBT) variables in healthy children under spontaneous breathing conditions. Under these conditions, it is difficult to control certain respiratory parameters, such as tidal volume, respiratory rate, and inspiratory and expiratory time ratio (TI:TE). Compared with spontaneous breathing conditions, it is easier to regulate breathing parameters under general endotracheal anesthesia. However, to the best of our knowledge, EBT measurements and the relationship between EBT and core temperature under general endotracheal anesthesia, have not been reported to date. Since exhaled breath comes from inside the body, its temperature may be more representative of core temperature. Therefore, the aim of the present study was to investigate the breathing parameters that influence EBT and the feasibility of using the EBT to monitor core temperature under general endotracheal anesthesia. In the present study, it was hypothesized that a correlation between the EBT and the nasopharyngeal temperature (T nose) may provide a novel way of monitoring temperature in patients undergoing general anesthesia.

Material and methods

Patient and public involvement. In the present retrospective self-controlled trial, patients who underwent a laparotomy under general anesthesia at the First Affiliated Hospital of Harbin Medical University (Harbin, China) between April 2011 and September 2012 were screened as study subjects. The protocol of the present study was approved by the Ethics Committee of Harbin Medical University (approval no. 201314), and written informed consent was obtained from the patients prior to study inclusion.

Exclusion criteria. The following exclusion criteria were used: i) Past history of asthma or chronic obstructive pulmonary disease (COPD); ii) recent respiratory infection (within 2 weeks); iii) space-occupying lesions of the lung (e.g. lung tumor or tuberculosis); iv) pulmonary vascular disease (e.g. pulmonary embolism or vasculitis); v) thoracic and pleural disease (e.g. flail chest, pneumothorax or pleural effusion); vi) respiratory failure; vii) acute lung injury or acute respiratory distress syndrome; and viii) severe cardiac disease defined as New York Heart Association class (17) III or IV, acute coronary syndrome or persistent ventricular tachyarrhythmia.

Standard procedures. An intraoperative colloid infusion of hydroxyethyl starch (130/0.4) and a crystalloid infusion of acetated Ringer's solution were infused. Up to 500 ml was administered to the patient with induction of anesthesia and was subsequently continued at a rate of 2-4 ml/kg/h. All solutions were pre-heated to 36˚C in an incubator. Intraoperative liquid infusion and ion adjustment were performed in accordance with perioperative fluid therapy guidelines.

All patients were preoxygenated with a fraction of inspired oxygen (FiO_2) of 1.0 prior to tracheal intubation and were maintained at an FiO_2 of 0.4 during the entire procedure of anesthesia. General anesthesia was induced using 0.02 mg/kg midazolam, 0.4 μg/kg sufentanil, 1-2 mg/kg propofol and 0.2 mg/kg cis-atracurium for endotracheal intubation. Anesthesia was maintained by inhalation of sevoflurane (end tidal concentration ≥0.7 minimum alveolar concentration) and the fresh gas flow rate was controlled at 2 l/min; analgesia was induced with continuous remifentanil infusion (0.05-0.3 μg/kg/min) or sufentanil (0.1-0.3 μg/kg bolus) as required, and intermittent application of 0.05 mg/kg cis-atracurium every 40 min during surgery until 1 h prior to the end of surgery. Intraoperative monitoring was performed using a dedicated monitor (DatexOhmeda D-LCC15.03; Planar Systems, Inc.) and included non-invasive blood pressure, pulse oximetry, end-tidal fractions of carbon dioxide, electrocardiogram and bispectral index measurements. A side stream spirometer (DatexOhmeda S/5 Avance; Cytiva) and a D-lite transmitter were connected to monitor peak airway pressure, plateau inspiratory pressures, compliance and tidal volume.

Ventilation protocol. The basic ventilation consisted of volume-controlled mechanical ventilation (DragerFabius GS premium; Drägerwerk AG & Co. KGaA) at an FiO_2 of 0.40, TI:TE of 1:2, a respiratory rate of 12 breaths/min, positive end-expiratory pressure (PEEP) of 0 cm H_2O and tidal volume of 8 ml/kg ideal body weight (IBW). IBW was calculated as follows: 50+0.91 [height (cm) -152.4] for men and 45.5+0.91 [height (cm) -152.4] for women (18). The breathing loop contained a heat moisture exchanger (HME). The T nose probe (GE Healthcare) was placed according to the method published by Lee *et al* (19); the temperature of the operating room, the T nose, the inhaled air temperature and the minimum EBT were recorded following 15 min of basic ventilation. The temperature of the air was measured by fast-response temperature probes (at 50-msec intervals). The probe for measuring the EBT was placed between the HME and the tracheal tube, and the probe for measuring the inhaled air temperature was placed in the inspiratory limb outlet close to the Y-piece (Fig 1).

Following 15 min of basic ventilation, all patients were ventilated in accordance with the following protocol (Fig 2): In step 1, the respiratory rate was adjusted to 8 times/min and the other respiratory parameters were maintained at a constant level. Following 2 min of stabilization, the maximum temperature of exhaled air in each min (T exhale), the inhaled gas temperature (T inhale) and the T nose at that time point were recorded. The recording was repeated 3 times. The respiratory rate was then adjusted to 12 times/min while maintaining the other respiratory parameters; following 2 min of stabilization, the aforementioned parameters were recorded. The recording was repeated 3 times. Similarly, the respiratory rate was subsequently adjusted to 16 times/min, and lastly, basic ventilation was conducted for 5 min. In step 2, the tidal volume was adjusted to the standard weight [(kg) x 6 ml] and the other respiratory parameters were maintained at basic ventilation level. Following 2 min of stabilization, the maximum T exhale, the T inhale and the T nose were recorded. The recording was repeated 3 times. Similarly, the tidal volumes were sequentially adjusted to the standard weight [(kg) x 8 ml and (kg) x10 ml, respectively] and the T exhale, the T inhale and the T nose were recorded. The recording was repeated 3 times. Subsequently, basic ventilation was conducted for 5 min. In step 3, the TI:TE was altered to 1:4, while the other respiratory parameters remained unaltered. Following 2 min of stabilization, the T exhale, the T inhale and the T nose were recorded. The recording was repeated 3 times. Similarly, TI:TE was adjusted sequentially to 1:2 and 4:1, and the T exhale, the T inhale and the T nose were recorded. The recording was repeated 3 times. Subsequently, basic ventilation was conducted for 5 min. In step 4, the PEEP was set to 5 cm H_2O, while the other respiratory parameters remained unchanged. Following 2 min of stabilization, the T exhale, the T inhale and the T nose were recorded. The recording was repeated 3 times. Similarly, the PEEP was sequentially adjusted to 0 and 5 cm H_2O, respectively, and the T exhale, the T inhale and the T nose were recorded. The recording was repeated 3 times. The respiratory parameters were then maintained at basic ventilation level until the end of surgery. The temperature in the operating room was maintained at a range of 22-24˚C.

The criteria for protocol discontinuation were as follows: i) Hemodynamic instability (mean arterial blood pressure <60 mmHg); ii) end-tidal carbon dioxide partial pressure <30 or >40 mmHg; iii) oxygen saturation <90%; and iv) peak airway pressure >40 cm H_2O.

Statistical analysis. One-way ANOVA with Bonferroni's post-hoc test was used to assess whether the T inhale of

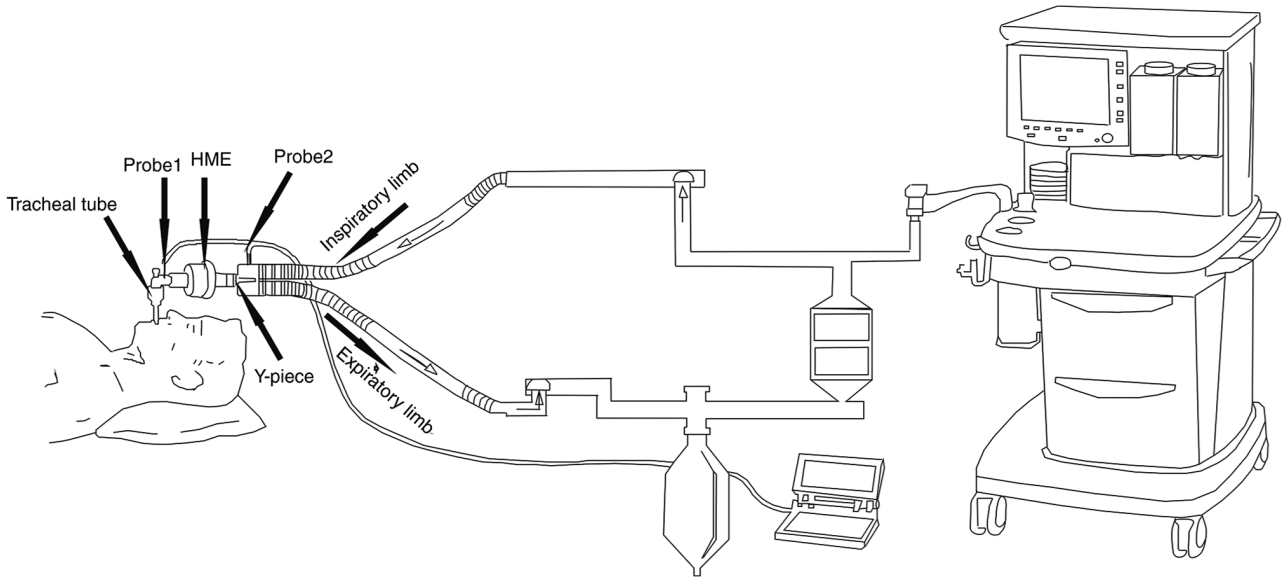

Figure 1. Exhaled breath temperature measurement diagram. Temperature probe 1 was placed between the HME and the tracheal tube, and was used to measure the exhaled breath temperature. Probe 2 was placed in the inspiratory limb outlet close to the Y-piece and was used to measure the temperature of the inspired limb outlet. HME, heat and moisture exchanger.

the patients varied with the alterations in time. To assess whether the four different parameters affected the T exhale, a repeated-measures ANOVA with Bonferroni's post-hoc test was used for the four respiratory parameters. Pearson's correlation coefficients were used to assess the agreement between EBT and the T nose. The results are expressed as the mean ± SD. All statistical analyses were performed with the SPSS (version 19; IBM Corp.) statistical software package. $P<0.05$ was considered to indicate a statistically significant difference.

Results

A total of 568 consecutive patients who were scheduled to undergo major abdominal surgery were screened, of whom 543 were excluded due to one or more of the aforementioned exclusion criteria, leading to a final inclusion of 25 patients in the study. A total of 5 patients experienced one or more protocol discontinuation criteria; 2 cases involved end-tidal carbon dioxide partial pressure <30 mmHg, 2 cases had a mean arterial blood pressure <60 mmHg and 1 case had an oxygen saturation level of <90%. A total of 20 patients (age range, 45-65 years) therefore participated in the final study, including 5 men and 15 women (Fig 3). The precision of the temperature probe was determined by the relative standard deviation (RSD). The intraday RSD values of the exhaled and inhaled air probes were 0.58 and 0.70%, respectively, and the interday RSD values for the exhaled and inhaled air probes were 0.96 and 0.85%, respectively. The demographics, EBT, operating room temperature, operation time, intraoperative blood loss, liquid infusion and baseline T nose at the beginning of the experiment are presented in Table I.

During the experiment, the T inhale of the patients did not vary significantly over time (Fig 4). During the first stage, no significant difference was noted in the EBT at different levels of respiratory rate (Fig 5). At the second stage, no significant differences were noted in the EBT at different levels of tidal volume (Fig 6). At the third stage, no significant differences were observed in the EBT at different levels of TI:TE (Fig 7). At the last stage, no significant difference was noted in the EBT at the different levels of PEEP (Fig 8). Moreover, the data indicated that the EBT was significantly correlated with the T nose (Pearson's correlation $r^2=0.119$, $P<0.001$; Fig 9).

Discussion

Various factors can cause hypothermia during an operation. For example, anesthetics may impair thermoregulation, whereas other factors include the high airflows and cold temperatures in the operation rooms, as well as the exposure to and use of cold fluids or blood for infusion (1). Intraoperative hypothermia is a serious complication, which contributes to higher mortality rates and increases surgical wound infection incidence, blood loss and duration of post-anesthetic recovery (2). The increase in body temperature during general anesthesia is rare; however, it is often associated with serious adverse events, such as malignant hyperthermia or sepsis (20,21). Therefore, temperature monitoring is of great significance during an operation.

The present study demonstrated that the EBT of patients undergoing abdominal surgery under general endotracheal anesthesia was not affected by specific respiratory parameters (tidal volume, respiratory rate, TI:TE and PEEP) when they were within a certain range (tidal volume, 6, 8 and 10 ml/kg IBW; respiratory rate, 8, 12 and 16 breaths/min; TI:TE, 1:2, 1:4 and 4:1; PEEP, 0, 5 and 10 cm H_2O). To the best of our knowledge, these findings represent the first report on the relationship between EBT and respiratory parameters in patients undergoing general anesthesia.

Previous studies have reported that the EBT of patients with asthma is higher than that of healthy subjects (22,23). These studies reported a correlation between EBT and the

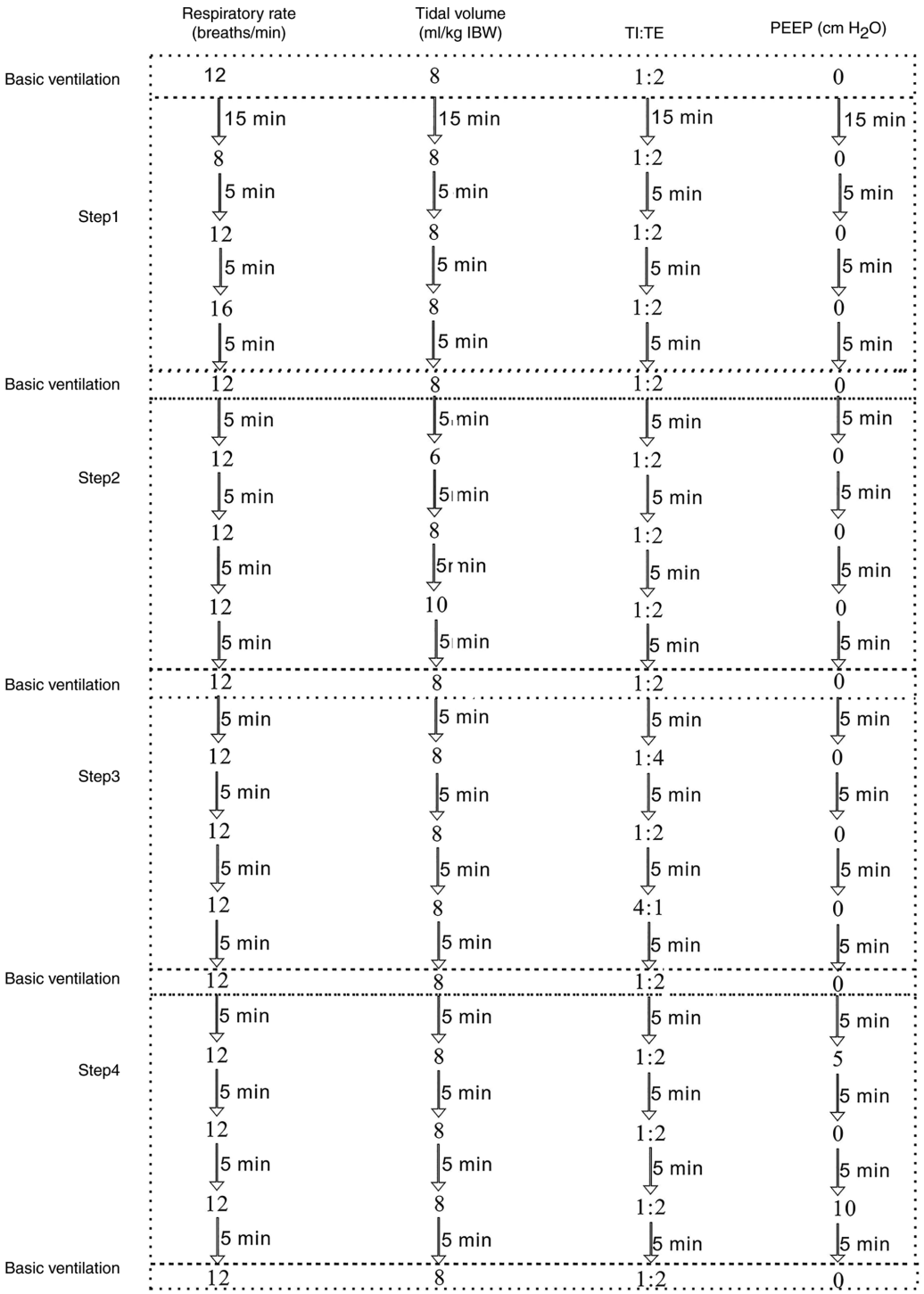

Figure 2. Ventilation protocol. IBW, ideal body weight; TI:TE, inspiratory and expiratory time ratio; PEEP, positive end expiratory pressure.

level of exhaled nitric oxide, which is an inflammatory marker present in asthmatics (24). Vascularization increases in the airway mucosal layer of asthmatics, which also increases the heat exchange of the gas during exhalation and leads to increased EBT. The latter has been suggested to be a novel biomarker for patients with asthma (25,26).

Previous studies that examined the effect of EBT in various subject types were performed under spontaneous breathing conditions. Recently, Logie *et al* (16) reported that room temperature and SVC significantly influenced EBT variables in healthy children. Flouris and Cheung (15) reported that EBT was not influenced by the breathing patterns. However, under spontaneous breathing, it is impossible to precisely control ventilator parameters, such as respiratory rate, tidal volume, inspiratory time and expiratory time. In the present study, all patients were under a controlled respiratory status during general anesthesia, and it was possible to more easily regulate breathing parameters as well as measure the relationship between respiratory parameters and EBT. Logie *et al* (16) demonstrated that the inhaled air temperature could affect the EBT. In the present study, the inhaled air temperature of the patients did not change

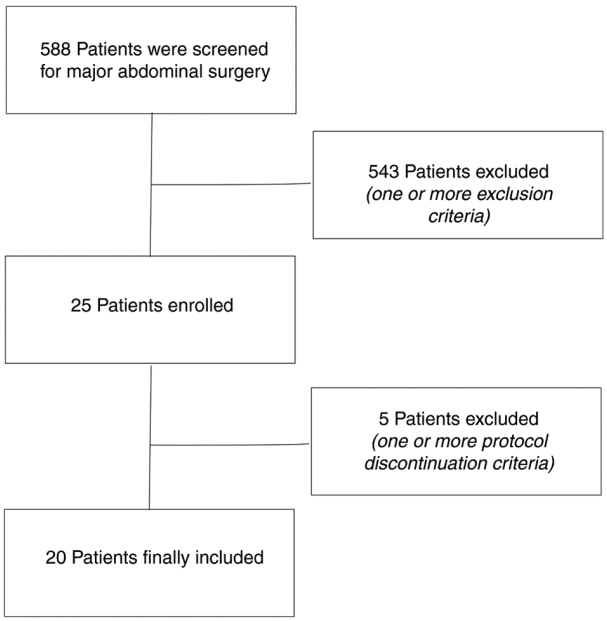

Figure 3. Flow diagram of study inclusion.

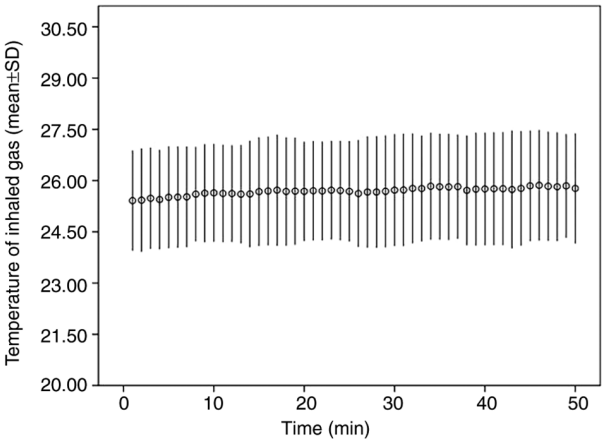

Figure 4. Temperature of inhaled gas during the experiment. During the experiment, the temperature of inhaled gas did not change over time. The values are expressed as the mean ± SD (P>0.05).

Table I. Baseline characteristics of the patients.

Characteristic	Patients (n=20)
Mean age (±SD), years	55.15 (11.71)
Mean height (±SD), cm	167.2 (8.02)
Mean weight (±SD), kg	
Actual	62.78 (12.43)
Predicted	56.80 (5.39)
Smoking history, n (%)	11 (55)
Type of surgery, n (%)	
Partial hepatectomy	4 (20)
Colorectal resection	4 (20)
Gastrectomy	3 (15)
Exploratory surgery	3 (15)
Pancreaticoduodenectomy	2 (10)
Other procedure	4 (20)
Mean operation time (±SD), min	123.15 (3.35)
Mean intraoperative blood loss (±SD), ml	152.75 (16.61)
Mean intraoperative liquid infusion (±SD), ml	1505.25 (18.75)
Mean inspired temperature during basic ventilation (±SD), ˚C	25.41 (1.47)
Mean expired temperature during basic ventilation (±SD), ˚C	35.64 (0.70)
Mean operating room temperature (±SD), ˚C	23.34 (0.19)
Mean nasopharyngeal temperature during basic ventilation (±SD), ˚C	36.15 (0.38)

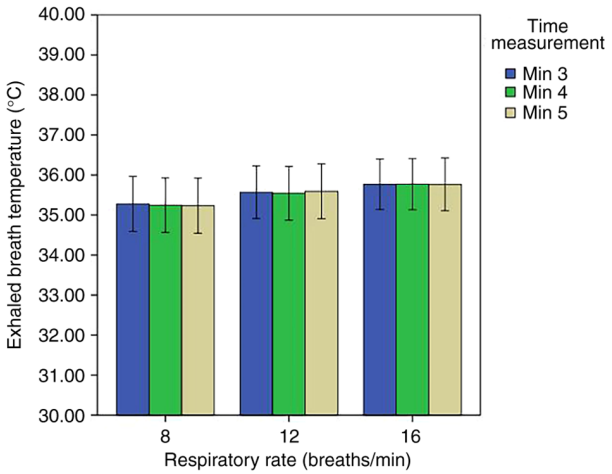

Figure 5. Effects of different levels of respiratory rate (8, 12 and 16 breaths/min) on the exhaled breath temperature in intubated patients during general anesthesia. The values are expressed as the mean ± SD (P>0.05). Time 3, third min; time 4, fourth min; time 5, fifth min.

with time, which is consistent with the results of the study by de Castro Jr *et al* (27).

It has previously been hypothesized that the level of EBT is related to the degree of airway inflammation (22,23,28,29). Previous studies have shown that EBT is increased in asthmatic children (30-33) and in patients with non-small cell lung cancer (34), as well as in patients exhibiting exacerbated COPD (35); therefore, patients who presented with the aforementioned diseases were excluded in the present study.

During the conduct of the study, the T nose of each patient was monitored. Although extraordinary caution was taken during the installation of the probe, which was used for the detection of the T nose according to the method by Lee *et al* (19), epistaxis occurred in 4 patients. Similarly, placement of the temperature probe in the ear canal, esophagus, rectum or other body parts represents a risk for tissue damage. Relative to the temperature measurement of the aforementioned body parts, the measurement of EBT is non-invasive and may potentially represent the optimal means of measuring the core temperature. Flouris and Cheung (15) confirmed that under spontaneous breathing, an optimal correlation was present between the EBT and the rectal temperature. In the present study, a significant

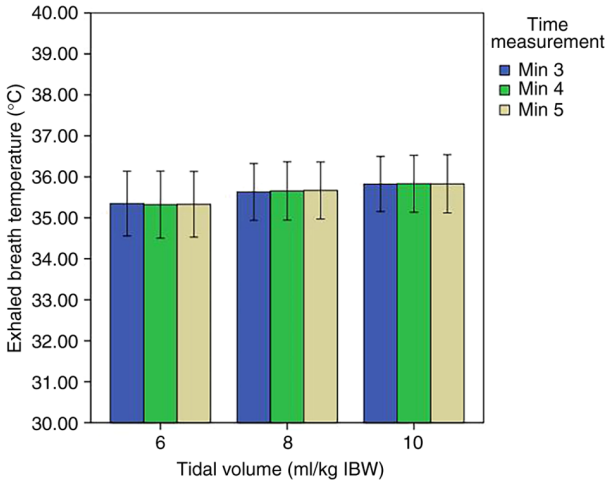

Figure 6. Effects of different levels of tidal volume (6, 8 and 10 ml/kg IBW) on the exhaled breath temperature in intubated patients during general anesthesia. The values are expressed as the mean ± SD (P>0.05). Time 3, third min; time 4, fourth min; time 5, fifth min. IBW, ideal body weight.

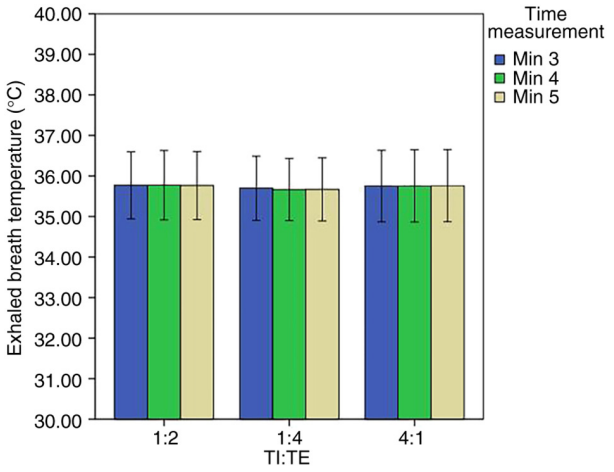

Figure 7. Effects of different levels of TI:TE (1:2, 1:4 and 4:1) on the exhaled breath temperature in intubated patients during general anesthesia. The values are expressed as the mean ± SD (P>0.05). Time 3, third min; time 4, fourth min; time 5, fifth min. TI:TE, inspiratory and expiratory time ratio.

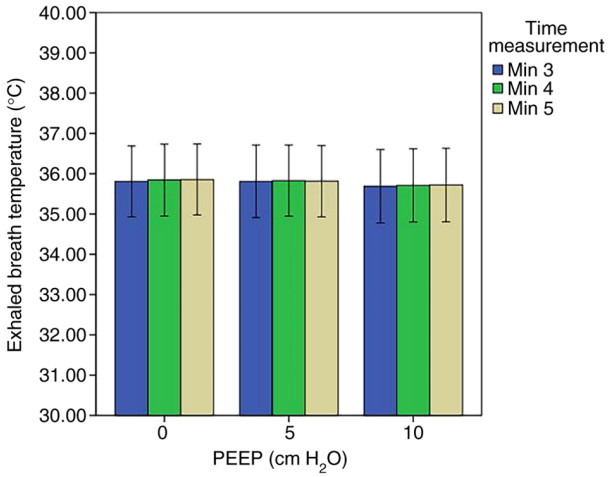

Figure 8. Effects of different levels of PEEP (0, 5 and 10 cm H_2O) on the exhaled breath temperature in intubated patients during general anesthesia. The values are expressed as the mean ± SD (P>0.05). Time 3, third min; time 4, fourth min; time 5, fifth min. PEEP, positive end-expiratory pressure.

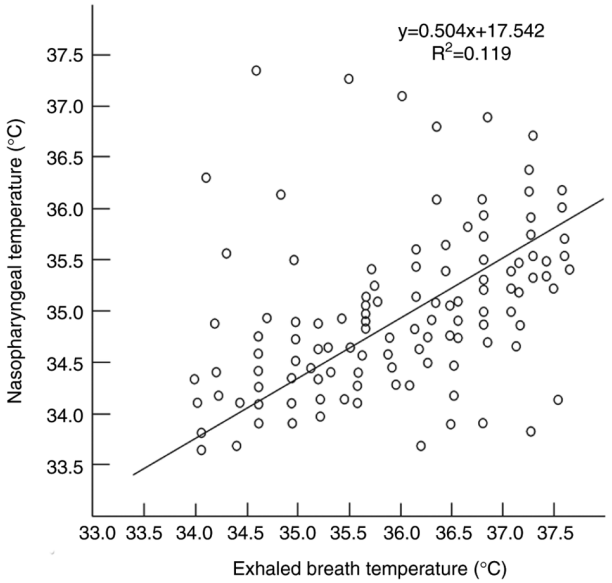

Figure 9. Correlation between T nose and EBT. Scatterplot and regression linesdemonstrating the correlation between the T nose and the EBT in intubated patients during general anesthesia (r^2=0.119, P<0.001). T nose, nasopharyngeal temperature; EBT, exhaled breath temperature.

correlation between the T nose and the EBT was also found, which led to the postulation that under controlled breathing conditions, an optimal correlation may exist between the EBT and the core temperature. In future experiments, the relationship between the EBT and the blood temperature of the pulmonary artery (the gold standard of core temperature) under controlled breathing conditions will be investigated to validate the present hypothesis. The present study highlights a novel outline for the application of the EBT as a marker for monitoring the core temperature of patients undergoing general endotracheal anesthesia.

The low number of subjects was a limitation of the present study. Larger trials can provide a better correlation between the EBT and the T nose. Another limitation of the present study was the sole assessment of well-prepared inpatients who underwent laparotomy under general anesthesia. The addition of other types of patients and surgery types may increase the validity of the findings. In addition, a limitation of this study is that the nasopharyngeal temperature was used to represent core temperature, rather than the gold standard of pulmonary artery blood temperature, which will be investigated in the following study.

The present study demonstrated that the EBT of patients undergoing abdominal surgery under general endotracheal anesthesia was not affected by specific respiratory parameters when they were within a certain range and that the EBT represented a viable method to monitor the core temperature.

Acknowledgements

Not applicable.

Funding

Financial support was provided by the National Natural Science Foundation of China (grant no. 81402462) and the Foundation of Heilongjiang Educational Committee (grant no. 12531245).

Availability of data and materials

The data and materials used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

All authors participated in the collection of samples and the observation/analysis of data and results. EL and CW provided the conception and design of the study. DL, YW, HT, YL, PY and YF performed sample collection. LG and JS analyzed the samples. JS and DL confirm the authenticity of all the raw data. All authors have read and approved the manuscript.

Ethics approval and consent to participate

The protocol in this study was approved by the Ethics Committee of Harbin Medical University (Harbin, China; approval no. 201314), and written informed consent was obtained from the patients prior to study involvement.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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