



Effect of electrically heated humidifier on intraoperative core body temperature decrease in elderly patients: a prospective observational study

*Department of Anesthesiology and Pain Medicine, Seoul National University Hospital, Department of Anesthesiology and Pain Medicine, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

Hyungseok Seo*, Kyungmi Kim, Eun-a Oh*, Yeon-jin Moon, Young-Kug Kim, and Jai-Hyun Hwang

Background: Core body temperature (T_c) can decrease during general anesthesia. Particularly in elderly patients, more aggressive strategies to prevent intraoperative hypothermia may be required. Here, we investigated the effect of a heated humidifier on intraoperative T_c decrease in the elderly.

Methods: Twenty-four elderly patients were randomly assigned into two groups: those who used a heated humidifier (group H) and those who used a conventional ventilator circuit with a heat moisture exchanger (group C). T_c was measured continuously at the esophagus at several time-points during surgery.

Results: In group C, T_c significantly decreased 90 minutes after skin incision ($P < 0.001$), while significant differences were not noted in group H during surgery. Comparing the two groups, T_c decreased more in group C than in group H at 60, 90, 120, and 150 minutes after skin incision (group C vs. group H: -0.6°C vs. -0.3°C , $P = 0.025$; -0.7°C vs. -0.4°C , $P = 0.012$; -0.9°C vs. -0.4°C , $P = 0.006$; and -1.0°C vs. -0.5°C , $P = 0.013$, respectively). There were no significant differences between the two groups for any other parameters.

Conclusions: A heated humidifier is more effective in preventing intraoperative T_c decrease in elderly patients than a heat moisture exchanger. However, further studies with a larger population are required to substantiate its clinical use. (*Anesth Pain Med* 2016; 11: 211-216)

Key Words: Body temperature, Closed circuit anesthesia, Heating, Humidity, Hypothermia.

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Corresponding author: Jai-Hyun Hwang, M.D., Ph.D., Department of Anesthesiology and Pain Medicine, Asan Medical Center, University of Ulsan College of Medicine, 88, Olympic-ro 43-gil, Songpa-gu, Seoul 05505, Korea. Tel: 82-2-3010-3868, Fax: 82-2-3010-6790, E-mail: jhhwang@amc.seoul.kr

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INTRODUCTION

Core body temperature (T_c) can decrease during general anesthesia and surgery [1]. Various factors including low ambient temperature [2], cold intravenous fluids, open abdominal surgery [3], drug induced vasodilation [2], and the inspiration of cold fresh gas can decrease T_c [4], which can contribute to perioperative complications such as delayed awakening and coagulopathy [5,6]. Particularly in elderly patients, heat production can decrease and vasoconstrictor response to a cold stress can be attenuated during surgery [7,8]. This can lead to decreased T_c ; therefore, careful consideration is required to maintain temperature homeostasis during general anesthesia in elderly patients [9].

Many active warming devices, such as a forced-air warming system and water-circulating mattress, are used to prevent intraoperative T_c decrease [10,11]. Electrically heated humidifiers (HH) can deliver warmed gas directly to the lower respiratory tract. Compared to a heat and moisture exchanger (HME), which is widely used during mechanical ventilation, HH may provide additional heat energy, thereby being more effective for maintaining T_c [12-15]. However, previous studies comparing HH to a conventional circuit without HME [12] were limited by use of aural canal temperature, which is not representative of T_c , [13] or by being performed in specialized surgical conditions such as liver transplantation [15]. Therefore, the effect of HH, compared to HME, on intraoperative T_c decrease has not been well defined, particularly in elderly patients under general anesthesia.

Because HH can provide direct heat energy, we thought that using HH would be more effective in preventing T_c decrease than using HME. To evaluate the effect of both devices on

intraoperative T_c change, we serially measured T_c at specific time-points and investigated the change in T_c from baseline.

MATERIALS AND METHODS

After obtaining approval from our Institutional Review Board and registering with Clinical Research Information Service (registration number: KCT0000910), this study was conducted between March 2013 and December 2013. A total of 24 elderly patients undergoing open urologic surgery were enrolled after obtaining written informed consent. All patients were ASA physical status 1 or 2, and patients with any history of severe cardiopulmonary disease, abnormal pulmonary function on preoperative testing, obese patients (body mass index, BMI $> 30 \text{ kg/m}^2$), thin patients (BMI $< 18.5 \text{ kg/m}^2$), and those with abnormal preoperative temperature ($> 38^\circ\text{C}$ or $< 36^\circ\text{C}$) were excluded. All patients were evaluated with standard preoperative work-up examinations at our institution. None of the patients were premedicated.

After admission for surgery, all patients were randomly assigned into one of two groups by using computer-generated random numbers. Mechanical ventilation was achieved using a conventional ventilator circuit with HME in group C ($n = 12$) or using a HH in group H ($n = 12$). In group C, HME (Humid Vent, Gibeck, Sweden), was placed between the tracheal tube and a Y-piece of the ventilatory circuit. In group H, HH (ANAPODTM, Westmed Inc. Tucson, AZ, USA) was used to deliver warmed and humidified inspiratory gas. HH consisted of an electrically heated wire that was set to 38°C by a servo-control system and water-absorbing sponge in the inspiratory limb.

In accordance with our institutional standards, the same intraoperative patient monitoring protocol was applied in both groups. General anesthesia was induced with thiopental sodium 5 mg/kg , and vecuronium 0.15 mg/kg was used to facilitate tracheal intubation. Anesthesia was maintained by administering 1–3 vol% sevoflurane and 2 L/min of 50% oxygen and medical air mixture. The depth of anesthesia was monitored using the bispectral index (BIS A-1050 Monitor, Aspect Medical Systems, Newton, MA) and was maintained between 40–60 during surgery. Patients were connected to the anesthesia machine (Primus[®]; Drägerwerk AG & Co., Lübeck, Germany) and ventilated using a tidal volume of 6–8 ml/kg of the patient's ideal body weight and 8 cmH₂O of positive end-expiratory pressure. The respiratory rate was adjusted to maintain normocapnia. Administered intravenous fluid was

warmed to 37°C by a fluid warming device, and packed red blood cells were administered at ambient temperature. During surgery, mean blood pressure was maintained $> 65 \text{ mmHg}$ and heart rate at $< 110 \text{ beats/min}$. Transfusion was initiated when the intraoperative hemoglobin level was $< 8 \text{ g/dl}$. Patients were aggressively warmed by forced-air warming system (Bair HuggerTM, 3M, St. Paul, MN, USA) when T_c decreased $< 35.5^\circ\text{C}$ or after 150 minutes of skin incision.

Outcome measurement

Temperatures were measured at three different sites (esophagus, aural canal, and right forearm) during surgery. Esophagus temperature, considered as the T_c , was continuously measured using an esophageal stethoscope with temperature sensor (Esophageal Stethoscope; DeRoyal Inc., Powell, TN, USA). An esophageal stethoscope was placed at the site where the heartbeat was best heard. Skin temperature (T_s) was measured using an attachable probe (Skin temperature probe; Datex- Ohmeda, Helsinki, Finland) that was placed at the center of the anterior aspect of the right forearm. The right forearm of each patient was exposed to ambient environment during the intraoperative period.

To measure the primary outcomes, an esophageal probe was inserted immediately after tracheal intubation to the depth of the maximal cardiac sounds on auscultation. T_c was recorded immediately after intubation as the baseline reading. After baseline values were measured, T_c was repeatedly recorded at 15, 30, 45, 60, 90, 120, and 150 minutes after skin incision, and at the end of surgery. At each time-point, T_s was monitored to assess the peripheral vasodilation occurring at the initial phase of T_c decrease. Each T_s measurement was performed simultaneously with the corresponding T_c measurement.

For other outcomes, we assessed the amount of administered fluid and transfusion incidence. Additionally, we evaluated temperature, the amount of administered opioid, and the incidence of shivering at the postanesthesia care unit.

Statistical analysis

In a previous pilot study, the mean T_c decrease from baseline 150 minutes after skin incision was $1.3^\circ\text{C} \pm 0.5^\circ\text{C}$ in patients using HME and $0.7^\circ\text{C} \pm 0.5^\circ\text{C}$ in patients using HH. Assuming a type I error of 0.05 and a desired power of 0.80 to test the alternative hypothesis that T_c decrease was different between group H and group C, 12 patients were required for the present analysis. All data were expressed as numbers (%), the median [interquartile range], or the mean \pm standard

deviation (SD). Statistical analyses were performed using IBM SPSS 21.0 (IBM Corp., Armonk, NY, USA). The Shapiro-Wilk test was used to test the normality of the data. Repeated measure analysis of variance was performed to evaluate T_c changes in each group. The Mann-Whitney rank-sum test was used to compare temperature between the two groups at each time-point. The student's t-test was used to compare linear data, and Fisher's exact test or the chi-square test was used to compare categorical data between groups. A $P < 0.05$ is considered to be statistically significant.

RESULTS

A total of 24 patients were enrolled, and none dropped out during the course of the study. Demographic data of patients are presented in Table 1. No significant differences were seen in demographics between group C and group H. Intraoperative and postoperative data are listed in Table 2. There were no

significant differences in intraoperative data and postoperative outcomes between the two groups.

Changes in T_c during the entire measurement period are presented in Fig. 1. T_s was similarly changed in both groups, with no significant difference in any time-point between group C and group H (Fig. 2, $P = 0.919$). In group C, T_c was significantly lower at 90, 120, and 150 minutes after skin incision compared to baseline ($P < 0.001$), while in group H, there was no significant T_c decrease until the end of surgery ($P = 0.46$). Between group C and group H, T_c differed at 60, 90, 120, and 150 minutes after skin incision ($-0.6 [-0.7-0.4]^{\circ}\text{C}$ vs. $-0.3 [-0.5-0.1]^{\circ}\text{C}$, $P = 0.022$; $-0.7 [-0.9-0.5]^{\circ}\text{C}$ vs. $-0.4 [-0.7-0.1]^{\circ}\text{C}$, $P = 0.015$; $-0.9 [-1.1-0.6]^{\circ}\text{C}$ vs. $-0.4 [-0.5-0.2]^{\circ}\text{C}$, $P = 0.006$; and $-1.0 [-1.3-0.7]^{\circ}\text{C}$ vs. $-0.5 [-0.5-0.1]^{\circ}\text{C}$, $P = 0.013$, respectively).

Table 1. Patient Demographics and Type of Surgery

Variables	Group C (n = 12)	Group H (n = 12)	P value
Age (yr)	70.3 ± 3.8	68.3 ± 2.6	0.15
Body mass index (kg/m ²)	23.6 ± 2.7	24.3 ± 3.4	0.56
Duration of anesthesia (min)	376.9 ± 134.6	351.6 ± 109.5	0.62
Ambient room temperature (°C)	23.9 ± 0.8	23.9 ± 0.7	0.98
Type of surgery			
Radical cystectomy	9 (75%)	7 (58%)	0.65
Radical retropubic prostatectomy	3 (25%)	3 (25%)	0.33
Radical Nephrectomy (supine position)	0 (0%)	2 (17%)	0.45

Data are expressed as the mean ± SD or numbers (percent).

Table 2. Intraoperative Data and Postoperative Outcomes

Variables	Group C (n = 12)	Group H (n = 12)	P value
Intraoperative data			
MAC-hr	5.9 ± 2.5	5.2 ± 1.3	0.58
Awake time (seconds)	568.7 ± 258.5	440.8 ± 204.3	0.19
Crystalloid administered (ml)	4,200 ± 2,106	2,975 ± 1,268	0.09
Transfusion incidence	7 (58.3%)	3 (25.0%)	0.21
Packed RBCs administered (unit)	1.5 ± 1.4	0.4 ± 0.8	0.03
Postoperative outcomes			
Temperature at PACU (°C)	36.3 ± 0.4	36.3 ± 0.3	0.65
Opioid administered (μg)	65.4 ± 28.7	75.0 ± 39.9	0.51
Shivering at PACU	1 (8.3%)	1 (8.3%)	

Data are expressed as the mean ± SD, or number (percent). Awake time was defined as the time from anesthetic discontinuation to the first response to a verbal command. At PACU, intravenous fentanyl was only used for opioid administration. MAC-hr: the integral of minimal alveolar concentration (MAC) by time (hr) of exposure, RBC: red blood cell, PACU: postanesthesia care unit, PaO₂: partial pressure of arterial oxygen.

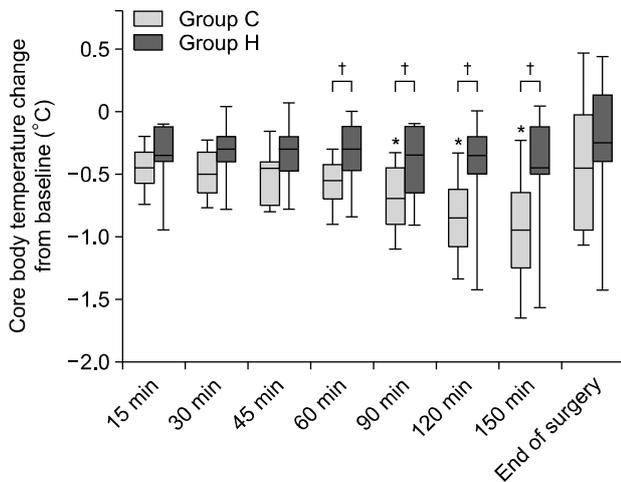


Fig. 1. Core body temperature change in group C and group H. In group C (using heat moisture exchanger, light-gray box), the core body temperature significantly decreased compared to the baseline values at 90, 120, and 150 minutes after skin incision, but in group H (using heated humidifier, dark gray box), the core body temperature did not significantly change at these time-points compared to baseline. In the vertical box-plot, the median value is indicated by a horizontal line in the box, and the upper/lower ends of the box indicate the interquartile range. *P < 0.05, compared to the baseline value, †P < 0.05, compared between group C and group H.

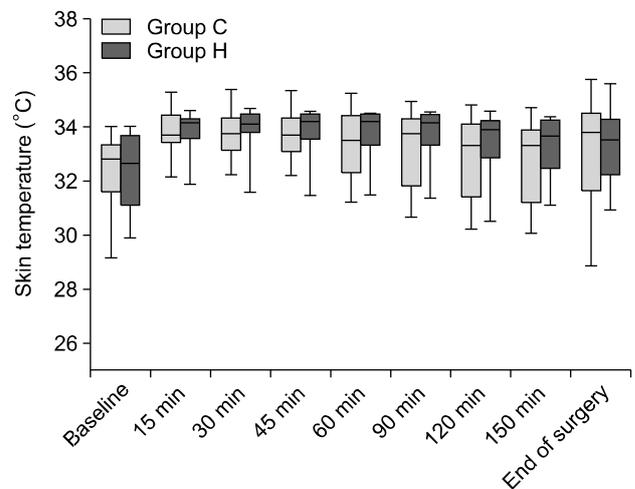


Fig. 2. Intraoperative skin temperature in group C and group H. Between group C (using heat moisture exchanger, light-gray box) and group H (using heated humidifier, dark gray box), there were no differences in skin temperature at any time-point. In the vertical box-plot, the median value is indicated by a horizontal line in the box, and the upper/lower ends of the box indicate the interquartile range.

DISCUSSION

In our present study, the T_c decreased significantly in patients using HME, but did not change in patients using HH. Between the two groups, the difference in T_c change became significant 90 minutes after skin incision, whilst the T_s showed similar values across time points. These findings suggested a role for HH in intraoperative temperature management.

HME was effective in optimizing inspiratory gas, but had no beneficial effect on T_c change during general anesthesia [16]. However, HH can directly supply convective heat energy and humidified gas to the tracheobronchial tree, which consequently reduces evaporation from mucosal surfaces. The proportion of heat loss from the respiratory tract is known to be < 10% of the total intraoperative heat loss [17], but the large surface area of tracheobronchial tree may allow for effective delivery of heat energy from warmed inspiratory gas. Moreover, heat loss from mucosal vaporization can decrease > 50% in fully humidified gas [17], which may also contribute to decreased heat loss. Therefore, despite the relatively small proportion of total intraoperative heat loss, directly providing heat energy to the lower respiratory tract via HH may effectively limit T_c

decrease to < 0.5°C.

Intraoperative T_c is known to decrease in two different phases. After anesthesia is induced, T_c decreases quickly via core-to-peripheral heat redistribution by anesthetic-induced peripheral vasodilation (phase 1) [1,18-20]. Then, T_c decreases slowly by heat loss via convection and radiation (phase 2) [14,20]. In phase 1, anesthetic-induced peripheral vasodilation can make prompt heat redistribution while preserving body heat content constantly and result in T_s increase [21]. Our data showed that the T_s change during surgery was similar between group H and group C, suggesting that initial peripheral vasodilation did not differ between these groups. In phase 2, the negative balance between heat production and loss was a major cause of T_c decrease [1], and peripheral vasodilation in phase 1 subsequently can also contribute to T_c decrease [22]. In elderly patients, decreases in both heat production and thermoregulated vasoconstriction may be responsible for the increased risk of intraoperative hypothermia [9]. Thus, we hypothesized that the role of HH on T_c decrease is more important in phase 2 than in phase 1 when the ability of heat production is compromised. HH can provide heated inspiratory gas, thereby reducing the temperature gradient between inspiratory and expiratory airflow during mechanical ventilation. Moreover, by maintaining optimal relative humidity, HH may contribute to preventing heat loss via mucosal evaporation. In this regard, by reducing heat loss in the lower respiratory

tract, HH may have a superior effect on maintaining T_c , particularly in phase 2. In our current study, T_c was maintained in group H even at 90 minutes after skin incision, but was significantly decreased in group C.

Intraoperative hypothermia has been associated with increased perioperative morbidity including delayed emergence and increased blood loss [5]. Particularly in elderly patients with decreased thermoregulatory response and drug metabolism, inadvertent hypothermia can cause serious postoperative complications [9,23]. However, our present data showed that emergence time, defined as the time from discontinuation of volatile anesthetics to the first response to a verbal command, was not statistically different between the two groups. Mild intraoperative hypothermia can inhibit platelet aggregation, thereby increasing risk of transfusion [13]. Although the fact that HH is associated with decreased transfusion [12,24,25], and that our data showed a significant amount of administered RBC, our results did not provide sufficient clinical evidence of the role of HH on decreased transfusion due to the relatively small sample size and different proportion of surgery types. Further studies with larger sample sizes are needed to investigate the incidence of postoperative complications.

Several previous studies have reported the effect of HH on the prevention of intraoperative hypothermia, but such studies included cases undergoing specialized surgical conditions such as liver transplantation [15] or did not monitor esophageal temperature as an indication of T_c [12,13]. In contrast, in our present study, we monitored esophageal temperature, which is a well-known indicator of T_c [1] and focused to the effect in elderly patients. Because T_c normally decreases more than 0.5°C during phase 1 [1], the small difference in intraoperative T_c change between the two groups in the present study, which was less than 0.5°C , may be clinically important in terms of maintenance of intraoperative temperature homeostasis [7,8]. Elderly patients have decreased skeletal muscle mass, resulting in both lower resting metabolic rate [26] and impaired metabolic response to cold stimulus [27]. Moreover, even in the awakened state, T_c may not be maintained because of reduced vasoconstriction response to cold stress [7]. Therefore, elderly patients are more vulnerable to intraoperative hypothermia than younger patients, and the effect of warming devices on maintaining T_c during general anesthesia of elderly patients can be important. Our results suggest the usefulness of HH for preventing intraoperative hypothermia.

There were possible limitations to this study of note. First, despite the significant difference in T_c between the two

groups, the main outcome did not support our hypothesis. Thus, the results of our present study can be regarded as preliminary only and should be interpreted carefully. Intravenous administration of warmed fluid and application of PEEP [28] may have contributed to the relatively small difference in T_c in the present study. Moreover, the number of cases of radical cystectomy, which involves intestinal manipulation, was different between the two groups, which may also contribute to the results. However, our study particularly focused on the phases of T_c decrease and suggested the role of HH in intraoperative temperature management. Second, although our positive result revealed the usefulness of HH in preventing T_c decrease, its effectiveness is still controversial and should not be overestimated. Previous studies showed that forced-air warming system [19], as well as warmed intravenous fluid [29] were more effective on intraoperative T_c decrease than HH. Therefore, HH should not be considered a novel device and may contribute, among other various warming techniques, to preventing intraoperative hypothermia.

In conclusion, HH is helpful in preventing T_c decrease in elderly patients, particularly a phase 2 T_c decrease. Although the present results indicate that HH use is effective during general anesthesia in elderly patients, the results should be interpreted prudently, and further studies with larger populations are needed to substantiate its use in clinical practice.

REFERENCES

1. Sessler DI. Temperature monitoring and perioperative thermoregulation. *Anesthesiology* 2008; 109: 318-38.
2. Sessler DI. Mild perioperative hypothermia. *N Engl J Med* 1997; 336: 1730-7.
3. Cereda M, Maccioli GA. Intraoperative temperature monitoring. *Int Anesthesiol Clin* 2004; 42: 41-54.
4. Stone DR, Downs JB, Paul WL, Perkins HM. Adult body temperature and heated humidification of anesthetic gases during general anesthesia. *Anesth Analg* 1981; 60: 736-41.
5. Sessler DI. Complications and treatment of mild hypothermia. *Anesthesiology* 2001; 95: 531-43.
6. Frank SM, Fleisher LA, Breslow MJ, Higgins MS, Olson KF, Kelly S, et al. Perioperative maintenance of normothermia reduces the incidence of morbid cardiac events. A randomized clinical trial. *JAMA* 1997; 277: 1127-34.
7. Degroot DW, Kenney WL. Impaired defense of core temperature in aged humans during mild cold stress. *Am J Physiol Regul Integr Comp Physiol* 2007; 292: R103-8.
8. Macario A, Dexter F. What are the most important risk factors

- for a patient's developing intraoperative hypothermia? *Anesth Analg* 2002; 94: 215-20.
9. Jin F, Chung F. Minimizing perioperative adverse events in the elderly. *Br J Anaesth* 2001; 87: 608-24.
 10. Hasegawa K, Negishi C, Nakagawa F, Ozaki M. Core temperatures during major abdominal surgery in patients warmed with new circulating-water garment, forced-air warming, or carbon-fiber resistive-heating system. *J Anesth* 2012; 26: 168-73.
 11. Taguchi A, Ratnaraj J, Kabon B, Sharma N, Lenhardt R, Sessler DI, et al. Effects of a circulating-water garment and forced-air warming on body heat content and core temperature. *Anesthesiology* 2004; 100: 1058-64.
 12. Lee HK, Jang YH, Choi KW, Lee JH. The effect of electrically heated humidifier on the body temperature and blood loss in spinal surgery under general anesthesia. *Korean J Anesthesiol* 2011; 61: 112-6.
 13. Yam PC, Carli F. Maintenance of body temperature in elderly patients who have joint replacement surgery. A comparison between the heat and moisture exchanger and heated humidifier. *Anaesthesia* 1990; 45: 563-5.
 14. Shanks CA. Heat balance during surgery involving body cavities. *Anaesth Intensive Care* 1975; 3: 114-7.
 15. Han SB, Gwak MS, Choi SJ, Kim MH, Ko JS, Kim GS, et al. Effect of active airway warming on body core temperature during adult liver transplantation. *Transplant Proc* 2013; 45: 251-4.
 16. Johansson A, Lundberg D, Luttrupp HH. The effect of heat and moisture exchanger on humidity and body temperature in a low-flow anaesthesia system. *Acta Anaesthesiol Scand* 2003; 47: 564-8.
 17. Graff TD, Benson DW. Systemic and pulmonary changes with inhaled humid atmospheres: clinical application. *Anesthesiology* 1969; 30: 199-207.
 18. Matsukawa T, Sessler DI, Sessler AM, Schroeder M, Ozaki M, Kurz A, et al. Heat flow and distribution during induction of general anesthesia. *Anesthesiology* 1995; 82: 662-73.
 19. Hynson JM, Sessler DI. Intraoperative warming therapies: a comparison of three devices. *J Clin Anesth* 1992; 4: 194-9.
 20. Díaz M, Becker DE. Thermoregulation: physiological and clinical considerations during sedation and general anesthesia. *Anesth Prog* 2010; 57: 25-32.
 21. Sessler DI. Perioperative heat balance. *Anesthesiology* 2000; 92: 578-96.
 22. Hart SR, Bordes B, Hart J, Corsino D, Harmon D. Unintended perioperative hypothermia. *Ochsner J* 2011; 11: 259-70.
 23. Kurz A, Plattner O, Sessler DI, Huemer G, Redl G, Lackner F. The threshold for thermoregulatory vasoconstriction during nitrous oxide/isoflurane anesthesia is lower in elderly than in young patients. *Anesthesiology* 1993; 79: 465-9.
 24. Winkler M, Akça O, Birkenberg B, Hetz H, Scheck T, Arkilic CF, et al. Aggressive warming reduces blood loss during hip arthroplasty. *Anesth Analg* 2000; 91: 978-84.
 25. Schmied H, Kurz A, Sessler DI, Kozek S, Reiter A. Mild hypothermia increases blood loss and transfusion requirements during total hip arthroplasty. *Lancet* 1996; 347: 289-92.
 26. Falk B, Bar-Or O, Smolander J, Frost G. Response to rest and exercise in the cold: effects of age and aerobic fitness. *J Appl Physiol* (1985) 1994; 76: 72-8.
 27. Horvath SM, Radcliffe CE, Hutt BK, Spurr GB. Metabolic responses of old people to a cold environment. *J Appl Physiol* 1955; 8: 145-8.
 28. An TH, Yang JW. Effects of PEEP on the thermoregulatory responses during TIVA in patients undergoing tympanoplasty. *Korean J Anesthesiol* 2011; 61: 302-7.
 29. Kim E, Lee SY, Lim YJ, Choi JY, Jeon YT, Hwang JW, et al. Effect of a new heated and humidified breathing circuit with a fluid-warming device on intraoperative core temperature: a prospective randomized study. *J Anesth* 2015; 29: 499-507.