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ORIGINAL PAPER

Examination of intra-operative core temperature in joint arthroplasty: a single-institution prospective observational study

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Abstract

Purpose Peri-operative hypothermia is associated with increased blood loss, delayed wound healing, and surgical site infections. However, it is not known when or how rapidly hypothermia develops during arthroplasty. This study observed patients undergoing lower extremity arthroplasty to identify the times of greatest heat loss or gain.

Methods This single-institution prospective observational study enrolled 120 patients undergoing elective knee or hip arthroplasty for peri-operative temporal temperature measurements at ten prespecified intervals. Incidence of hypothermia was the primary outcome. A secondary aim was to identify patient and operative factors associated with hypothermia. Descriptive statistics were calculated for fixed time variables. Associations for the occurrence of hypothermia over time were conducted using generalized linear mixed models with a logit link and a random subject effect to account for repeated measures on the same individual over time.

Results Most patients, 72.6%, experienced hypothermia with 20.6% hypothermic for over one hour and 47.1% hypothermic after surgery. In the multivariable model, increased odds of hypothermia were associated with female gender ($P = 0.017$), knee arthroplasty ($P < 0.001$), neuraxial anaesthesia ($P < 0.001$), lower patient pre-operative temperature ($P < 0.001$), and lower operating room temperature ($P = 0.042$). A 0.5 °C decrease in patient pre-operative temperature or operating room temperature was associated with a 97 and 11% increase in the odds of hypothermia, respectively, controlling for other factors.

Conclusion In our series, peri-operative hypothermia remains common for patients undergoing arthroplasty. Female gender, low pre-operative temperature, knee arthroplasty, and neuraxial anesthesia were associated with hypothermia. Further preventative strategies and studies on interventions to reduce hypothermia are needed.

Keywords Total joint arthroplasty · Hypothermia · Intra-operative care · Temperature regulation · Hypothermia prevention · Neuraxial anesthesia

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Introduction

Peri-operative hypothermia can have deleterious effects. While there is no standard consistent definition within the literature, mild hypothermia is commonly defined as a core temperature between 34 and 36 °C [1]. Mild hypothermia has been shown to increase the occurrence of surgical site infections [2, 3], cardiac morbidity [4], coagulopathy leading to increased blood loss and transfusion requirements [5, 6], impaired drug metabolism [7, 8], and prolonged emergence from anaesthesia [9]. In addition, there is evidence that maintaining intra-operative normothermia can shorten hospital length of stay [2].

Despite the fact that intra-operative temperature monitoring and warming are considered standard of care, peri-operative hypothermia in total joint arthroplasty patients remains an issue for several reasons. A large proportion of patients undergoing joint replacement are elderly, making them susceptible to peri-operative hypothermia. In addition, regional anaesthesia causes vasodilation and promotes heat flow from the core to the periphery [10, 11] and impairs central and autonomic thermoregulation such that patients receiving neuraxial anaesthesia can be particularly susceptible to peri-operative hypothermia [1]. Finally, core temperature monitoring is typically not used during regional anaesthesia and hypothermia may go undetected for long periods of time [1].

The primary goal of this study was to examine the incidence of hypothermia during lower extremity arthroplasty. A secondary aim was to identify patient and operative factors associated with hypothermia in order to improve future preventative strategies. Our hypothesis was that peri-operative hypothermia occurs in the majority of patients undergoing lower extremity arthroplasty. In addition, we hypothesized that certain patient and anaesthetic factors (such as low body mass index and receiving general anaesthesia) would increase the incidence of hypothermia.

Methods

Following institutional IRB approval (Pro00035290) and written informed consent, 120 patients undergoing elective knee or hip arthroplasty were enrolled in this prospective observational study. Patients consented and were enrolled either in the anaesthesia pre-operative clinic or in the holding area on the day of surgery. Inclusion criteria included English-speaking patients who were at least 18 years of age and able to provide informed consent. Four orthopaedic surgeons performed all surgical procedures.

Hypothermia was defined as a temperature less than 36.0 °C. All temperatures were assessed with an Exergen temporal thermometer (precise to 0.1 °C). Each temporal measurement was taken and recorded three times for accuracy and the mean value utilized for data analysis at each time point. Temperatures were measured upon (1) leaving holding area; (2) operating room (OR) arrival; (3) after anaesthetic induction; (4) upper body forced air warmer initiation (used for all patients); (5) incision; (6–8) every 30 minutes after incision; (9) leaving the OR; and (10) arrival to PACU.

OR temperature and humidity were recorded throughout by standardized wall-mounted monitors, which are standard in our ORs. OR mattress temperature was measured with an infrared laser thermometer (Craftsman 3450455: Craftsman Digital Infrared Thermometer) on arrival to the OR. Additional information captured on each subject included gender, age, BMI, type of anaesthesia used, primary or revision arthroplasty, total intravenous crystalloid and colloid administered, and utilization of intra-operative phenylephrine.

As neuraxial anesthesia is our institutional standard of practice for lower extremity arthroplasty, general anaesthesia was planned only in those patients for whom a spinal anaesthetic was unsuccessful or contraindicated. For post-operative pain control, TKA patients received adductor canal catheters (20 ml, 0.5% ropivacaine pre-operative bolus), while THA patients received lumbar plexus single injection blocks (20 ml, 0.5% ropivacaine with 4 mg dexamethasone pre-operative). All blocks were performed pre-operatively in the surgical holding area.

Statistical analysis

This observational study was designed to understand hypothermia development, estimate the mean temperature (or temperature change from baseline) at specific time points, and examine the incidence of hypothermia. The thermometers are precise up to 0.1 °C and the standard deviation of patient temperature was expected to be approximately 0.5 °C. A minimum sample size of 97 subjects produced a two-sided 95% confidence interval with a distance from the mean temperature (or change in temperature) equal to 0.1 °C assuming the standard deviation of 0.5 °C. The sample size was increased to 120 subjects to account for patients that declined to participate on the day of surgery.

Descriptive statistics were calculated for all fixed time variables. For continuous variables, if the values appeared to be skewed, median (IQR) was reported instead of mean (SD).

The incidence of ever being hypothermic (temperature < 36.0 °C at one or more measurements) was the primary outcome. Evaluation of the association between ever being hypothermic and categorical variables was conducted using chi-square or Fisher's exact tests. The association between ever being hypothermic and continuous variables was evaluated using unpaired t tests or Wilcoxon rank sum test.

Since the presence of hypothermia at multiple time points may have greater clinical relevance, hypothermia development over time was examined by looking at all whether a subject was hypothermic at each data collection point. For example, this allows the comparison of subjects that were never hypothermic, experienced hypothermia at one or two data collection points, or experienced multiple episodes of hypothermia. Univariate and multivariable associations for the occurrence of hypothermia over time were conducted using a series of generalized linear mixed models with a logit link and a random subject effect to account for repeated measures on the same individual over time. All variables with significance $P \leq 0.2$ in univariate models were considered in the multivariable model. Backwards selection was used to select the final model retaining all covariates with significance of $P \leq 0.05$. All analyses were conducted in SAS v. 9.3 (SAS Institute, Cary, NC).

Results

Patient enrollment occurred between September 2014 and February 2015. Of the 120 patients consented, 18 patients chose not to participate on the day of surgery and the final study population consisted of 102 subjects with 54 patients undergoing TKA and 48 THA.

Baseline characteristics for all patients, separated by if subjects experienced hypothermia (< 36.0 °C) at any time point, are presented in Table 1. As neuraxial anaesthesia is our institutional standard of practice for lower extremity arthroplasty, the majority of the arthroplasty patients received neuraxial anaesthetics. The majority of patients were female (62.7%) with a mean age of 63.5 years old. Slightly more patients (52.9%) underwent total knee arthroplasty (TKA) and 83.3% of patients (85/102) received neuraxial anaesthesia. Most patients (72.6%) experienced hypothermia at least once. The incidence of ever being hypothermic was associated with female gender, surgical procedure (TKA), and neuraxial anaesthesia ($P = 0.036$, 0.032, 0.010, respectively).

Hypothermia over time

Figure 1 presents the percentage of patients experiencing hypothermia and the observed patient temperatures for each data collection point. The mean (±SD) patient temperature across all times was 36.3 °C (± 0.6) and the lowest mean temperature for all patients, 36.1 °C (± 0.9), was recorded when the forced air warmer was turned on. Approximately one fifth (20.6%) of subjects remained hypothermic greater than one hour and 38.8% remained hypothermic after 30 minutes or greater of forced air warming. Almost half of patients (47.1%) experienced post-operative hypothermia.

Estimated odds ratios for univariate and multivariable analyses for the occurrence of hypothermia over time are reported in Table 2. In univariate analyses, hypothermia over time was associated with female gender, increased age, decreased BMI, decreased blood loss, increased fluid administration, decreased pre-operative patient temperature, and decreased OR temperature and mattress temperature (Table 2). In the multivariable model, female gender, TKA, neuraxial anaesthesia

Table 1 Patient characteristics for all subjects, separated by the presence of hypothermia (< 36.0 °C) at any time point

	All (*n* = 102)	Never hypothermic (*n* = 28)	Ever hypothermic (*n* = 72)	*P*
Demographics				
Gender (male)[a]	38 (37.3)	15 (53.5)	23 (31.1)	0.036
Age (years)[b]	63.5 (11.3)	61.0 (11.7)	64.5 (11.0)	0.168
BMI (kg/m^2)[b]	32.8 (7.91)	34.0 (7.03)	32.0 (8.13)	0.098
Surgical variables				
Total knee arthroplasty[a]	54 (52.9)	10 (35.7)	44 (59.5)	0.032
Total hip arthroplasty[a]	48 (47.1)	18 (64.3)	30 (40.5)	
Revision[a]	22 (21.8)	6 (22.2)	16 (21.6)	0.948
Total OR time (min)[b]	227.7 (78.1)	224.0 (69.8)	229.0 (81.4)	0.775
Time from entering OR to incision (Min)[b]	83.1 (52.3)	74.5 (33.8)	86.4 (57.6)	0.307
Time from incision to procedure end (min)[b]	133.5 (42.0)	140.0 (51.5)	131.0 (37.9)	0.334
Anaesthesia variables				
Neuraxial anaesthesia[a]	85 (83.3)	19 (67.9)	66 (89.2)	0.010
Intravenous fluid warmer used[b]	100 (98.0)	27 (96.4)	73 (98.7)	1.00
Total intravenous fluid (ml)[b]	1792 (928.2)	1933 (1064)	1739 (873.5)	0.476
Transfusion[a]	4 (3.92)	1 (3.57)	3 (4.05)	1.00
Total blood given (ml)[c]	0 (0)	0 (0)	0 (0)	0.947
Phenylephrine administered[b]	77 (76.2)	19 (57.9)	58 (79.5)	0.220
Phenylephrine dose (μg)[c]	2360 (5720)	1840 (6233)	2360 (4995)	0.846
Environmental variables (°C)				
Mattress temperature[b]	21.2 (1.61)	21.5 (1.93)	21.1 (1.50)	0.317
Operating room temperature[b]	20.5 (0.68)	20.3 (1.17)	20.6 (0.53)	0.719
Operating room humidity[b]	39.6 (2.67)	39.5 (3.53)	39.7 (2.77)	0.949

OR operating room

[a] Categorical variables are reported as *n* (%)

[b] Continuous variables are reported as mean (SD)

[c] Continuous variables are reported as median (IQR)

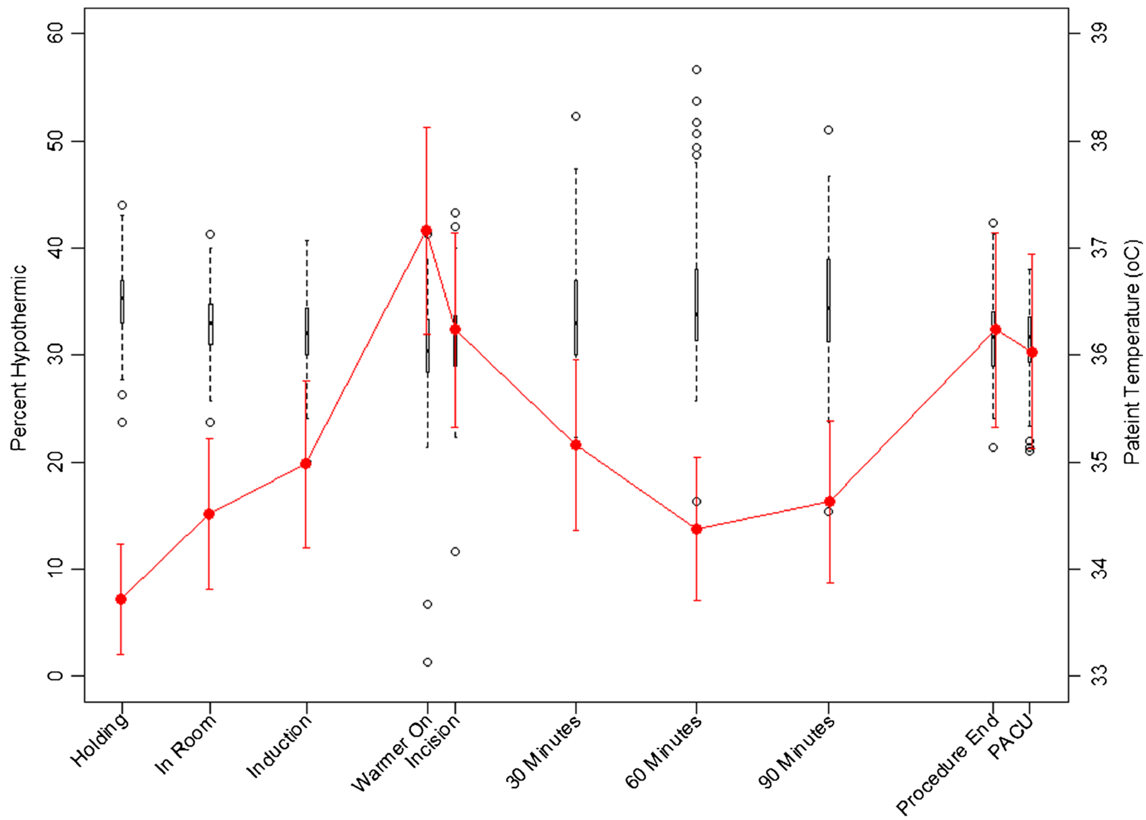

Fig. 1 Percentage of patients experiencing hypothermia and the observed patient temperatures for each data collection point. Closed circles represent the percent of hypothermic patients (temperatures < 36.0 °C) with 95% confidence intervals at each data collection point. Boxplots represent observed patient temperatures and are defined by the 25th, 50th, and 75th percentiles (lower whiskers are the 25th percentile minus 1.5 times the inner quartile range (IQR) and upper whiskers are the 75th percentile plus 1.5 times the IQR). Open circles represent values outside the range defined by the whiskers

lower patient temperature entering the OR, and lower OR ambient temperature remained significant. Controlling for other factors, females had twice the odds of experiencing hypothermia relative to males ($P = 0.017$, 95% CI 1.14–3.72), and neuraxial anaesthesia was associated with five times the odds of experiencing hypothermia ($P < 0.001$, 95% CI 2.00–12.3). Patients that underwent TKA had 2.4 times the odds of experiencing hypothermia relative to patients that had THA,

Table 2 Univariate and multivariable odds ratios from generalized linear mixed models examining the probability of hypothermia over time

	Univariate		Multivariable	
Variable	OR (95% CI)	*P*	OR (95% CI)	*P*
Patient and procedure				
Gender (female vs. male)	1.98 (1.43, 2.76)	< 0.001	2.06 (1.14, 3.72)	0.017
Age (5 year increase)	1.16 (1.08, 1.24)	< 0.001		
BMI (kg/m^2; 2-unit decrease)	1.05 (1.01, 1.09)	0.019		
Surgical and anaesthesia				
Procedure (TKA vs. THA)	2.06 (1.51, 2.65)	< 0.001	2.43 (1.40, 4.22)	< 0.001
Estimated blood loss (100 ml decrease)	1.12 (1.06, 1.18)	< 0.001		
Anaesthesia type (neuraxial vs. general)	2.38 (1.47, 3.85)	< 0.001	5.00 (2.00, 12.3)	< 0.001
Total intravenous fluid (500-ml increase)	1.15 (1.05, 1.26)	0.003		
Temperature specific (0.5 °C decrease)				
Patient temperature entering OR	3.21 (2.18, 4.75)	< 0.001	1.97 (1.39, 2.81)	< 0.001
OR temperature	1.13 (1.05, 1.21)	< 0.001	1.11 (1.00, 1.24)	0.042
Mattress temperature	1.05 (1.00, 1.10)	0.041		

controlling for other factors ($P = 0.002$, 95% CI 1.40–4.22). Figure 1 presents the mean (95% CI) temperatures for all patients over time. A 0.5 °C lower patient temperature upon entrance into the OR was associated with twice the odds of experiencing hypothermia ($P < 0.001$, 95% CI 1.39–2.81) while a 0.5 °C decrease in OR temperature was associated with an 11% increase in the odds of hypothermia ($P = 0.042$, 95% CI 1.00–1.24).

Discussion

With an estimated 400,000 THA and TKA surgeries performed in the USA in 2014, lower joint arthroplasty is one of the most common procedures performed worldwide and the most common inpatient surgery for Medicare patients, contributing to an estimated US$7 billion in hospital costs [12]. With the evolution of bundled payment models for many surgical procedures, it is even more imperative to identify modifiable factors to both prevent complications and shorten inpatient hospital stays. It is well known that peri-operative hypothermia can increase the risk of infection and duration of hospitalization in multiple groups including trauma patients, colorectal surgery patients, and hip fracture patients [1–3, 6, 13].

As the benefits of maintaining normothermia throughout the peri-operative period are well delineated, peri-operative normothermia is recommended by the World Health Organization (WHO), National Quality Forum (NQF), and the Surgical Care Improvement Project (SCIP) [14–16]. However, complying with peri-operative normothermia standards does not always result in achieving normothermia. A recent retrospective study that included over 10,000 surgical patients noted a hypothermia rate of 5.8% when hypothermia prevention measures including active warming were employed 97.9% of the time. However, despite a 99.3% compliance rate, the cohort of over 4000 orthopaedic patients experienced increased rates (7.7%) of hypothermia upon admission to the PACU compared to other specialties [16]. Thus, it may be more challenging to achieve peri-operative normothermia in orthopaedic patients.

The primary goal of our study was to examine the incidence and duration of hypothermia during the peri-operative period for patients undergoing TKA and THA. Most patients (72.6%) experienced hypothermia at some point, over 20% were hypothermic longer than one hour, and 47.1% were hypothermic after the procedure. Our incidence of hypothermia was much higher when compared to that published by Leijtens et al. who reported a 27% incidence for hypothermia in THA and TKA patients. However, they measured temperature via the tympanic membrane only after surgical closure [17]. Our results are similar, as our incidence of hypothermia was 32% at the end of the procedure. Frisch et al. reported a slightly higher incidence (37%) of intra-operative hypothermia. However, this study was a retrospective review that averaged patients' intra-operative temperatures and temperature was monitored by a variety of methods [18]. Postulated reasons for our higher rate of hypothermia may be related to our frequent temperature measurements throughout the peri-operative period; however, our predominance of neuraxial anaesthesia may also have impacted our results.

A surprising result of our study was the finding that patients undergoing general anaesthesia had a lower chance of developing hypothermia over time when compared to regional anaesthesia. This is in contrast to a recent large retrospective study on patients undergoing lower extremity joint arthroplasty that reported a higher rate of hypothermia with general anaesthesia as compared to regional anesthesia [18]. While general anesthetics are in fact typically associated with increased rates of hypothermia, neuraxial anaesthesia still results in both central and autonomic impairment of thermoregulation. In fact, a recent small descriptive study of women undergoing Cesarean delivery under spinal anaesthesia reported a 50% incidence of hypothermia [19]. As the majority of our patients received neuraxial anaesthesia, the standard of care at our institution, those patients that received general anesthesia most likely had certain medical conditions that precluded neuraxial anaesthesia, potentially skewing our results.

These prior publications and our findings highlight that patients undergoing neuraxial anaesthetics remain at risk for peri-operative hypothermia. A perceived bias may exist that patients who undergo neuraxial anaesthesia would be more likely to verbally complain of feeling cold, thereby leading the anaesthesia team to implement warming strategies earlier in these patients, making hypothermia less likely to occur. However, in practice this is probably not accurate. In reality, patients undergoing neuraxial anaesthesia often do not complain of feeling cold despite lower measured temperatures which may lead to delayed or complete lack of warming strategies implemented by the anaesthesia team, thus making hypothermia more likely to occur. Our current practice during regional anesthetics is to monitor axillary skin temperature and actively warm patients with a forced air warmer. Unfortunately, skin temperature probes are less accurate than core temperature monitors used with general anaesthetics and may lead to a delay in implementation of hypothermia prevention strategies. As hypothermia remains a risk with neuraxial anaesthetics, closer temperature monitoring and hypothermia prevention strategies require further investigation.

Another interesting finding was that TKA patients were more likely to develop hypothermia over time compared to THA patients. Leijtens et al. also noted an increased incidence of hypothermia in TKA procedures compared with THA [17]. They attributed this finding to the tourniquet use, which may lead to systemic washout of cold lactic acid and metabolites upon deflation and result in a decrease in body temperature.

Our THA patients also had greater blood loss and received more warmed IV fluids than the TKA patients. Consequently, the greater volumes of IVFs received by THA patients may have helped to maintain normothermia and avoid prolonged hypothermia.

Finally, both female gender and temperature entering the OR were statistically significant with developing hypothermia over time. Other studies have noted several patient factors to be associated with increased rates of peri-operative hypothermia including increased age and female gender [13, 18]. These results may suggest that providers should be more aggressive in either preventing or treating hypothermia in females. In addition, prewarming all patients with lower initial temperature in the pre-operative holding area via forced air warmers may be prudent as it is easily implemented [20, 21].

Limitations

This study does have some limitations. Although, several studies have found high reliability between temporal artery thermometers and oesophageal temperature monitoring during the peri-operative period in adult patients [22–25], an external temperature monitor may be considered a limitation. However, it was crucial that we utilize a consistent means of temperature measurement throughout the study. In addition, we did not collect any outcome data to evaluate if developing hypothermia was associated with increased complications or prolonged hospital stay. We also did not examine the impact of the time of the day (i.e., morning, afternoon, evening) on the incidence of hypothermia. This study was also conducted at a single tertiary care institution which may not be generalizable to all surgical institutions.

Conclusions

Overall, this study adds to the growing body of literature characterizing hypothermia in arthroplasty patients. Hypothermia is not rare in this patient population, and it typically lasts greater than one hour in a substantial proportion of patients. Based on our data, it appears that patients undergoing regional anaesthesia are at significant risk of developing peri-operative hypothermia. In addition, patients undergoing TKA, female patients, and those patients who had a lower pre-operative temperature were more likely to develop hypothermia over time, suggesting that these patients may need more aggressive interventions to maintain normothermia. Further studies are needed to investigate which warming strategies are most beneficial in preventing hypothermia in patients undergoing arthroplasty.

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Compliance with ethical standards

Informed consent was obtained from all individual participants included in the study. All procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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

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