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Original Article

Maternal temperature in emergency caesarean section (MATES): an observational multicentre study

P.T. Thorburn [a,*], R. Monteiro [a], A. Chakladar [a], A. Cochrane [b], J. Roberts [a], South East Anaesthetic Research Chain (SEARCH)[1] C. Mark Harper [a]

[a] Department of Anaesthesia, Brighton & Sussex University Hospitals NHS Trust, Brighton, UK
[b] Department of Anaesthesia, St Helens and Knowsley Teaching Hospital NHS Trust, St Helens, UK

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ABSTRACT

Background: Temperature regulation in women undergoing emergency caesarean section is a complex topic about which there is a paucity of evidence-based recommendations. The adverse effects of inadvertent peri-operative hypothermia are well described. Hyperthermia is also associated with adverse neonatal outcomes, an increased risk of obstetric intervention and increased treatment for suspected sepsis. We conducted a multi-centre observational cohort study to identify the prevalence of hypothermia and hyperthermia during emergency caesarean section.

Methods: Participants undergoing emergency caesarean section were recruited across 14 sites in the UK. The primary end point was maternal temperature in the recovery room. Temperature was measured using a zero heat-flux temperature monitoring device.

Results: Two hundred and sixty-five participants were recruited over a 12-month period. The prevalence of hypothermia (<36.0°C) was 10.7% and the prevalence of hyperthermia (>37.5°C) was 14.7% on admission to recovery. The prevalence of hypothermia, normothermia, and hyperthermia differed among type of anaesthesia: 71.4% of the hypothermic group had received a spinal anaesthetic whereas 76.9% of the hyperthermic group had received epidural top-up anaesthesia. There was a significant decrease in maternal temperature between the time of delivery and admission to the recovery room of 0.20°C (95% CI 0.15 to 0.25, $P<0.001$).

Conclusions: Both hypothermia and hyperthermia are prevalent findings in mothers who undergo emergency caesarean section. Therefore, accurate temperature measurement is essential to ensure that an appropriate intra-operative temperature management strategy is employed.

Introduction

The adverse effects of inadvertent peri-operative hypothermia are well described and include increased blood loss, wound infection, shivering, pain, cardiovascular complications and longer hospital stay.[1] Maintenance of normothermia has been shown to improve outcomes and national guidelines exist for the prevention of inadvertent peri-operative hypothermia, however obstetric patients are specifically excluded from the scope of these guidelines.[2] Conversely, the adverse effects of hyperthermia are not as well described. Hyperthermia may be associated with adverse neonatal outcomes, an increased risk of obstetric intervention and increased treatment for suspected sepsis.[3–5]

The majority of obstetric units in the UK do not routinely warm patients undergoing elective caesarean section (CS) and the published studies have involved small numbers of participants.[6] Audits have shown that up to 50% of patients undergoing elective CS are hypothermic (as defined by the National Institute for Health and Care Excellence (NICE)) at the time of admission to the recovery room after surgery.[7] The results of audits suggest that all patients undergoing CS with spinal or epidural anaesthesia should receive intra-operative warming.[8]

A randomised controlled trial (RCT) published by members of our group is the largest trial to date to examine hypothermia in the elective CS population. This trial identified a prevalence of inadvertent peri-operative hypothermia of 19% in the control group (standard care,

* Correspondence to: P.T. Thorburn, Department of Anaesthesia, Princes Royal Hospital, Lewes Road, Haywards Heath RH16 4EX, UK.
E-mail address: patrick.thorburn@nhs.net (P.T. Thorburn).

[1] Trainee-led Research Network, Higher Education Kent, Surrey and Sussex, UK.

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not warmed) and showed that an electrical resistive warming mattress could significantly reduce the incidence of inadvertent peri-operative hypothermia after elective CS.[9] A subsequent RCT showed the prevalence of inadvertent peri-operative hypothermia in elective CS to be 48% in the control group (not warmed).[10] A meta-analysis indicates that active warming at elective CS decreases peri-operative temperature reduction and the incidence of hypothermia and shivering.[11]

The prevalence of inadvertent peri-operative hypothermia in the emergency CS population is unknown. Decreased mobility, longer operative times, significant blood loss, intravenous fluid requirements and the possibility of combined general and neuraxial anaesthesia infer greater opportunity for heat loss. Conversely, women with an epidural catheter sited for labour analgesia are at risk of epidural-related maternal fever (ERMF)[12] and prolonged labour is a risk factor for chorio-amnionitis,[13] however the prevalence of maternal hyperthermia after emergency CS is also unknown.

The commercially available zero heat-flux thermometer gives accurate, continuous temperature readings in awake patients. We used this monitor to quantify the prevalence of maternal hypothermia and hyperthermia after emergency CS.

Methods

We conducted a multi-centre observational cohort study to quantify the prevalence of hypothermia and hyperthermia in women undergoing emergency CS. Ethical approval was granted by the North of Scotland Research Ethics Committee (16/NOS/0050) on May 17, 2016. Health Research Authority (HRA) approval was granted on November 29, 2016. The study was then approved by the local research and development departments of participating centres, and the project adopted into the National Institute of Health Research (NIHR) portfolio. Women were recruited from all labour units offering emergency CS in Kent, Surrey and Sussex (Supplementary Material 1).

Prior to submission for ethical approval, the proposed study and data collection form was peer reviewed by an obstetric anaesthetist at every proposed study location. Furthermore, the study process was reviewed by 25 women who had recently given birth by emergency CS to refine its design and assess acceptability to the target population. Local Research and Development approval was granted at each site and all equipment was tested by the local Electronic and Biomedical Engineering department prior to use.

Inclusion criteria were age ≥16 years and category 1 or 2 emergency CS. Patients were excluded if they chose not to use the standardised thermometer, did not consent to follow-up telephone interview, had a language barrier, or for any other reason that precluded consent to a follow-up phone interview. Written, informed consent was granted by women retrospectively, during routine anaesthetic follow-up on the postnatal ward. Patients who did not give consent were excluded from participation in the study and their data were destroyed. Those who gave consent were asked to recall their pain and thermal discomfort in the recovery room and 24 h postoperatively. These were scored using a 10 cm horizontal visual analogue scale (VAS) labelled 'NO pain' to 'MAX pain' (0–10 cm) and 'complete DIScomfort' to 'complete COMfort' (0–10 cm) respectively.

The primary outcome was temperature on arrival in the recovery room after emergency CS. Hypothermia was defined as <36.0 °C (as per NICE Clinical Guideline (CG) 65)[2] and hyperthermia defined as >37.5 °C. All women undergoing emergency CS who met the inclusion criteria had their temperature measured using the 3M™SpotOn™ thermometer (3 M, Maplewood, MN, USA). This is a zero heat-flux, peripherally placed thermometer that accurately represents core temperature (mean difference from nasopharyngeal temperatures 0.07 °C).[14,15] Temperature monitoring started intra-operatively and continued until discharge from the recovery room. Data were entered onto a pre-designed spreadsheet locally to ensure data consistency. Data were anonymised using a unique study identifier and then uploaded to a secure, password-protected database to assimilate results.

There is no universally agreed definition of hyperthermia, pyrexia or fever in the literature, so we chose 37.5°C because it is the first temperature to score on most Maternal Early Warning System charts recommended by the MBRRACE-UK report.[16,17] Secondary data points included the mode of anaesthesia, maternal temperature at time of delivery, use of active warming devices, fluids administered, operating time (skin incision to dressing application), anaesthetic time (time from entering theatre to adequate neuraxial block or general anaesthesia) and demographic data. These data were collected to identify trends in temperature throughout the peri-operative journey and differences between normothermic patients and those who were hypothermic or hyperthermic. Exploratory data were collected to identify potential maternal and neonatal complications that might be associated with temperature dysregulation and to inform future research. Parameters included anaemia estimated blood loss and change in haemoglobin (Hb) defined as pre-operative Hb minus lowest postoperative Hb, Apgar scores, umbilical venous and arterial blood pH, maternal thermal discomfort and pain both in recovery and 24 h postoperatively.

We aimed to recruit a convenience sample of 250 participants from 14 sites. A sample size calculation was performed using the formula in Supplementary Material 2. The prevalence of hyperthermia is unknown, however the prevalence of hypothermia in elective CS is estimated at 19%.[9] Assuming a similar prevalence of hypothermia in emergency CS, the calculated sample size was 246 subjects.

Descriptive statistical analysis was performed to calculate the primary outcome, prevalence of hypothermia and hyperthermia. For secondary analysis, patients were grouped according to the primary outcome (hypothermic, hyperthermic or normothermic in the recovery room). One-way ANOVA was used to compare these three groups with regard to demographic data, mode of anaesthesia and other secondary variables. Maternal temperature at delivery and in the recovery room (parametric continuous variables with two dependent samples) were compared using paired Student's t-test. Pearson chi-square test was used to compare the prevalence of normo-, hypo- and hyperthermia at delivery to the prevalence in the recovery room. This statistical plan was used to identify any differences between the three temperature groups and identify trends in temperature throughout the peri-operative period. Statistical analyses were performed using IBM SPSS Statistics for Macintosh, version 25.0 (IBM Corporation, Armonk, NY, USA). Statistical significance was defined as a P-value <0.05.

Results

Two hundred and sixty-six women were recruited between February 1, 2017 and January 31, 2018. One woman was excluded from analysis due to the absence of primary end-point data. On average, each site recruited 22.9% of their category 1 CS and 22.1% of category 2 CS during the recruitment window. The prevalence of hypothermia was 10.6% (95% CI 7.1 to 14.9%) and the prevalence of hyperthermia was 14.7% (95% CI 10.7 to 19.6%) on admission to the recovery room.

The demographic and peri-operative characteristics of the 265 participants are described in Table 1. Hypothermic patients had lower body mass index compared with normothermic and hyperthermic women ($P=0.019$), but there were no other statistically significant differences in baseline demographics. Importantly there was no difference in ambient theatre temperature between groups. The fluid warmer was the most commonly used device intra-operatively (44.9%) and there was very little use of a forced air warming device (0.8%). Fifty-five percent of cases used one method of warming and 9.1% used two methods; 35.5% of cases used no warming device and 71.8% of patients who were hyperthermic in recovery had been actively warmed in theatre.

Table 1
Demographic and peri-operative characteristics of women undergoing emergency caesarean section

Characteristic	All (n = 265)	Normothermic (n = 198)	Hypothermic (n = 28)	Hyperthermic (n = 39)	*P*-value
Age: years	31.4 ± 5.5	31.7 ± 5.6	32.0 ± 5.6	29.9 ± 4.9	0.166
BMI: $kg{\cdot}m^{-2}$	26.5 ± 5.4	26.7 ± 5.4	24.5 ± 5.0	26.8 ± 5.9	0.019
ASA physical status					
1	136 (51.3%)	97 (49%)	16 (57.1%)	23 (59%)	0.630
2	123 (46.4%)	97 (49%)	11 (39.3%)	15 (38.5%)	
3	6 (2.3%)	4 (2%)	1 (3.6%)	1 (2.6%)	
Gestation: days	274 ± 19	273 ± 20	270 ± 15	277 ± 19	0.324
Category of CS[a]					
1	52 (19.6%)	34 (17.2%)	9 (32.1%)	9 (23.1%)	0.204
2	213 (80.4%)	164 (82.8%)	19 (67.9%)	30 (76.9%)	
Mode of anaesthesia					
spinal	127 (47.9%)	101 (51%)	20 (71.4%)	6 (15.4%)	0.001
epidural top-up	114 (43%)	80 (40.4%)	4 (14.3%)	30 (76.9%)	
general	21 (7.9%)	16 (8.1%)	4 (14.3%)	1 (2.6%)	
other (1 CSE, 2 cGA)	3 (1.1%)	1 (0.5%)	0 (0%)	2 (5.1%)	
Time of day					
day (0800–1700) h	108 (40.8%)	83 (41.9%)	14 (50%)	11 (28.2%)	0.362
evening (1700–2000) h	34 (12.8%)	26 (13.1%)	3 (10.7%)	5 (12.8%)	
night (2000–0800) h	123 (46.4%)	89 (44.9%)	11 (39.3%)	23 (59%)	
Warming devices used					
fluid warmer	119 (44.9%)	90 (45.5%)	11 (39.3%)	18 (46.2%)	
pre-warmed fluid	23 (8.7%)	17 (8.6%)	2 (7.1%)	4 (10.3%)	
forced air blanket	2 (0.8%)	1 (0.5%)	1 (3.6%)	0 (0%)	
mattress and fluid warmer	22 (8.3%)	15 (7.6%)	1 (3.6%)	6 (15.4%)	
blanket	3 (1.1%)	1 (0.5%)	2 (7.1%)	0 (0%)	
other	2 (0.8%)	2 (1%)	0 (0%)	0 (0%)	
none	94 (35.5%)	72 (36.4%)	11 (39.3%)	11 (28.2%)	
Theatre temperature: °C	22.3 ± 1.7	22.4 ± 1.7	22.5 ± 1.7	21.9 ± 1.7	0.257
IV fluids administered: mL	1273 ± 550	1255 ± 533	1210 ± 469	1405 ± 670	0.522
Anaesthetic time[b]: min	14 ± 9	15 ± 9	11 ± 7	13 ± 7	0.152
Operating time[c]: min	49 ± 18	49 ± 17	45 ± 16	47 ± 19	0.117

Comparison is made between those who were normothermic (36.0–37.5°C), hypothermic (< 36.0°C) and hyperthermic (> 37.5°C) in recovery. Values are mean ± SD or number (%). BMI: body mass index. CS: caesarean section. ASA: American Society of Anesthesiologists. [a]Category 1 – immediate threat to life of woman or fetus. Category 2 – no immediate threat to life of woman or fetus, but with maternal/fetal compromise.[18] CSE: combined spinal-epidural. cGA: conversion to general anaesthesia. [b]Time from entering theatre to being ready for surgery (neuraxial block checked or general anaesthesia achieved). [c]Time from skin incision to skin dressing application.

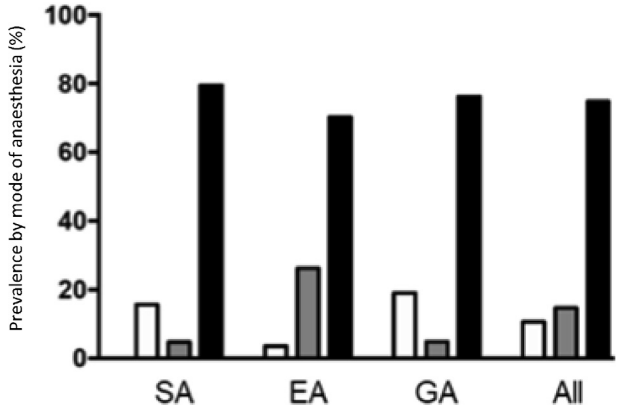

Fig. 1. Prevalence of hypothermia and hyperthermia relating to mode of anaesthesia. Values are given as a percentage (%). Hypothermia ☐ Hyperthermia ▒ Normothermia ■ SA: spinal anaesthesia. EA: epidural anaesthesia. GA: general anaesthesia. The difference in prevalence of thermal dysregulation by mode of anaesthesia was statistically significant ($P < 0.001$)

Fig. 1 shows the prevalence of hypothermia, hyperthermia and normothermia for each mode of anaesthesia. The prevalence of hypothermia was 15.7% (95% CI 9.9 to 23.3%), 19% (95% CI 5.5 to 41.9%) and 4% (95% CI 0.96 to 8.7%) for spinal anaesthesia, general anaesthesia and epidural top-up anaesthesia respectively ($P < 0.001$). The prevalence of hyperthermia was 26.3% (95% CI 18.5 to 35.4%) in the epidural top-up group compared with 4.7% (95% CI 1.8 to 10%) and 4.8% (95% CI 0.1 to 23.8%) in the spinal anaesthesia and general anaesthesia groups respectively ($P < 0.001$).

Table 2 compares maternal temperature category immediately after delivery, and the subsequent temperature category in the recovery room. There was a statistically significant relationship between these variables ($P < 0.001$). The prevalence of hypothermia more than doubled between delivery and arrival in recovery. Conversely, the prevalence of hyperthermia decreased from the time of delivery to the recovery room. This equates to 46 (17.4%) of patients dropping a temperature category between delivery and the recovery room. Fig. 2 shows a box and whiskers plot of the maternal temperature after delivery of the newborn and the maternal temperature in the recovery room. The mean maternal temperature after delivery of the newborn decreased from 37.0°C to 36.8°C. There was a strong correlation

Table 2
Prevalence of maternal hypothermia and hyperthermia after delivery of the newborn compared with recovery after emergency caesarean section

	Maternal temperature category after delivery of newborn[a]	Maternal temperature category in recovery
Normothermic	182 (68.7%)	198 (74.7%)
Hypothermic	13 (4.9%)	28 (10.6%)
Hyperthermic	64 (24.2%)	39 (14.7%)
Not recorded	6 (2.3%)	0 (0%)

Values are number and percent (% of total participants n = 265). [a]First temperature recorded after delivery of the newborn. Chi-square = 18.229, df = 3, $P < 0.001$.

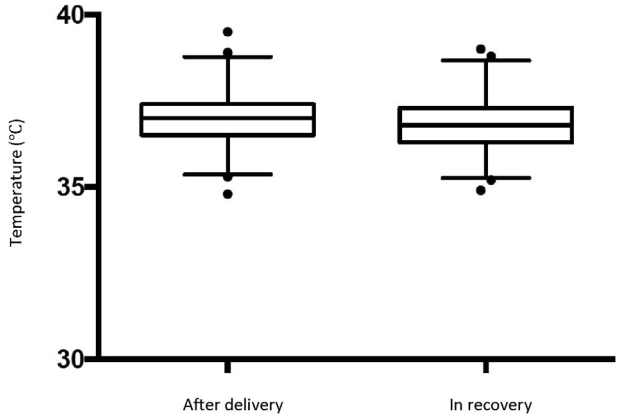

Fig. 2. Box and whiskers plot showing maternal temperature after delivery of the newborn and the maternal temperature in the recovery room. Box is the interquartile range with median line (37.0°C after delivery and 36.8°C in recovery). Whiskers indicate the 1st and 99th centile and the dots indicate outliers. There was a paired sample correlation $r = 0.817$ and a statistically significant reduction in mean temperature of 0.20°C (95% CI 0.15 to 0.25°C, $P < 0.001$)

($r = 0.817$) within paired samples and a reduction in mean temperature of 0.20°C (95% CI 0.15 to 0.25°C; $P < 0.001$).

Table 3 shows maternal and neonatal secondary outcomes for all temperature categories (normothermic, hypothermic and hyperthermic). There were no statistically significant differences in any of the secondary outcomes. There was no statistical difference between temperature category in the recovery room and the patient-reported outcomes for pain and thermal comfort in the recovery room or at 24 h postoperatively. Response rates for follow-up telephone interview were less than 15%, therefore these data are not presented.

Discussion

This multi-centre observational study has identified the prevalence of hypothermia to be 11% and the prevalence of hyperthermia to be almost 15% in women who have undergone emergency CS. Given that there are approximately 82 500 emergency CS in the UK each year,[19] a large number of patients may be at risk of thermal dysregulation in the peri-operative period.

The NICE CG65 recommends using direct measurement or direct estimates of core temperature that are accurate to within 0.5°C during the peri-operative period.[2] Importantly, infrared tympanic, temporal and forehead thermometers are not recommended. In using a zero heat-flux thermometer, this study presents accurate data (compliant with NICE guidelines) on thermal dysregulation, the prevalence of which is high and may be clinically relevant.

Hypothermia can affect numerous physiological and pathological processes.[1,20] In this patient group, it may increase shivering, pain and thermal discomfort. These factors may lead to delays in breastfeeding and bonding with a newborn, and the prevalence of 14.9% found in this study may have clinical significance. However, this prevalence appears to be lower than in the elective CS population, in which it has been reported to lie between 19% and 48%.[9,10] The reason for this difference is likely to be multifactorial. We observed the lowest prevalence of hypothermia in the epidural anaesthesia group which constituted 43% of our sample. Epidural anaesthesia is rarely used in the elective CS setting. We also observed that this group was more likely to be hyperthermic than patients who received spinal or general anaesthesia. The association between epidural analgesia for labour and hyperthermia has been noted in other studies.[3–5,12,21] The mechanism for this ERMF is unclear but likely to be multifactorial. Firstly, an imbalance between heat production (from uterine contraction and epidural-related shivering) and heat loss may contribute. Secondly, inflammation may contribute to ERMF. Women who use epidural analgesia are more likely to have prolonged rupture of membranes, develop chorio-amnionitis or placental inflammation, and have repeated internal examinations and prolonged labour, all factors that increase the inflammatory burden and contribute to temperature gain.[22–25] Thirdly, it is surmised that epidural labour analgesia may impair the release of anti-pyrogenic interleukins and that the immunomodulatory effects of bupivacaine during labour may promote ERMF.[26] All of these pre-operative epidural analgesia-related factors may contribute to the high prevalence of hyperthermia after emergency CS.

Conversely, in the non-obstetric population, intra-operative epidural anaesthesia is associated with hypothermia. Heat loss results from a combination of reduced metabolic heat production and peripheral redistribution secondary to sympathetic blockade and cutaneous vasodilatation.[27] This also occurs when epidural anaesthesia is used for elective CS.[28] However, there is evidence that topping up epidural analgesia for emergency CS is associated with hyperthermia.[29] This was significant for our population, among which 77% of the hyperthermic group received an epidural top-up anaesthetic. Maternal heat production (associated with labour, fetoplacental unit and uterine metabolic demands) continues to rise until delivery of the baby. Sympathetic blockade by an epidural top-up in a heat-stressed population appears to have no effect on skin blood flow, suggesting that equal vasodilator and vasoconstrictor tone is present before the top-up and the net effect of sympatholysis is zero.[27] The expected increase in heat loss may not occur, leading to an increase in maternal core temperature.[29] These pre-operative and intra-operative phenomenon may

Table 3
Maternal and neonatal secondary outcomes following emergency caesarean section

	All (n = 265)	Normothermic (n = 198)	Hypothermic (n = 28)	Hyperthermic (n = 39)	*P*-value
Estimated blood loss (mL)	683 ± 470	687 ± 480	563 ± 321	745 ± 498	0.300
Haemoglobin reduction (g/L)	19.0 ± 12.0	19.3 ± 12.5	15.5 ± 13.2	19.6 ± 9.9	0.507
Apgar score					
1 min	9 [2–10]	9 [2–10]	9 [3–10]	9 [5–10]	0.426
5 min	10 [6–10]	10 [6–10]	10 [7–10]	10 [8–10]	0.371
10 min	10 [7–10]	10 [7–10]	10 [9–10]	10 [9–10]	0.869
Umbilical vein pH	7.30 ± 0.07	7.30 ± 0.07	7.29 ± 0.11	7.32 ± 0.06	0.457
Umbilical artery pH	7.25 ± 0.08	7.25 ± 0.08	7.24 ± 0.11	7.27 ± 0.05	0.545
Thermal comfort[a] in recovery (cm)	7.6 ± 2.5	7.8 ± 2.4	6.9 ± 2.7	7.1 ± 3.1	0.145
Thermal comfort[a] at 24 h (cm)	7.2 ± 2.7	7.2 ± 2.6	7.1 ± 3.0	6.9 ± 3.1	0.728
Pain[a] in recovery (cm)	2.0 ± 2.7	1.8 ± 2.7	2.3 ± 3.0	2.8 ± 3.0	0.119
Pain[a] at 24 h (cm)	4.3 ± 2.4	4.2 ± 2.4	4.4 ± 2.6	4.7 ± 2.3	0.585

Values given as mean ± SD or mode [range]. [a]Thermal comfort and pain measured by 10 cm horizontal visual analogue scale (VAS) labelled 'complete DIScomfort' to 'complete COMfort' (0–10 cm) and 'NO pain' to 'MAX pain' (0–10 cm).

explain why inadvertent peri-operative hypothermia rates are lowest in women who received epidural top-up anaesthesia (3.5%) and why hyperthermia is so prevalent in our study population.

The prevalence of maternal hyperthermia during recovery was as high as 20%. Although a recognised phenomenon, there is a paucity of literature concerning the clinical impact, if any, of hyperthermia after CS. However, the deleterious effects of a high core temperature are well documented in other clinical situations such as heat stroke, post-cardiac arrest and sepsis.[30,31] Even mild hyperthermia for a short period of time can affect memory, attention and processing of information, all of which are important for the new mother.[32–34] Maternal hyperthermia has also been linked to adverse neonatal outcomes, an increased risk of obstetric intervention and treatment for suspected sepsis.[3–5]

One of the most clinically relevant findings of this study is the strong correlation between maternal temperature after delivery and maternal temperature in recovery. This suggests heat loss occurs during the peri-operative period. Heat production can decrease by up to 57% after delivery and an associated decrease in mean body temperature, probably resulting from the complex interaction between reduced heat production after delivery of the fetoplacental unit and anaesthesia.[29] It is likely that this postdelivery period is when the anaesthetist may have the largest impact on thermal dysregulation, and our findings highlight the importance of accurate regular temperature monitoring throughout the peri-operative period. Despite this heat loss, a significant number of women remained hyperthermic on admission to recovery. Seventy-two percent of these patients had some method of active warming in the operating theatre. This represents a rather arbitrary approach to peri-operative temperature management, and one that would be unacceptable for other forms of major surgery governed by the NICE CG65. There is a strong argument for the ubiquitous use of continuous zero heat-flux temperature monitoring and a method of warming that can be easily switched on and off if needed for all emergency CSs. Future research should aim to establish whether an individualised assessment and intervention such as this can reverse or prevent thermal dysregulation.

This study was not powered to detect any differences in secondary outcomes. No adverse outcomes were associated with thermal dysregulation although some areas of interest for future research have been highlighted. Patient temperature in recovery did not have any significant effect on pain or thermal comfort scores, making the clinical significance of the observed thermal dysregulation questionable. In addition, postoperative analgesia was not controlled in this study and the retrospective consent process introduced recall bias, so the results should be viewed with caution.

The study was conducted in 14 sites throughout the South-East of England, thus mitigating the effects of single-centre practices and successfully recruiting at a rate above target. Recruitment numbers for each site were not predetermined and the study continued until the total recruitment target was reached. Some busier units contributed fewer participants than expected, which may have led to selection bias. However, category 1 and 2 CSs were equally represented in the data. The main reason for recruitment was the lack of availability of investigators out of hours and over the weekend. In addition, mothers were excluded from the study if they were not approached for consent before discharge from hospital. Recruitment occurred throughout one calendar year and consequently captured patients during climate variations, therefore reducing potential environmental bias. However, the results may be influenced by other sources of bias. The conduct of anaesthesia was determined by clinician preference. Data on the use of neuraxial opioids, adrenaline use in the epidural top-up mixture or intra-operative vasopressor use were not collected but could potentially influence temperature change. Data on antibiotic use and infection rates were not collected to further inform our analysis of hyperthermic patients. The epidural anaesthesia rate was higher than the national average for emergency CS (43% vs 26%)[35] which may have resulted in a high hyperthermia prevalence. Mothers who were non-English speaking or under the age of 16 years were excluded from the study due to technical and ethical issues of consent, compounding recruitment bias. However, the obstetric patient undergoing an emergency procedure is a very difficult patient group to prepare, consent, recruit and study. As a result, there is a paucity of research published on emergency CS but our motivated group of trainees who executed this study (from the South-East Anaesthetic Research Chain, SEARCH) has demonstrated that it is feasible to collect robust data in this patient group.

This study has shown that it is possible to perform accurate continuous temperature monitoring in this challenging patient group; as a result it was possible to estimate the prevalence of maternal hypothermia and hyperthermia after emergency CS. Given the frequency and unpredictability of thermal dysregulation observed, the most important recommendation is that accurate continuous temperature monitoring be implemented in all emergency CS patients. This can be achieved in an awake patient by the use of an indirect measurement device, such as the zero heat-flux thermometer.[2] The readings can then be used to tailor peri-operative temperature management strategies that aim to achieve normothermia in this complex and varied group. Further research is necessary to determine whether active temperature management will lead to improved maternal and neonatal outcomes.

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Declaration of interests

CM Harper was an author and working group member for the NICE guidance (CG 65) pertaining to the prevention of inadvertent peri-operative hypothermia and monitoring of peri-operative temperature. He is also a Lead Expert Adviser for the NICE Medical Technologies Advisory Committee.

The authors declare that 3M™ loaned base units for the SpotOn™ temperature monitoring system to each site at no cost. All disposable components were purchased. 3M™ had no involvement in study design, conduct or analyses.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijoa.2021.102963.

References

1. Harper CM, Andrzejowski JC, Alexander R. NICE and warm. *Br J Anaesth*. 2008;101:293–295.
2. National Institute for Health and Clinical Excellence. Perioperative hypothermia (inadvertent): the management of inadvertent perioperative hypothermia in adults. In: NICE Clinical Guideline 65. London: National Institute for Health and Clinical Excellence, 2008, updated 2016. Available at: https://www.nice.org.uk/guidance/cg65. Accessed March 22, 2019.
3. Greenwell EA, Wyshak G, Ringer SA, Johnson LC, Rivkin MJ, Lieberman E. Intrapartum temperature elevation, epidural use, and adverse outcome in term infants. *Pediatrics*. 2012;129:e447–e454.
4. Goetzl L, Cohen A, Frigoletto F, Lang JM, Lieberman E. Maternal epidural analgesia and rates of maternal antibiotic treatment in a low-risk nulliparous population. *J Perinatol*. 2003;23:457–461.
5. Mayer D, Chescheir N, Spielman F. Increased intrapartum antibiotic administration associated with epidural analgesia in labor. *Am J Perinatol*. 1997;14:83–86.
6. Woolnough MJ, Hemingway C, Allam J, Cox M, Yentis M. Warming of patients during caesarean section: a telephone survey. *Anaesthesia*. 2009;64:50–53.
7. Petsas A, Vollmer H, Barnes R. Perioperative warming in caesarean sections. *Anaesthesia*. 2009;64:921–922.
8. Harper CM, Alexander R. Hypothermia and spinal anaesthesia. *Anaesthesia*. 2006;61:612.
9. Chakladar A, Dixon MJ, Crook D, Harper CM. The effects of a resistive warming mattress during caesarean section: a randomised, controlled trial. *Int J Obstet Anesth*. 2014;23:309–316.
10. Jun JH, Chung MH, Jun IJ, et al. Efficacy of forced-air warming and warmed intravenous fluid for prevention of hypothermia and shivering during caesarean delivery under spinal anaesthesia: a randomised controlled trial. *Eur J Anaesth*. 2019;36:442–448.
11. Sultan P, Habib AS, Cho Y, Carvalho B. The effect of patient warming during Caesarean delivery on maternal and neonatal outcomes: a meta-analysis. *Br J Anaesth*. 2015;115:500–510.
12. Segal S. Labor epidural analgesia and maternal fever. *Anesth Analg*. 2010;111:1467–1475.
13. Rickert VI, Wiemann CM, Hankins GD, McKee JM, Berenson AB. Prevalence and risk factors of chorioamnionitis among adolescents. *Obstet Gynecol*. 1998;92:254–257.
14. Iden T, Horn E-P, Bein B, Böhm R, Beese J, Höcker J. Intraoperative temperature monitoring with zero heat flux technology (3M SpotOn sensor) in comparison with sublingual and nasopharyngeal temperature: An observational study. *Eur J Anaesth*. 2015;32:387–391.
15. Jack JM, Ellicott H, Jones CI, Bremner SA, Densham I, Harper CM. Determining the accuracy of zero-flux and ingestible thermometers in the peri-operative setting. *J Clin Monit Comput*. 2019;33:1113–1118.
16. Knight M, Nair M, Tuffnell D, et al. on behalf of MBRRACE-UK. Saving Lives, Improving Mothers' Care - Surveillance of maternal deaths in the UK 2012-14 and lessons learned to inform maternity care from the UK and Ireland Confidential Enquiries into Maternal Deaths and Morbidity 2009-14. Oxford: National Perinatal Epidemiology Unit, University of Oxford 2016. Available at: https://www.npeu.ox.ac.uk/downloads/files/mbrrace-uk/reports/MBRRACE-UK Maternal Report 2016 - website.pdf. Accessed August 10, 2020.
17. Nair S, Dockrell L, Mac Colgain S. Maternal Early Warning Scores (MEWS). Available at: https://www.wfsahq.org/components/com_virtual_library/media/d937986303b4f35cdf1b366555ac8f5a-383Maternal-Early-Warning-Scores.pdf. Accessed August 10, 2020.
18. Royal College of Obstetrics and Gynaecologists and The Royal College of Anaesthetists. Classification of Urgency of Emergency Caesarean Section – A continuum of Risk. Good Practice No. 11 2010. Available at: https://www.rcog.org.uk/globalassets/documents/guidelines/goodpractice11classificationofurgency.pdf. Accessed March 22, 2019.
19. The NHS Maternity Statistics, England: 2013-14. Health and Social Care Information Centre website. Available at: http://www.hscic.gov.uk/catalogue/PUB16725. Accessed February 10, 2019.
20. Sessler DI. Complications and treatment of mild hypothermia. *Anesthesiology*. 2001;95:531–543.
21. Fusi L, Maresh MA, Steer P, Beard R. Maternal pyrexia associated with the use of epidural analgesia in labour. *Lancet*. 1989;333:1250–1252.
22. Herbst A, Wolnerhanssen P, Ingemarsson I. Risk factors for fever in labor. *Obstet Gynecol*. 1995;86:790–794.
23. Dashe JS, Rogers BB, Mcintire DD, Leveno KJ. Epidural analgesia and intrapartum fever: placental findings. *Obstet Gynecol*. 1999;93:341–344.
24. Dolak JA, Brown RE. Epidural analgesia and neonatal fever. *Pediatrics*. 1998;101:492–494.
25. Philip J, Alexander JM, Sharma SK, Leveno KJ, McIntire DD, Wiley J. Epidural analgesia during labor and maternal fever. *Anesthesiology*. 1999;90:1271–1275.
26. del Arroyo AG, Sanchez J, Patel S, et al. Role of leucocyte caspase-1 activity in epidural-related maternal fever: a single-centre, observational, mechanistic cohort study. *Br J Anaesth*. 2019;122:92–102.
27. Matsukawa T, Sessler DI, Christensen R, Ozaki M, Schroeder M. Heat flow and distribution during epidural anesthesia. *Anesthesiology*. 1995;83:961–967.
28. Horn EP, Schroeder F, Gottschalk A, et al. Active warming during caesarean delivery. *Anesth Analg*. 2002;94:409–414.
29. Mullington CJ, Low DA, Strutton PH, Malhotra S. Body temperature, cutaneous heat loss and skin blood flow during epidural top up for emergency caesarean section. *Anaesthesia*. 2018;73:1500–1506.
30. Pease S, Bouadma L, Kermarrec N, Schortgen F, Régnier B, Wolff M. Early organ dysfunction course, cooling time and outcome in classic heatstroke. *Intensive Care Med*. 2009;35:1454–1458.
31. Lee BH, Inui D, Suh GY, et al. Association of body temperature and antipyretic treatments with mortality of critically ill patients with and without sepsis: multi-centred prospective observational study. *Crit Care*. 2012;16:R33.
32. Racinais S, Gaoua N, Grantham J. Hyperthermia impairs short-term memory and peripheral motor drive transmission. *J Physiol*. 2008;586:4751–4762.
33. Sun G, Yang X, Jiang Q, et al. Hyperthermia impairs the executive function using the Attention Network Test. *Int J Hyperthermia*. 2012;28:621–626.
34. Sun G, Li Li, Li M, Jiang Q. Hyperthermia impaired pre-attentive processing: an auditory MMN study. *Neurosci Lett*. 2011;502:94–98.
35. NHS Digital. NHS Maternity Statistics, England 2018-19. Table 3.b: Method of delivery by anaesthetics used before or during delivery, 2018-19. Published 31st October 2019. Available at: https://digital.nhs.uk/data-and-information/publications/statistical/nhs-maternity-statistics/2018-19. Accessed March 4, 2020.