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Original Article

Reevaluating anesthesia maintenance strategies to prevent intraoperative hypothermia in hip arthroplasty: a randomized controlled trial

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Abstract: Background: Intraoperative hypothermia is a common occurrence influenced by multiple factors, and the effect of maintenance anaesthetic agents on intraoperative temperature remains controversial. In this study, we compared the incidence of hypothermia between inhalational and intravenous maintenance anaesthesia under identical induction protocols. Methods: 172 adult patients were randomly assigned to receive maintenance anaesthesia with either sevoflurane (2%-3%) or intravenous agents (propofol and remifentanil). The primary endpoint was the incidence of intraoperative hypothermia. Results: There was no significant difference in the incidence of intraoperative hypothermia between the inhalational and intravenous maintenance groups (55/86 [64%] vs. 52/86 [60.5%]; RR = 1.06; 95% CI, 0.84 to 1.34; $P = 0.753$). The lowest intraoperative core temperature did not differ significantly between groups (median [IQR]: 35.7 [35.5-36.0] vs. 35.9 [35.5-36.2]°C; $P = 0.107$); however, the final core temperature at the end of surgery was significantly lower in the inhalational group (median [IQR]: 35.8 [35.6-36.1] vs. 36.1 [35.6-36.4]°C; $P = 0.004$). Emergence time was significantly longer in the inhalational group ($P < 0.001$). All other baseline, perioperative, and safety outcomes were comparable between the two groups. Conclusions: In patients undergoing total hip arthroplasty, there was no significant difference in the incidence of intraoperative hypothermia between inhalational and intravenous maintenance anaesthesia.

Keywords: Inhalation, sevoflurane, intravenous, propofol, remifentanil, hypothermia

Introduction

Hypothermia during surgery, characterized by core temperatures below 36°C, is a common complication. Reported incidence rates reach up to 70% [1-3], and in some studies, as high as 90% [4]. Patients undergoing total hip arthroplasty (THA), a major orthopedic procedure, are particularly vulnerable due to advanced age, reduced basal metabolic rate, and prolonged intraoperative exposure [5-7]. Intraoperative hypothermia is linked to a higher incidence of postoperative wound infections [8], coagulopathy, greater intraoperative blood loss, higher transfusion requirements [9], delayed metabolism of anesthetic agents, prolonged recovery time, cardiovascular complications [10, 11], and postoperative shivering. These adverse effects elevate patient risk, hinder postoperative recovery, and may prolong hospital stay [12].

There are several reasons that can lead to hypothermia in patients during surgery. For example, anesthetics can inhibit the thermoregulatory center, dilate blood vessels, and redistribute heat within the body. In addition, the operating room temperature is relatively low, the liquid or blood administered to the body is not preheated, and a large amount of room-temperature washing liquid is used, which can make the body cold [13] despite effective active warming measures and clear clinical guidelines [14, 15]. Although medical staff are paying attention to it, the incidence of hypothermia in surgery is still very high. This long-standing problem may be related to the patient's own situation, or it may be due to anesthesia affecting body temperature regulation and allowing heat to radiate from the core to the limbs [16, 17], which is difficult to prevent completely. Previous studies have yielded inconsistent findings. Some suggest that propofol anesthesia

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induction leads to more pronounced declines in core temperature [18], whereas others report that high-concentration inhalational anesthesia exerts a greater thermoregulatory effect [19]. Nevertheless, other studies have indicated that the occurrence of intraoperative hypothermia does not differ significantly across various maintenance strategies [20, 21]. General anesthesia is commonly sustained through total intravenous (TIVA) or inhaled methods. The method of maintenance may influence the likelihood of intraoperative hypothermia. However, existing studies are limited in number and often involve small sample sizes. Many trials include concurrent administration of opioid adjuncts in both groups, possibly confounding a comparative analysis. Furthermore, heterogeneity in study designs, including variations in induction regimens and baseline body temperatures, complicates direct comparisons. The divergence in intraoperative hypothermia incidence between intravenous and inhalational anesthesia maintenance continues to be a topic of considerable discussion.

Therefore, a randomized controlled trial was conducted to compare the incidence of intraoperative hypothermia between inhalation-only anesthesia and TIVA-only in patients undergoing total hip arthroplasty, using standardized anesthetic induction protocols. Secondary outcomes encompassed hospitalization duration, incidence of postoperative shivering, and postoperative nausea and vomiting (PONV).

Patients and methods

Ethics and study design

This randomized controlled trial, which was conducted in the same center in which subjects were blinded to their grouping, was approved by Qilu Hospital Ethics Committee of Shangdong University (Chairman: Professor Xiaoyang Chen) in Jinan, China on May 24th, 2022 (approval number: KYLL-202205-008), and then registered in China Clinical Trial Registration Center (registration number: ChiCTR2200064401). This study completely followed the "Declaration of Helsinki" and carefully followed the CONSORT guidelines. Most importantly, all participants signed a written informed consent form before undergoing the operation.

Patients

People aged 18-80 years who belong to the American Society of Anesthesiologists (ASA) physical condition I-III and having a body mass index (BMI) of 18-30 kg/m could participate if they plan to have a total hip replacement. Those who were excluded include: (1) Patients having serious heart, lung, liver or kidney problems; (2) Coagulation disorder before operation, abnormal thyroid function or recent infectious diseases; (3) Abnormal basal body temperature (lower than 36°C or higher than 37.5°C); (4) History of malignant hyperthermia or dysthermoregulation, such as malignant syndrome of antipsychotics; (5) Central fever caused by nervous system diseases; (6) The estimated operation time is shorter than 1 hour or longer than 3 hours; or (7) Refusal or inability to sign the informed consent form.

Randomisation and blinding

Participants were randomly assigned to two groups: those receiving intravenous maintenance anesthesia (propofol and remifentanil continuous infusion) or those receiving inhalational maintenance anesthesia (sevoflurane alone). The randomization sequence was computer-generated and concealed using sequentially numbered, opaque, sealed envelopes held by an independent third party not involved in patient care. Each participant was enrolled by a study coordinator, who opened the next envelope immediately before anaesthesia induction to assign the participant to the allocated group. Participants were unaware of their group assignment; however, anesthesiologists remained informed in order to facilitate precise drug delivery and anesthetic care. Surgeons and researchers responsible for intraoperative data collection and postoperative follow-up remained blinded until data analysis was complete.

Anesthesia and procedures

None of the patients received any specific preoperative medication or pre-warming intervention. The pre-op waiting zone was maintained at 22-25°C, whereas the operating room was set to 23-24°C. Following entry into the operating room, participants were randomly allocated to either intravenous or inhalational anesthesia maintenance. Standard monitoring involved

noninvasive blood pressure, pulse oximetry, ECG, and heart rate. Anesthetic depth was measured via bispectral index (BIS). Baseline mean arterial pressure (MAP) and heart rate (HR) were recorded before induction. In the calm, pre-induction state, a disposable oral temperature probe (MR411; Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China) was placed sublingually to measure baseline oral temperature. Ambient temperature was measured using a wet-bulb thermometer (TA298; Jintuojia Electronic Technology Co., Ltd., Shenzhen, China), positioned at patient height and away from heat-emitting equipment. Surface temperature probes (400 Series; REF M1024254; GE Healthcare, Chicago, USA) were applied to the inner forearm and the index finger's surface for peripheral temperature measurement. The infused fluids were heated to 37°C using a warming apparatus. Both patient cohorts were administered the same induction protocol, which included midazolam at 0.05 mg/kg, rocuronium at 0.6 mg/kg, etomidate at 0.3 mg/kg, and sufentanil at 0.5 μg/kg. Once consciousness was lost, a laryngeal mask airway (LMA) was inserted and then attached to the anesthesia apparatus. A single-use core temp probe was advanced via the LMA's oesophageal lumen and placed in the lower esophageal third for continuous monitoring. Following anesthetic induction, commence maintenance anesthesia based on the assigned group (inhalation or intravenous). Concurrently, we obtained baseline measurements of core body temperature, forearm temperature, finger temperature, ambient temperature, blood pressure, and heart rate. We continued monitoring these indicators every 15 minutes thereafter.

During the maintenance period of anesthesia, patients receiving intravenous drugs were continuously infused with propofol at a rate of 4-12 mg/kg/h and remifentanil at a rate of 0.1-0.3 ug/kg/min. Patients in the inhalation group used 2%-3% sevoflurane alone as an anesthetic. The anesthetic dose was adjusted to maintain a BIS value between 40 and 60. All patients received standardized intraoperative management and monitoring, except for the maintenance strategy. Additional muscle relaxants and analgesics were given as needed during the operation. We did not use non-steroidal anti-inflammatory drugs or other drugs that may affect thermoregulation. If used, the participant would be removed from the trial. Throughout the process, all patients were passively insulated with surgical towels, sheets, or cotton blankets. The washing solution used in the operation is at room temperature and is not preheated. If the core temperature dropped below 35°C, we would immediately use forced-air warming or other methods to keep the patient warm to prevent hypothermia. At the end of the operation, the anesthesia of both groups of patients was stopped. As long as the extubation conditions are met, the anesthesiologist decided to unplug the LMA. We then recorded the operation time, awakening time, intraoperative infusion, blood loss, and irrigation volume. The patient was sent to the PACU, where the room temperature was kept at 22-25°C. If the patient reported feeling cold or we observed him shivering, we used forced-air warming to maintain his body temperature. The shivering was recorded by the same designated researcher.

Outcomes

The primary outcome was the incidence of intraoperative hypothermia in the 2 groups. Hypothermia was defined as a core temperature (esophageal temperature) lower than 36°C at any time during the perioperative period. Secondary outcomes included the minimum intraoperative core temperature (defined as the lowest oesophageal temperature recorded from anaesthesia induction to the end of surgery), core temperature at the end of surgery (defined as the last oesophageal temperature recorded at completion of skin closure), and intraoperative haemodynamic variables measured at predefined time points. Forearm and fingertip skin temperatures were measured and recorded at predefined time points, and the forearm-to-fingertip temperature gradient was calculated as forearm skin temperature minus fingertip skin temperature to reflect peripheral perfusion and thermal redistribution. The incidence of shivering was also assessed; shivering was defined as involuntary muscle activity with visible tremor or a Bedford shivering score of 2 or higher. Emergence time was defined as the interval from complete discontinuation of anaesthetic agents to eye opening in response to verbal command. Additional outcomes included length of postoperative hospital stay and postoperative pain intensity

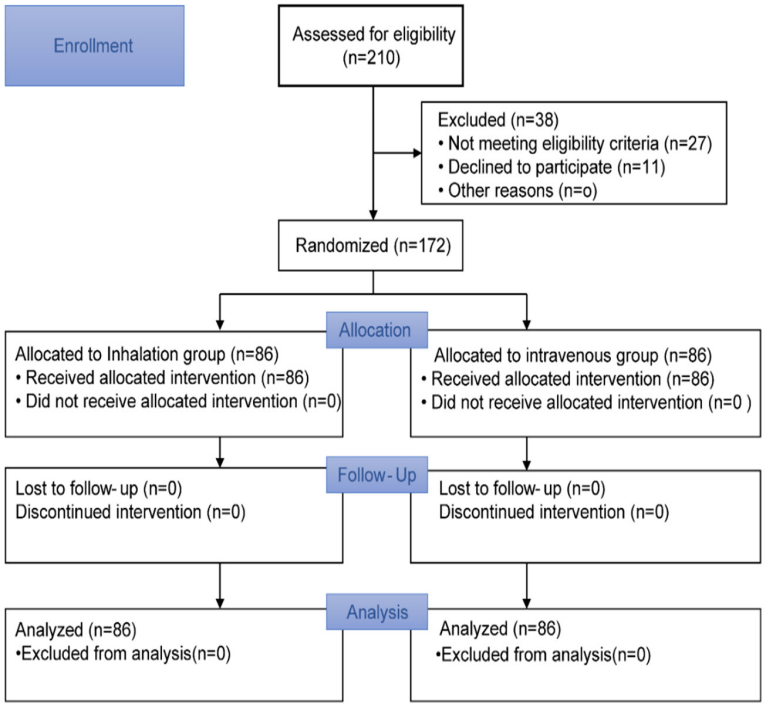

Figure 1. Trial flow diagram.

assessed with the visual analogue scale (VAS), scored from 0 to 10, with 0 indicating no pain and 10 indicating the worst pain imaginable.

Sample size

Based on preliminary data (n = 30 per group), the incidence of hypothermia was 70% (21/30) in the inhalation maintenance group and 47% (14/30) in the intravenous maintenance group. To determine the necessary number of participants, we employed PASS 15.0 software. Our calculations were based on a two-sided test with an alpha level of 0.05 and a power of 0.8 (1-β). After factoring in an anticipated 20% dropout rate, the study requires a total of 172 participants, with 86 per group.

Statistical analysis

Statistical analyses were conducted in R (v4.4.2). The Shapiro-Wilk test assessed normality. The Wilcoxon rank-sum test was used to analyze non-normally distributed data. Homogeneity of variance was checked with Levene's test. Normally distributed data with homogeneous variances were analyzed with Student's t-test; otherwise, Welch's t-test was used. Continuous data are presented as mean ± SD or median (IQR). The classified data were expressed as counts (%). Between-group comparisons of categorical variables were performed using the chi-square test; Fisher's exact test was used when any expected cell count was less than 5. The result of binary classification was expressed by relative risk (95% CI). The continuous results of normal distribution are expressed by mean differences (95% CI). To account for repeated measurements, we fitted linear mixed-effects models. In the mixed-effects model, a participant-specific random intercept was included to account for within-participant temporal correlation arising from repeated temperature measurements. The model specified fixed effects for treatment group, time point, and their interaction. We also measured the Forearm-Fingertip Temperature Gradients at each time point. Receiver operating characteristic (ROC) curves were generated to express sensitivity and specificity as interpolation points and draw smooth curves. The optimal threshold was found using the Youden index, and we recorded the area under the curve (AUC), sensitivity, and specificity at each time point. A two-sided method was used for all statistical tests, and a *P* value less than 0.05 was considered significant.

Results

From October 2022 through April 2023, researchers evaluated 210 eligible patients (**Figure 1**). After excluding 38 individuals who did not meet the criteria, the study proceeded with 172 participants. These subjects were then randomly divided into two treatment arms: one receiving inhalational maintenance therapy and the other receiving intravenous maintenance therapy. All randomized patients underwent surgery under the assigned anaesthesia protocols. Thus, all 172 participants (86 per group) were included in the analysis. Complete data on both primary and secondary outcomes were obtained for all participants at the cor-

Table 1. Baseline characteristics and perioperative data for all patients

	Inhalational group (n = 86)	Intravenous group (n = 86)	Statistic	*P*-value
Age (yr)	58 (47-64.8)	58 (46.3-63)	3650	0.884
Male	55 (64)	53 (61.6)	0.1	0.875
Height (cm)	167.2 (8.2)	166.4 (7.4)	0.685	0.494
Weight (kg)	69 (9.5)	68 (10)	0.683	0.495
BMI (kg m^{-2})	24.6 (2.4)	24.5 (2.7)	0.287	0.774
Baseline oral temperature (°C)	36.2 (36.1-36.4)	36.2 (36.1-36.4)	3727	0.929
Ambient temperature (°C)	24 (23.7-24.3)	24 (23.5-24.4)	3606	0.779
Baseline HR (beats min^{-1})	78.5 (75-84)	83.5 (76.3-88)	3000.5	0.033
Baseline MAP (mm Hg)	87.7 (11.3)	88.3 (8.8)	-0.422	0.674
Post induction of anesthesia				
Core temperature (°C)	36.8 (36.6-37)	36.8 (36.6-37)	3376.5	0.322
Fingertip temperature (°C)	33.2 (32.4-34.1)	32.6 (31.6-33.6)	4380	0.037
Forearm temperature (°C)	32.2 (31.8-32.6)	32.7 (31.8-33.7)	2995	0.031
Surgical time (min)	120 (110-120)	120 (105-120)	4171	0.124
Blood loss (ml)	200 (150-200)	200 (150-200)	3354	0.203
Fluid infusion (ml)	1500 (1500-1500)	1500 (1500-1500)	3615.5	0.596
Irrigation fluid (ml)	2000 (1500-2000)	1500 (1500-2000)	3913	0.448

Data are presented as mean (SD), median (interquartile range), or number (%). *P*-values were calculated by t-test, Wilcoxon test, or chi-square test. Test statistic reports t for t test, χ^2 for chi square test, and W for Wilcoxon rank sum test, Fisher exact test has no test statistic.

responding time points. Baseline characteristics and perioperative data were comparable between groups (**Table 1**). The 2 groups were comparable with respect to age, sex, and body mass index. The median (IQR) baseline oral temperature was identical in both groups at 36.2 (36.1-36.4)°C. No group differences were observed in baseline ambient temperature, HR, or MAP. Furthermore, perioperative characteristics, including surgical duration, estimated blood loss, intravenous fluid volume, and irrigation volume, were also similar between groups ($P > 0.05$) (**Table 1**).

Primary outcome

Intraoperative hypothermia incidence showed no significant divergence between inhalation and intravenous maintenance cohorts (55/86 [64%] vs. 52/86 [60.5%]; relative risk [RR] = 1.06; 95% confidence interval [CI], 0.84 to 1.34; $P = 0.753$) (**Table 2**; Supplementary Figure 1). The temporal trend of intraoperative core temperature is shown in **Figure 2A**. Both groups exhibited a progressive decline in core temperature over time, with similar trajectories on the line graph. Linear mixed-effects model analysis revealed that, immediately after anaesthesia induction, the intravenous group had a mean core temperature 0.1°C higher than the inhalation group (95% CI, -0.003 to 0.208; $P = 0.058$), a difference that was not statistically significant, indicating comparable baseline core temperatures following identical induction protocols. From induction to extubation, core temperature decreased at a consistent rate of approximately 0.007°C/min (95% CI, -0.008 to -0.007; $P < 0.001$). Nevertheless, group and time did not interact significantly ($P = 0.419$), indicating that the rate of temperature decline was comparable across groups.

Secondary and safety outcomes

The median intraoperative lowest core temperature in the inhalational group was 0.2°C lower than that of the intravenous maintenance group, but the difference was not significant (median [IQR]: 35.7 [35.5-36.0]°C vs. 35.9 [35.5-36.2]°C; $P = 0.107$). Core temperature at the end of surgery differed significantly, with lower values in the inhalational group (median [IQR]: 35.8 [35.6-36.1]°C vs. 36.1 [35.6-36.4]°C; $P = 0.004$) (**Figure 3**). Emergence time was longer in the inhalational group than in the intravenous group (median [IQR]: 18 [18-23.3] min vs. 17 [17-17] min; $P < 0.001$) (**Table 2**). PONV occurred in 25 patients (29.1%)

Table 2. Primary, secondary, and safety outcomes

	Inhalational group (n = 86)	Intravenous group (n = 86)	RR (95% CI)	*P*-value
Primary outcome				
Incidence of hypothermia	55 (64)	52 (60.5)	1.06 (0.84-1.34)	0.753
Secondary and safety outcomes				
Minimum core temperature (°C)	35.7 (35.5-36)	35.9 (35.5-36.2)	-	0.107
Final core temperature (°C)	35.8 (35.6-36.1)	36.1 (35.6-36.4)	-	0.004
Length of postoperative hospital stay (day)	4 (4-4)	4 (4-5)	-	0.871
VAS	3 (2-3)	3 (3-3)	-	0.554
PONV	25 (29.1)	20 (23.3)	1.25 (0.75-2.07)	0.488
Awakening time (min)	18 (18-23.3)	17 (17-17)	-	< 0.001
Incidence of shivering	3 (3.5)	5 (5.8)	0.60 (0.15-2.43)	0.720

Data are presented as median (interquartile range), or number (%). *P*-values were calculated by Wilcoxon test, chi-square test, or Fisher's exact test. PONV, postoperative nausea and vomiting; VAS, visual analogue scale; RR, relative risk; CI, confidence interval.

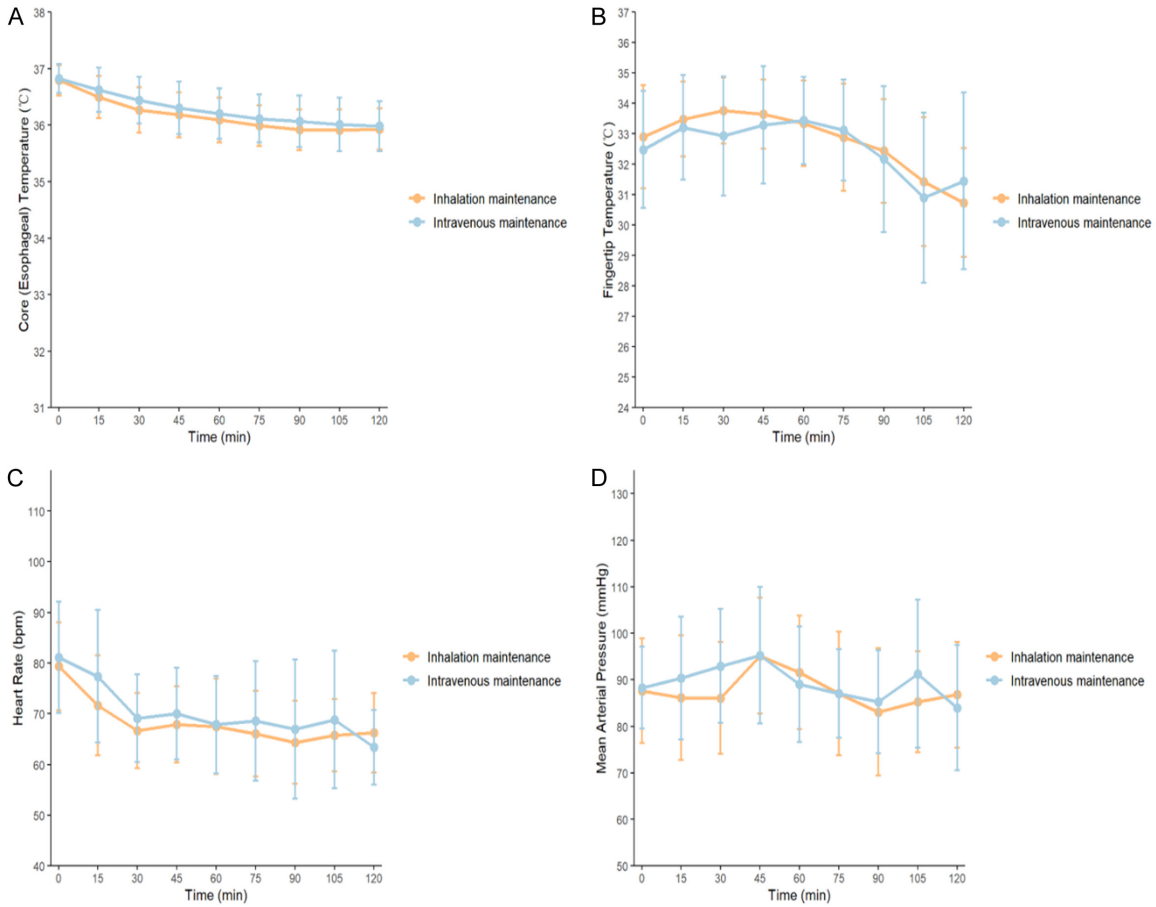

Figure 2. Curves of (A) core esophageal temperature, (B) fingertip temperature, (C) heart rate, and (D) mean arterial pressure changes during surgery in the inhalation maintenance and intravenous maintenance groups. Time 0 min was measured after induction of anesthesia, followed by measurements at 15-min intervals.

in the inhalation group and 20 patients (23.3%) in the intravenous group, with no significant difference (RR = 1.25; 95% CI, 0.75 to 2.07; *P* = 0.488). No significant difference was observed

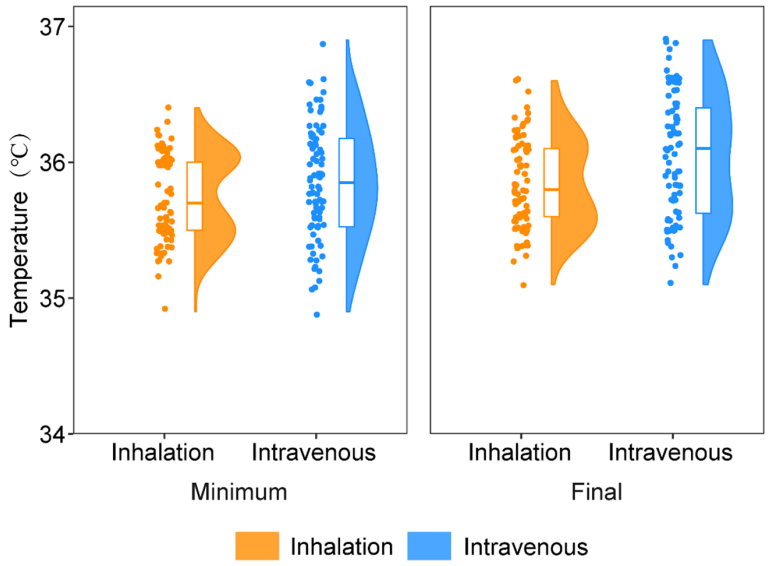

Figure 3. Cloud and rain plot of minimum intraoperative core temperature (Minimum) and end-of-operative core temperature (Final) in the inhalation group versus the intravenous group. *P* values for differences between groups were calculated by the Wilcoxon test (Minimum: $P = 0.107$; Final: $P = 0.004$).

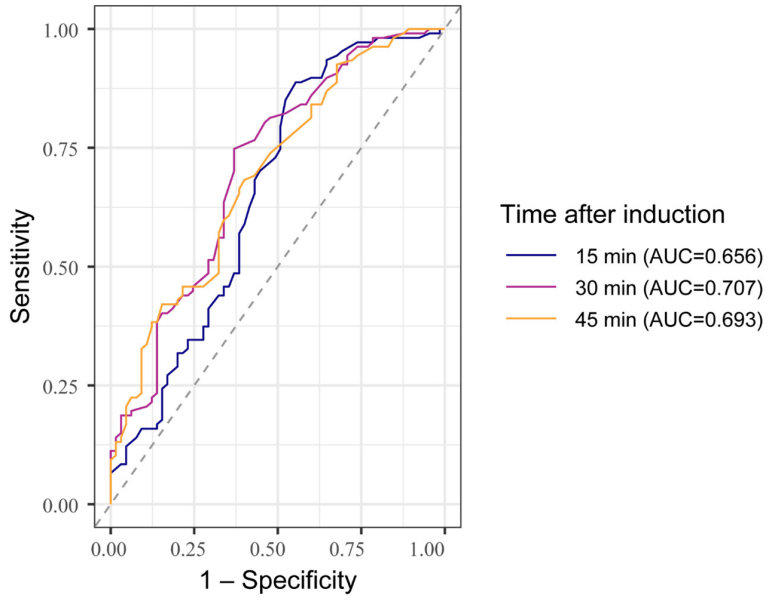

Figure 4. Intraoperative 15, 30, and 45 min forearm-fingertip temperature gradients predicting hypothermia (core temperature < 36°C) were superimposed on the smoothed ROC curve.

between groups in 24-hour postoperative VAS pain scores ($P = 0.554$) or hospitalization duration ($P = 0.871$). Shivering occurred in 3.5% (3/86) of inhalation group patients and 5.8% (5/86) of intravenous group patients (RR = 0.60; 95% CI, 0.15 to 2.43; $P = 0.720$) (**Table 2**).

As shown in **Figure 2B**, following induction, finger temperature reached its peak approximately 30 minutes later and then gradually decreased; the sevoflurane group showed a higher overall curve than the intravenous group. Line plots for forearm and ambient temperatures are provided in Supplementary Figure 2, and full details of all linear mixed-effects models are presented in Supplementary Table 1. HR showed an overall decreasing trend in both groups, with slightly lower values observed in the sevoflurane group (main effect of group: $P = 0.018$), whereas MAP remained relatively stable throughout surgery with no significant intergroup difference (**Figure 2C**, **2D**).

Details on the predictive performance of the forearm-**fin**gertip temperature gradient at different intraoperative time points for hypothermia are presented in Supplementary Table 2. Among all time points within the 0-120 min period, the AUC was highest at 30 minutes after induction, reaching 0.707. At this time point, the Youden index was also maximal (0.378), corresponding to an optimal threshold of -1.55°C. The discriminative performance at other time points was inferior to that at 30 minutes. ROC curves for three adjacent time points (15, 30, and 45 minutes) are shown in **Figure 4**.

Discussion

In this randomized controlled trial, the occurrence of hypothermia during surgery showed no notable variation between patients undergoing total hip arthroplasty who received intravenous maintenance anesthesia and those main-

tained with inhaled sevoflurane. The core temperature was lower at the end of surgery in the inhalation group, and the recovery time was significantly prolonged. No significant differences were observed between groups in the incidence of PONV, pain scores, shivering, or length of hospital stay within 24 hours postoperatively. In a previous study, Ikeda and colleagues [18] demonstrated that patients induced with propofol exhibited consistently lower intraoperative core temperatures than those induced with sevoflurane, suggesting that even transient, more intense vasodilation during anaesthetic induction can result in substantial and persistent core-to-peripheral heat redistribution. A recent study [22] further demonstrated that different induction agents, including propofol, sevoflurane, and propofol combined with vasoactive agents, resulted in varying degrees of temperature reduction. In the present study, both groups received identical induction protocols to eliminate confounding effects arising from heat redistribution during the induction phase. Therefore, the observed differences can be attributed almost entirely to the anaesthesia maintenance technique.

There are few studies investigating the effects of different anaesthetic techniques, including both induction and maintenance, on intraoperative temperature regulation, and the heterogeneity in anaesthetic drug combinations and dosages makes meaningful comparisons and robust conclusions difficult to achieve [23-27]. Intraoperative hypothermia is usually divided into three stages. The first stage is heat redistribution, which occurs within about 1 hour after anesthesia induction. At this time, the hypothalamus's thermoregulatory function is inhibited, peripheral blood vessels dilate, and core heat is transferred to the periphery and lost to the environment, a process that is irreversible. In the second stage, heat loss exceeds heat generation, resulting in a slow, linear decline in core temperature that lasts about 2-3 hours. Finally, when the core temperature reaches the critical threshold that triggers thermoregulatory vasoconstriction, we enter the plateau period. This vasoconstriction reduces heat loss, balances heat generation and dissipation, and thus stabilizes core temperature [28]. Among these phases, core-to-peripheral heat redistribution is considered the most significant contributor to core temperature reduction [29]. Some studies [30] have reported that post-induction redistribution causes a core temperature drop of 1.0-1.5°C within roughly 1 hour, accounting for up to 80% of the total intraoperative temperature decline. In our study, within the first 15 minutes post-induction, both participant groups displayed a swift decrease in core temperature, consistent with findings by Roth et al. [22], who reported a total decrease of less than 1°C during the first hour. This milder redistribution may be attributed to the specific induction agents used in our study, such as etomidate [31] and midazolam [32], which are known to exert minimal effects on thermoregulation.

In this study, core temperature decreased at similar rates in both groups, consistent with prior research. Iwata et al. [25] reported that during neurosurgery, core temperature decline and recovery rates did not differ significantly between patients managed with sevoflurane and those managed with propofol. Similarly, Kwak et al. [21] observed no variation in intraoperative core temperature modifications among patients undergoing prolonged laparoscopic surgery who received either sevoflurane with remifentanil or propofol with remifentanil, assuming identical induction agents. Research has also shown that the use of sevoflurane and propofol for maintaining anesthesia produces similar impacts on a patient's body temperature during transsphenoidal pituitary surgery [20]. These findings suggest that, under standardised warming protocols, the choice of maintenance anaesthesia may not significantly affect thermoregulation. In each of the aforementioned studies, the induction methods were consistent across groups, with differences only in maintenance strategies, which aligns with our study design. However, inconsistencies in drug regimens were noted; for instance, some studies administered intravenous remifentanil in the inhalational maintenance group, while others included nitrous oxide in the intravenous group, thereby illustrating the variability in anaesthetic protocols.

In our experiment, one group of patients only used inhaled drugs to maintain anesthesia, and the other group only used intravenous drugs, so that we could see more directly how the way of maintaining anesthesia, that is, using volatile drugs or intravenous drugs, affects the core body temperature during sur-

gery. In addition, most previous studies focused only on the changing trend of core body temperature during surgery and did not clearly explain or calculate how many times hypothermia occurred. ROC analysis was used in our study, and the AUC was 0.656 at 15 minutes, the highest at 30 minutes (0.707), and slightly decreased to 0.693 at 45 minutes. But after 60 minutes, the prediction ability is greatly reduced. These findings indicate that measuring the temperature difference between the forearm and the fingertip 30 minutes after anesthesia induction can effectively predict whether hypothermia will occur during the operation in advance and can serve as a clinical signal to prompt active warming for patients. According to the Youden index, the optimal threshold is -1.55°C, indicating that the fingertip temperature is about 1.55°C higher than the forearm temperature at that time. Under normal physical conditions, the forearm is closer to the core of our body, so its temperature should be higher than the fingertip. However, due to the dense presence of arteriovenous anastomoses (AVAs) in fingertip skin, rapid vasodilation and blood flow redistribution following anaesthetic induction or during early maintenance may transiently elevate fingertip temperature above that of the forearm. This phenomenon aligns with findings from previous studies [33-36] and likely reflects pronounced peripheral vasodilation and extensive AVA recruitment.

Our results showed that there was no obvious difference in the speed of core body temperature change between inhalation anesthesia and intravenous anesthesia during the operation. The core body temperature of the two groups of patients remained above 35.5°C during the operation, and there was no difference in postoperative complications. This finding is consistent with the largest recent randomized controlled trial on perioperative body temperature management, which showed that increasing core body temperature from 35.5°C to 37°C during surgery did not significantly reduce the risk of major cardiac complications [37].

Compared to previous research, our work had several key advantages. We used the largest sample so far to study the effects of different anesthesia maintenance methods on body temperature. We strictly controlled the factors that may cause trouble, such as warm-keeping measures before and after the operation, and also collect the temperature data of different parts and different time points, not only analyze the changing trend but also calculate the incidence rate, and even calculated the temperature difference from forearm to fingertip to predict whether hypothermia will occur during the operation, which made our results more reliable. However, our research also had some shortcomings. First of all, our pilot study may have overestimated the between-group difference, leading to an assumed effect size larger than that observed in the full trial. Because the absolute difference in the observed incidence was much smaller (approximately 3.5%), the study may have been underpowered to detect such a modest effect. In addition, in the absence of prophylactic active warming and with passive insulation only, both groups experienced a high incidence of hypothermia, which may have further attenuated any intrinsic between-group difference. Although the observed difference was small, the similarly high incidence in both groups supports our overall conclusion that the choice of maintenance anaesthesia was not associated with a significant difference in hypothermia incidence. Second, because of ethical requirements, we did not measure the distal esophageal temperature of conscious patients as the basic core temperature. We recorded the baseline temperature in everyone's mouth and found no obvious difference between the groups. We also measured esophageal temperature immediately after anesthesia. However, if, in fact, we could measure esophageal temperature before anesthesia, it might better reflect the true core body temperature. Third, we did not follow up on the long-term situation after the operation, such as how different anesthesia methods affect PONV (postoperative nausea and vomiting), trembling, or heart problems. Finally, because this study was conducted at a single hospital, our findings may not be generalizable. More research is needed, especially large-scale research involving more hospitals and more people, to find out the long-term effects of different anesthesia methods on hypothermia and its problems. This may disclose other factors that lead to hypothermia during the operation.

Conclusion

Overall, no notable variation in the occurrence of intraoperative hypothermia was observed in

those receiving total hip replacement surgery between those receiving inhalational anesthesia maintenance alone and those receiving intravenous anesthesia maintenance alone.

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All participants granted written informed consent before their surgical procedures.

Disclosure of conflict of interest

None.

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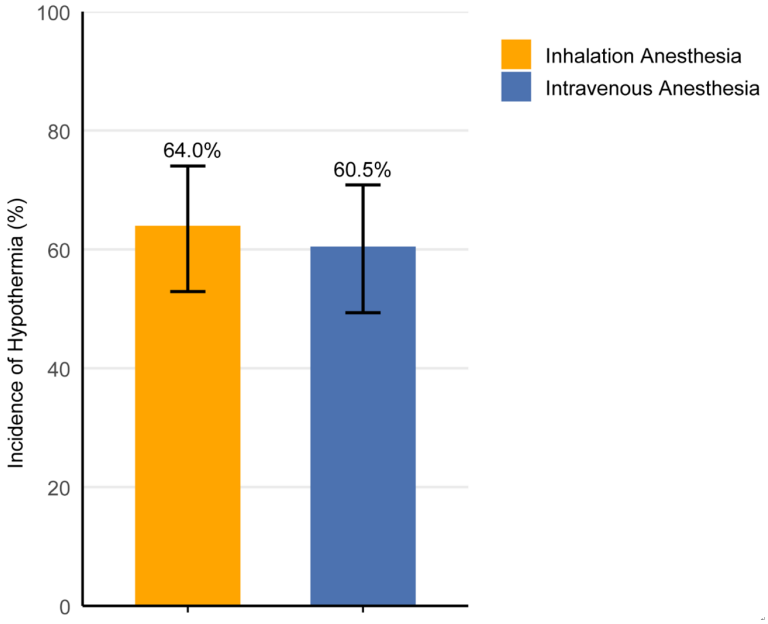
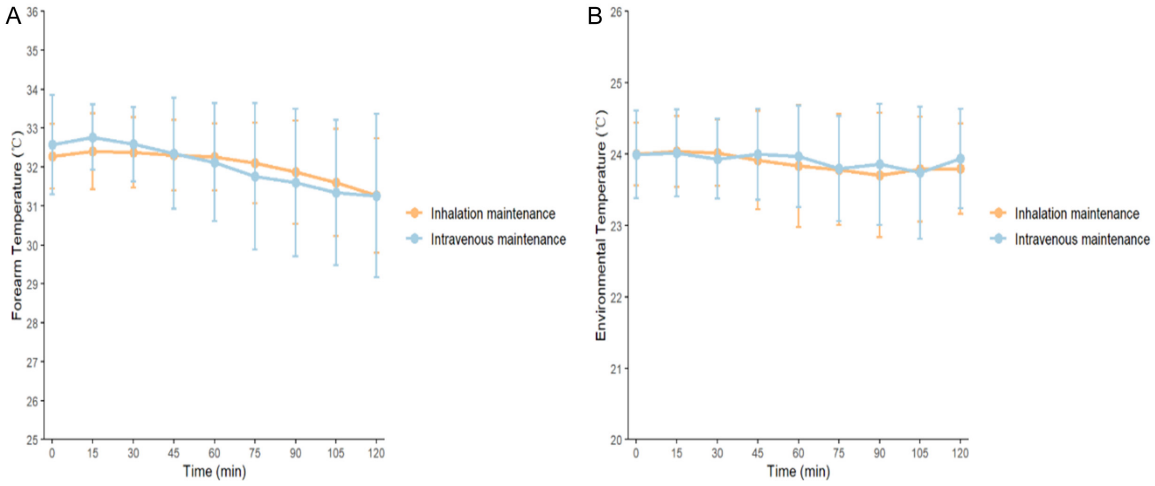


Supplementary Figure 1. Comparison of the incidence of hypothermia in the inhaled and intravenous groups.



Supplementary Figure 2. Curves of (A) forearm temperature and (B) ambient temperature changes during surgery in the inhalation maintenance and intravenous maintenance groups.

Supplementary Table 1. Linear mixed effects model: fixed effects results

	Estimate	Standard error	DF	95% CI lower	95% CI Upper	*P*-value
HR						
(Intercept)	73.794	0.958	236.2	71.918	75.671	< 0.001
time	-0.094	0.006	1294.2	-0.106	-0.081	< 0.001
group	3.257	1.356	237.4	0.599	5.915	0.017
time:group	-0.017	0.009	1294.4	-0.035	0.002	0.078
MAP						
(Intercept)	89.036	1.053	349.5	86.972	91.099	< 0.001
time	-0.023	0.010	1303.5	-0.043	-0.003	0.023
group	2.694	1.492	352.2	-0.231	5.619	0.072
time:group	-0.017	0.015	1304.0	-0.046	0.012	0.242
T1						
(Intercept)	24.040	0.062	264.8	23.918	24.163	< 0.001
time	-0.003	0.000	1295.7	-0.004	-0.002	< 0.001
group	-0.011	0.088	266.5	-0.184	0.163	0.904
time:group	0.001	0.001	1296.0	-0.001	0.002	0.251
T2						
(Intercept)	36.602	0.038	234.3	36.528	36.677	< 0.001
time	-0.007	0.000	1299.2	-0.008	-0.007	< 0.001
group	0.103	0.054	235.7	-0.003	0.208	0.058
time:group	0.000	0.000	1299.5	0.000	0.001	0.419
T3						
(Intercept)	32.544	0.115	301.3	32.319	32.769	< 0.001
time	-0.008	0.001	1308.9	-0.010	-0.006	< 0.001
group	0.327	0.163	303.4	0.008	0.646	0.045
time:group	-0.006	0.001	1309.5	-0.009	-0.003	< 0.001
T4						
(Intercept)	33.896	0.170	278.7	33.563	34.228	< 0.001
time	-0.019	0.001	1307.9	-0.021	-0.016	< 0.001
group	-0.560	0.241	280.4	-1.031	-0.088	0.021
time:group	0.007	0.002	1308.4	0.003	0.011	< 0.001

T1, environmental temperature; T2, core temperature; T3, forearm temperature; T4, fingertip temperature; DF, degrees of freedom; CI, confidence interval.

Supplementary Table 2. Results of ROC analysis of forearm-fingertip temperature gradients at different intraoperative time points to predict hypothermia

Time (min)	AUC	Threshold	Sensitivity	Specificity	Youden
0	0.645	-0.8	0.673	0.600	0.273
15	0.656	-2.05	0.888	0.446	0.334
30	0.707	-1.55	0.748	0.631	0.378
45	0.693	-1.65	0.682	0.600	0.282
60	0.610	-2.1	0.813	0.415	0.228
75	0.538	-3.65	1.000	0.154	0.154
90	0.568	-0.3	0.430	0.754	0.184
105	0.505	-0.85	0.697	0.458	0.155
120	0.537	0.95	0.380	0.791	0.171

The AUC reflects discrimination performance; the optimal threshold is determined by the Youden index method; sensitivity is the proportion of patients with hypothermia correctly identified at that threshold; specificity is the proportion of patients with non-hypothermia correctly excluded at that threshold; and Youden index = sensitivity + specificity - 1. AUC, area under the curve.