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Randomised trial comparing forced-air warming to the upper or lower body to prevent hypothermia during thoracoscopic surgery in the lateral decubitus position

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Abstract

Background: In the supine position, forced-air warming is more effective on the lower body than on the upper body to prevent intraoperative hypothermia. However, it is unknown in the lateral decubitus position. We thus compared forced-air warming on the upper and lower bodies in the lateral position.

Methods: Patients (n=123) were randomised to receive forced-air warming on the upper body or lower body during thoracoscopic surgery in the lateral position. We measured the nasopharyngeal temperature at 0, 30, 60, 90, and 120 min after lateral positioning during surgery and the infrared tympanic membrane temperature at 0, 30, 60, 90, and 120 min after surgery. Patients received both upper and lower body warming at a temperature of <35.5°C. The primary outcome was the incidence of intraoperative hypothermia with a temperature of <36.0°C.

Results: Intraoperative hypothermia was less frequent with the upper body warming than with the lower body warming {21/62 *vs* 35/61, risk ratio [95% confidence interval (CI)] 0.6 (0.4–0.9), P=0.011}. The intraoperative temperature was higher with the upper body warming than with the lower body warming at 30 (P=0.002), 60 (P<0.001), and 90 (P<0.001) min after lateral positioning, and the postoperative temperature was higher at 0 (P<0.001) and 30 (P=0.001) min after surgery. Fewer patients received both upper and lower body warming in the upper body warming group than in the lower body warming group during surgery (1 *vs* 7, P=0.032).

Conclusions: Forced-air warming was more effective on the upper body than on the lower body to prevent hypothermia during thoracoscopic surgery in the lateral decubitus position.

Clinical trial registration: NCT02993666.

Keywords: body temperature; hypothermia; thoracic surgery

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Editor's key points

- The effectiveness of forced-air warming during surgery depends on the body surface area covered.
- Forced-air warming of the lower body effectively prevents perioperative hypothermia when the patient is supine, but a smaller surface area is available in the lateral position and the best way of applying forced-air warming is unknown.
- In this randomised trial, forced air warming applied to the upper or lower body was compared in patients undergoing thoracoscopic surgery in the lateral position.
- Forced air warming of the upper body was more effective in these circumstances but neither method alone was completely effective in preventing hypothermia.

Inadvertent hypothermia is common during anaesthesia.[1–5] It may cause perioperative adverse events such as bleeding, infection, cardiac complications, and delayed recovery.[2,6–12] Therefore, active warming such as forced-air warming should be provided during anaesthesia longer than 30 min.[13]

To prevent hypothermia during abdominal or thoracic surgery, forced-air warming can be applied to the upper or lower bodies not involved in the surgical area. In the supine position, lower body warming covers a larger body surface area[1,14,15] and thus increases the core temperature more effectively than upper body warming.[16,17] However, it is unknown in the lateral decubitus position. We thus compared forced-air warming of the upper body with warming of the lower body during thoracoscopic surgery in the lateral position.

Methods

Design

This prospective, parallel-group, double-blind, randomised controlled trial was approved by the Institutional Review Board of Seoul National University Hospital (Seoul, Korea) and registered at ClinicalTrials.gov (NCT02993666). After obtaining written informed consent, we enrolled patients aged 18–80 yr with ASA physical status I–III, and undergoing elective thoracoscopic surgery in the lateral decubitus position between December 2016 and June 2017. We excluded patients with fever, hypothermia, septic condition, sinusitis, nasal trauma, and history of malignant hyperthermia. Patients were randomised into two groups to receive forced-air warming on the upper body or the lower body in the lateral position during surgery. An assistant unrelated to this study created the randomisation in a 1:1 ratio without block or stratification, and concealed the allocation sequence in opaque sealed envelopes.

Anaesthesia

The ambient temperature of the operating room was maintained at 22 (1)°C. A mattress (Norm-O-Temp; CSZ Medical, Cincinnati, OH, USA) with circulating water heated to 40°C was placed on the operating table and covered with a cotton blanket. Patients were asked which nostril was easier to breathe through. Without premedication, patients were monitored with non-invasive blood pressure, pulse oximetry, electrocardiography, bispectral index (A-2000 XP; Aspect Medical Systems, Newton, MA, USA), and acceleromyography (TOF-watch Sx; MSD, Haarlem, the Netherlands). Patients received forced-air warming with a full-body blanket (Model 300; 3M Bair Hugger, Eden Prairie, MN, USA) at a set temperature of 43°C during anaesthetic induction.

Propofol and remifentanil were administered with effect-site target-controlled infusion (Base Primea; Fresenius Vial Brézins, France). The initial target concentration was 4 μg ml^{-1} for propofol and 4 ng ml^{-1} for remifentanil. Rocuronium 0.6 mg kg^{-1} was given and train-of-four (TOF) responses were checked every 15 s. At a bispectral index of <60 and a TOF count of 0, a double-lumen tube (Mallinckrodt endobronchial tube; Covidien, Mansfield, MA, USA) was placed into the mainstem bronchus by direct or video laryngoscopy followed by fibreoptic bronchoscopy (LF-GP; Olympus Optical Co., Tokyo, Japan). The tracheal cuff pressure was set to 25 cm H_2O (VBM Medizintechnik GmbH, Sulz am Neckar, Germany).

An investigator (S.-H.M.) inserted a disposable thermistor (TOP Probe with YSI-400 standard sensor; MediTop, Seoul, Korea) into the nostril on the side with easier breathing and positioned it in the posterior upper nasopharynx with nasendoscopy (LF-GP; Olympus Optical Co., Tokyo, Japan).[5] The thermistor was fixed to the nares with a silk tape and connected to a monitor (Solar 8000i; GE Healthcare, Chicago, IL, USA). Both eyes were closed and secured with silicone tapes. Catheters were inserted into the urethra, radial artery, or internal jugular vein with minimal exposure of the skin to ambient air.

After lateral positioning, the patient's head was kept in a neutral position on the headrest. Both elbows were slightly flexed on the armrests, and a roll was placed just caudal to the dependent axilla (Fig. 1a). Padding was placed between both legs with the nondependent knee and hip flexed (Fig. 2b). The investigator re-checked positions of the double-lumen tube and the thermistor with bronchoscopy and nasendoscopy.

A disposable upper body blanket (Model 522; 3M Bair Hugger) was placed on the patient's occiput, back, and arms, avoiding the surgical field (Fig. 1a). The blanket was wrapped around the dependent arm from bottom to top, and a transparent film covered the face and superior and lateral parts of the head (Fig. 1a). A lower body blanket (Model 525; 3M Bair Hugger) was applied between the iliac crest and the foot (Fig 1b). Two forced-air blowers (Model 505; 3M Bair Hugger) were connected to each blanket. According to group assignment, either the upper or lower body was warmed with a set temperature of 43°C.

Investigators did not enter the operating room during the surgery and thus they were blinded to group assignment. Attending anaesthetists administered propofol and remifentanil within a bispectral index of 30–60, rocuronium for a TOF count of 0, and plasmalyte at 4–5 ml kg^{-1} h^{-1} without heating. One lung was ventilated with a tidal volume of 4–6 mg kg^{-1}, PEEP of 4–8 cm H_2O, respiratory rate of 12–20 bpm, and inspired oxygen fraction of 0.6–1.0. Ephedrine 5–10 mg, phenylephrine 30–50 μg or plasmalyte 200 ml were given at a mean blood pressure of <60 mm Hg, central venous pressure of <4 mm Hg, or urine output of <0.5 ml kg^{-1} h^{-1}. A packed red blood cell was transfused with heating (Hotline; Smiths Medical, Rockland, MA, USA) at a haemoglobin level of <6–8 g dl^{-1}.

After surgery, patients were turned to the supine position and warmed with the full-body blanket. I.V. patient-controlled analgesia (Anaplus; Ewha Biomedics, Goyang, Korea) was initiated with a 100 ml mixture of fentanyl 1000–2000 μg, morphine 40–80 mg, ramosetron 0.3–0.6 mg, and normal

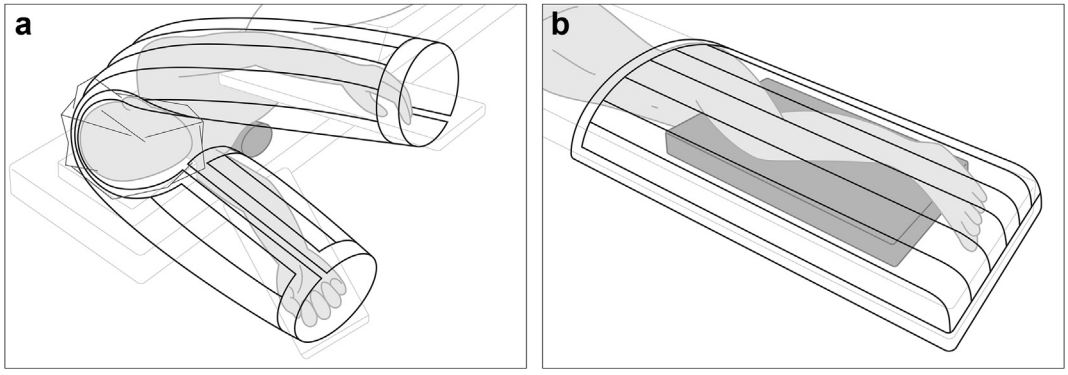

Fig 1. Forced-air warming blankets applied to the upper (a) and lower (b) bodies in the lateral decubitus position.

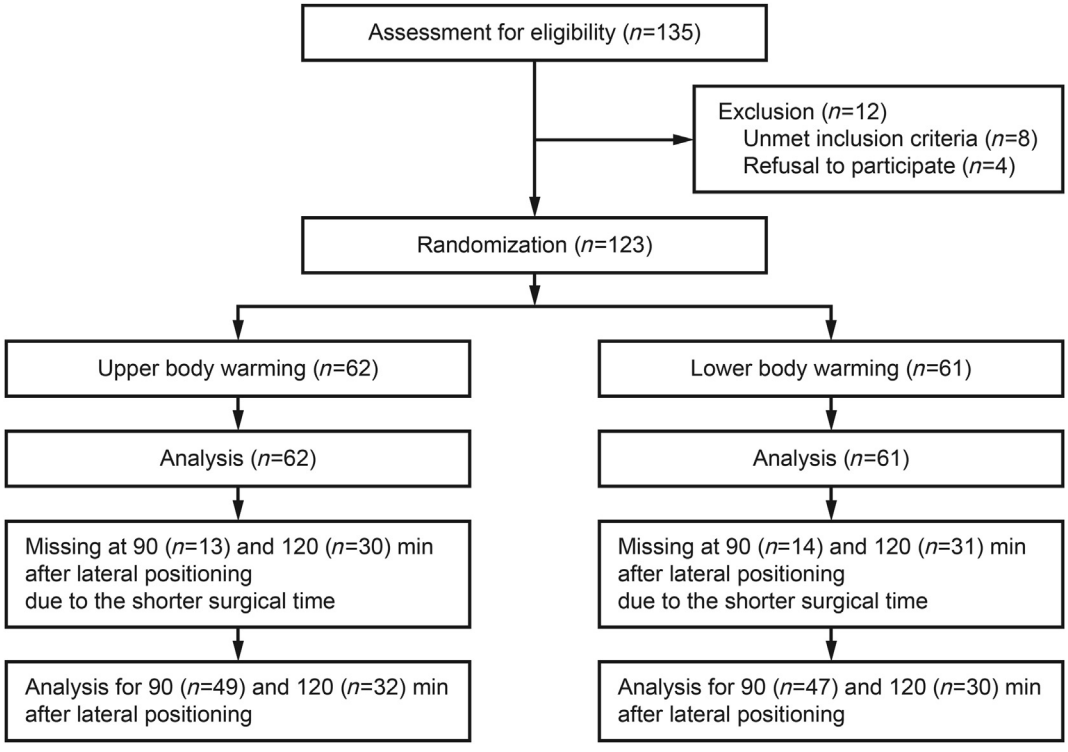

Fig 2. Consolidated Standards of reporting trials (CONSORT) diagram.

saline at an infusion of 1 ml h^{-1}, bolus of 0.5 ml, and lockout time of 10 min. After giving sugammadex 4 mg kg^{-1}, the double-lumen tube and the thermistor were removed when the patient was able to breathe spontaneously and respond to verbal commands at a TOF ratio of >0.9. If postoperative mechanical ventilation was required, the double-lumen tube was replaced with a single-lumen tube without administration of sugammadex. The patient was covered with a cotton blanket, and transferred to the post-anaesthesia room or the intensive care unit.

Outcomes

We recorded the amounts of anaesthetics, inotropes, fluids, and transfusion. In the supine position, the nasopharyngeal temperature was measured after intubation (baseline) and before extubation. At 0, 30, 60, 90, and 120 min after lateral positioning, we measured the nasopharyngeal temperature, mean blood pressure, heart rate, and arterial partial pressures of oxygen and carbon dioxide. Forced-air warming was applied to both upper and lower bodies at the nasopharyngeal temperature of <35.5°C but paused at ≥37.0°C.

At 0, 30, 60, 90, and 120 min after surgery, an investigator (S.Y.) measured the infrared tympanic membrane temperature (ThermoScan 5-IRT6020; Braun, Kronberg, Germany) and assessed shivering, thermal discomfort, and pain intensity. Shivering was graded as none, mild shivering noted by artifacts in electrocardiography, and severe shivering detected by observers.[18] Thermal discomfort was assessed with a five-point scale: cool, slightly cool, neutral, slightly warm, and warm sensations.[19] Pain intensity was scored on an 11-point visual analogue scale (0, no pain; 10, worst pain imaginable).

We recorded extubation time and lengths of stay in the post-anaesthesia room, intensive care unit, and hospital. The extubation time was defined as the duration from the administration of sugammadex to extubation. Patients were discharged from the post-anaesthesia room with a modified Aldrete score of 9–10[20]; from the intensive care unit when they showed stable cardiorespiratory status and did not require treatments with inotropes or oxygen; and from the hospital when they were able to walk, cough, and clear secretions without severe pain, fever, and complications. We checked any perioperative adverse events including thermal injury.

The primary outcome was the incidence of intraoperative hypothermia defined as a nasopharyngeal temperature of <36.0°C.[2,6,7,13,21] Secondary outcomes were intraoperative and postoperative body temperature and hypothermia at each measurement time point, requirement for both upper and lower body warming, shivering, thermal discomfort, recovery times, and adverse events.

Statistical analysis

Our pilot study (n=21) showed hypothermia in 30% of patients (3/10) with the upper body warming and in 55% (6/11) with the lower body warming during thoracoscopic surgery in the lateral position. Considering a 25% difference in the incidence of hypothermia, 61 patients were required in each group with a power of 0.8 and an α of 0.05 for two-tailed analysis.

Continuous variables are presented as mean (standard deviation) or median (interquartile range) after checking the normality with the Shapiro-Wilk test. Repeatedly measured continuous variables were analysed with linear mixed models for all time points, and then with unpaired or paired t-tests and the Mann-Whitney U or Wilcoxon signed-rank tests at each time point as appropriate. In the mixed model, fixed effects were the group, time, and interaction between group and time, and a random effect was the subject.

Categorical variables were the number of patients (%) and analysed with Fisher's exact test. Effect sizes with a 95% CI were calculated. A P-value of <0.05 was considered significant and adjusted with Bonferroni correction. All analyses were conducted in an intention-to-treat manner. STATA (Special Edition 14.2; Stata Corporation, College Station, TX, USA) was used for sample size calculation, randomisation, and statistical analyses.

Results

After screening 135 patients, 123 patients were randomised to the upper (n=62) or lower body (n=61) warming groups (Fig. 2). No differences were found in patient characteristics (Table 1); intraoperative mean blood pressure (P=0.835, linear mixed model), heart rate (P=0.233), and arterial partial pressures of oxygen (P=0.506) and carbon dioxide (P=0.532); and the baseline nasopharyngeal temperature after intubation (Table 2) between groups.

Compared with the baseline, the temperature was lower at 0–90 min after lateral positioning with the upper body warming and at 0–120 min after lateral positioning with the lower body warming (all P<0.001, paired t-test). Higher nasopharyngeal temperature and fewer hypothermic patients were found with the upper body warming than with the lower body warming at 30, 60, and 90 min after lateral positioning (Fig. 3). Fewer patients received both upper and lower body warming due to a temperature of <35.5°C in the upper body warming

Table 1 Characteristics of patient, anaesthesia, and surgery. Data are number of patients or mean (standard deviation) except age [mean (range)]. There are no differences between groups

	Upper body warming (n=62)	Lower body warming (n=61)
Age (yr)	58 (18–80)	59 (23–78)
Female	37	29
Weight (kg)	63 (10)	60 (11)
Height (cm)	162 (8)	161 (9)
Body mass index (kg m^{-2})	23.8 (3.5)	23.0 (2.9)
ASA physical status (II/III)	29/2	33/3
Medical conditions (hypertension/diabetes/stroke/hepatitis)	19/6/4/4	21/8/6/3
Side of surgery (left/right)	25/37	27/34
Type of surgery (wedge resection/segmentectomy/lobectomy)	23/5/34	23/3/35
Amount of anaesthetic drugs and a fluid		
Propofol (mg)	1219 (491)	1122 (558)
Remifentanil (μg)	1147 (484)	1176 (717)
Rocuronium (mg)	100 (28)	96 (23)
Plasmalyte (ml)	727 (382)	788 (404)
Inotropic requirement	21	19
Transfusion	0	1
Estimated blood loss (ml)	83 (57)	105 (65)
Urine output (ml)	128 (138)	127 (162)
Duration of surgery (min)	134 (48)	131 (60)
Duration of anaesthesia (min)	168 (54)	166 (70)

Table 2 Perioperative outcomes associated with body temperature. Data are number of patients or mean (standard deviation)

	Upper body warming (n=62)	Lower body warming (n=61)	P-value
Nasopharyngeal temperature			
After intubation	36.5 (0.4)	36.4 (0.4)	0.110
At the end of surgery	36.5 (0.4)	36.2 (0.5)	<0.001
Hypothermia of <36.0°C			
During surgery	21	35	0.011
At the end of surgery	7	16	0.039
Both upper and lower body warming at <35.5°C	1	7	0.032
Warming pause at ≥37.0°C	8	0	0.006
Postoperative shivering			0.496
Mild	0	0	
Severe	0	1	
Postoperative thermal discomfort			0.397
Cool	0	1	
Slightly cool	1	1	
Slightly warm	2	0	
Warm	2	0	
Postoperative mechanical ventilation	3	3	0.213
Extubation time (s)	291 (202) (n=59)	290 (177) (n=58)	0.982
Length of stay			
Post-anaesthesia room (min)	49 (9) (n=35)	51 (13) (n=34)	0.454
Intensive care unit (h)	31.7 (19.2) (n=27)	26.9 (9.3) (n=27)	0.629
Hospital (day)	8.0 (3.5)	8.0 (6.0)	0.435
Adverse events (atelectasis/pneumothorax/pleural effusion)	13/10/8	9/11/4	0.570

group (Table 2). The overall incidence of intraoperative hypothermia (primary outcome) was lower with the upper body warming than with the lower body warming (Table 2; 21 *vs* 35, risk ratio 0.6, 95% CI 0.4–0.9, P=0.011, Fisher's exact test).

At the end of surgery, the lower body warming group showed a lower temperature compared with the baseline (P<0.001, paired t-test) and more hypothermic patients compared with the upper body warming group (Table 2; risk ratio 1.6, 95% CI 1.1–2.2, P=0.039, Fisher's exact test). No patient had thermal injury by forced-air warming.

Higher infrared tympanic membrane temperature and fewer hypothermic patients were observed in the upper body warming group than in the lower body warming group immediately and 30 min after surgery (Fig. 4). No differences were found in postoperative shivering, thermal discomfort, recovery times, adverse events (Table 2), and pain intensity (P=0.183, linear mixed model).

Discussion

Forced-air warming increases core temperature more effectively when it covers a larger body surface area.[1,2,8,12,22,23] Because air has a low capacity to contain heat,[2,4,22,23] the temperature is high on the skin area that is in direct contact with the blanket, but low on the area that is not. In the supine position, forced-air warming is more effective on the lower body than on the upper body because the blanket covers 40–45% of the total body surface area on the lower body but 26–29% on the upper body.[3,14,15] In the lateral decubitus position, the upper body blanket covers a similar area to the supine position, but the lower body blanket has little contact with the dependent leg due to the padding between both legs. Therefore, a larger body surface area is likely to receive warm air on the upper body than on the lower body in the lateral position. This may be one of the reasons why the upper body warming showed a higher core temperature and fewer hypothermic patients in our study.

Because warm air cools rapidly, the heat distribution is heterogeneous not only under the blanket, but also within the blanket.[3,24] The homogeneity of heat distribution is known to be associated with the design and size of the blanket.[2,3,14,15,24] With a constant forced-air flow from the nozzle, heat is distributed more evenly in a smaller blanket than in a larger blanket, and thus heat is radiated more efficiently out of a smaller blanket.[3,14,15,24] The Bair-Hugger upper body blanket (188 cm×61 cm=11 468 cm^2) is smaller than the lower body one (152 cm×91 cm=13 898 cm^2; from the manufacturer's manual). This may be another reason for the higher body temperature with the upper body warming in our study.

It may be ideal to warm both upper and lower bodies to prevent hypothermia during thoracic surgery, but it is not always possible due to limited resources. We warmed both upper and lower bodies for rescue intervention to prevent moderate or severe hypothermia of <35.0°C which is known to increase cardiac morbidities,[6,12] and observed more rescues with the lower body warming than with the upper body warming. Besides, the blanket can cover the upper body—but not the lower body—even after surgical draping without interrupting the operation.[3,8,14] Therefore, the upper body warming compared with the lower body warming seems to be advantageous in its easy applicability as well as the warming effect during thoracoscopic surgery in the lateral position.

During the first hour after anaesthetic induction, the core temperature decreases by 0.5–1.5°C more likely due to heat redistribution within the body rather than heat loss from the body,[5,7,9,13,17,25] so even external active warming cannot completely prevent hypothermia,[22,26] as shown in our study. After this internal redistribution phase, the core temperature is regulated by a balance between heat loss and gain, thus hypothermia can be treated until the end of surgery by

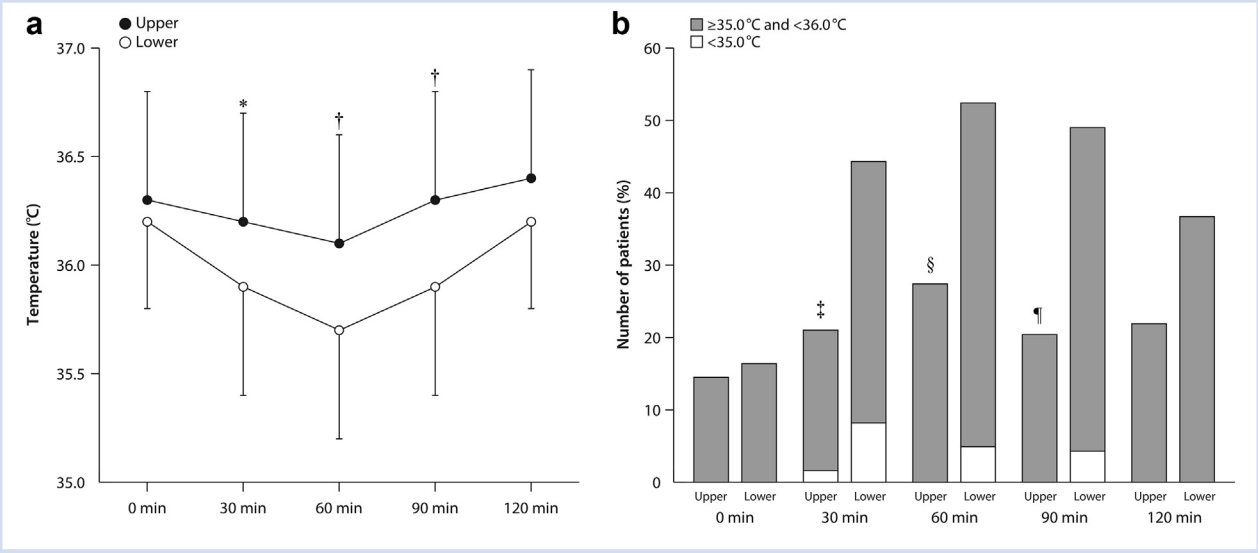

Fig 3. The intraoperative nasopharyngeal temperature (a) and incidence of hypothermia (b) at 0, 30, 60, 90, and 120 min after lateral decubitus positioning with the upper or lower body warming. Circles and error bars are mean and standard deviation. *Mean difference [95% confidence interval (CI)] 0.3°C (0.1–0.4°C), P=0.002 compared with the lower body warming, unpaired t-test. †0.4°C (0.2–0.5°C), P<0.001. ‡Risk ratio (95% CI) 0.6 (0.4–0.8), P=0.007 compared with the lower body warming, Fisher's exact test. §0.6 (0.4–0.9), P=0.006. ¶0.5 (0.4–0.8), P=0.005.

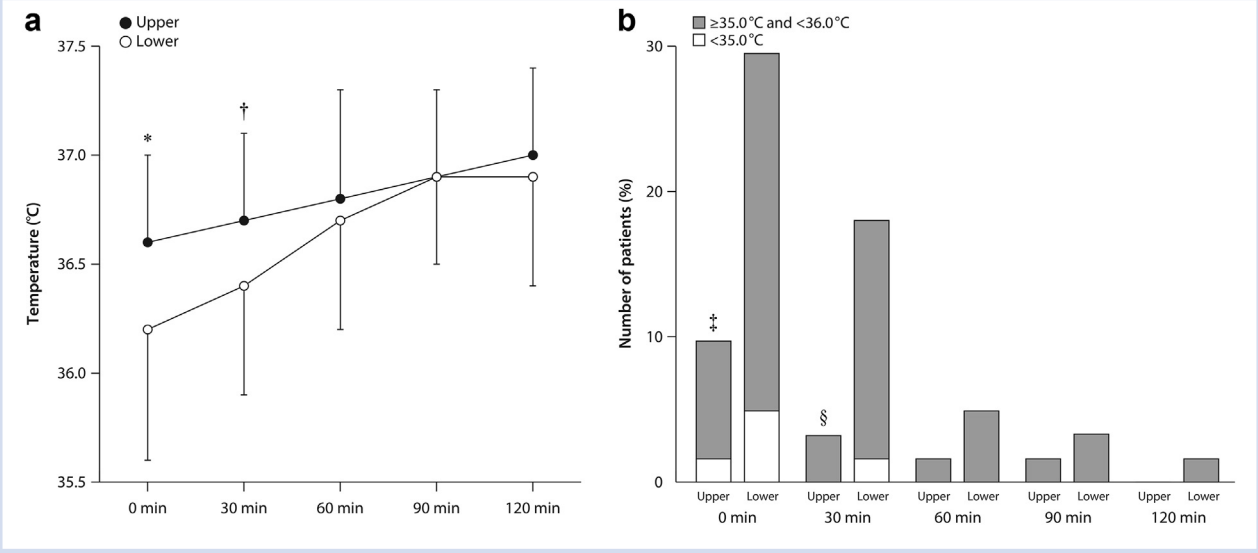

Fig 4. The infrared tympanic membrane temperature (a) and the incidence of hypothermia at 0, 30, 60, 90, and 120 min after surgery in the lateral decubitus position with the upper or lower body warming. Circles and error bars are mean and standard deviation. *Mean difference [95% confidence interval (CI)] 0.4°C (0.2–0.6°C), P<0.001 compared with the lower body warming, unpaired t-test. †0.3°C (0.1–0.4°C), P=0.001. ‡Risk ratio (95% CI) 0.6 (0.4–0.8), P=0.006 compared with the lower body warming, Fisher's exact test. §0.5 (0.4–0.7), P=0.009.

intraoperative active warming.[16,22,26] However, untreated intraoperative hypothermia may cause postoperative shivering or thermal discomfort.[10,12,22,23,26] We observed a higher body temperature and fewer hypothermic patients at the end of surgery and until 30 min after surgery in the upper body warming group than in the lower body warming group. However, no differences were found in postoperative shivering and thermal discomfort, probably because all patients received full-body warming in recovery theatres. Both groups also showed similar postoperative adverse events and recovery times, although these outcomes were underpowered.

The core temperature of vital organs including the brain can be reliably measured in the pulmonary artery, distal oesophagus, and nasopharynx.[5,7,13,27,28] However, pulmonary

arterial catheterization is too invasive,[29] and the oesophageal temperature can be biased by thoracic surgery. We thus measured the intraoperative temperature in the posterior upper nasopharynx located close to the internal carotid artery so as to estimate the brain temperature[5,27,30,31] by using the YSI-400 thermistor with an accuracy of $\leq$0.1°C. After surgery, we measured the infrared tympanic membrane temperature because it is impractical to measure the core temperature in awake patients. However, the infrared tympanic temperature has systematic errors more than 1°C[32,33] and is less likely to reflect the core temperature.[34] Therefore, the postoperative temperature might be less reliable than the intraoperative temperature in our study.

This study has limitations. We only studied patients undergoing thoracoscopic surgery with i.v. general anaesthesia, so our findings may not be extrapolated to other situations such as open thoracotomy or laparotomy with inhalational or regional anaesthesia. In addition, we did not warm the i.v. fluid, although 1 litre of unheated crystalloid is known to reduce the core temperature by 0.25–0.30°C.[7,21,35] However, because we restricted the fluid administration for thoracic surgery,[36–38] the bias would be minimized.

In conclusion, the upper body blanket may transfer heat more efficiently to a larger body surface area in the lateral decubitus position than the lower body blanket. Therefore, forced-air warming seems to be more effective on the upper body than on the lower body to prevent hypothermia during thoracoscopic surgery in the lateral position. However, upper and lower body warming should be employed together in patients at high risk of hypothermia whenever possible.

Authors' contributions

Study design: S.-H.M., S.Y., J.-H.B., J.-H.S.
Study conduct and data collection: S.-H.M., S.Y., S.-H.Y.
Data analysis: J.-H.B., J.-H.S.
Writing paper: S.-H.M., S.-H.Y., J.-H.S.
Revising paper: all authors.

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Declaration of interests

None declared.

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