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Review Article

REVIEW ARTICLES

The Effect of patient warming during Caesarean delivery on maternal and neonatal outcomes: a meta-analysis

P. Sultan[1,*], A. S. Habib[2], Y. Cho[3] and B. Carvalho[4]

[1]Department of Anaesthesia, University College London Hospital, London, UK, [2]Department of Anesthesia, Duke University School of Medicine, Durham, NC, USA, [3]Pacific Alliance Medical Center, Los Angeles, CA, USA, and [4]Department of Anesthesia, Stanford University School of Medicine, Stanford, CA, USA

*Corresponding author. E-mail: p.sultan@doctors.org.uk

Abstract

Background: Perioperative warming is recommended for surgery under anaesthesia, however its role during Caesarean delivery remains unclear. This meta-analysis aimed to determine the efficacy of active warming on outcomes after elective Caesarean delivery.

Methods: We searched databases for randomized controlled trials utilizing forced air warming or warmed fluid within 30 min of neuraxial anaesthesia placement. Primary outcome was maximum temperature change. Secondary outcomes included maternal (end of surgery temperature, shivering, thermal comfort, hypothermia) and neonatal (temperature, umbilical cord pH and Apgar scores) outcomes. Standardized mean difference/mean difference/risk ratio (SMD/MD/RR) and 95% confidence interval (CI) were calculated using random effects modelling (CMA, version 2, 2005).

Results: 13 studies met our criteria and 789 patients (416 warmed and 373 controls) were analysed for the primary outcome. Warming reduced temperature change (SMD −1.27°C [−1.86, −0.69]; P=0.00002); resulted in higher end of surgery temperatures (MD 0.43 °C [0.27, 0.59]; P<0.00001); was associated with less shivering (RR 0.58 [0.43, 0.79]; P=0.0004); improved thermal comfort (SMD 0.90 [0.36, 1.45]; P=0.001), and decreased hypothermia (RR 0.66 [0.50, 0.87]; P=0.003). Umbilical artery pH was higher in the warmed group (MD 0.02 [0, 0.05]; P=0.04). Egger's test (P=0.001) and contour-enhanced funnel plot suggest a risk of publication bias for the primary outcome of temperature change.

Conclusions: Active warming for elective Caesarean delivery decreases perioperative temperature reduction and the incidence of hypothermia and shivering. These findings suggest that forced air warming or warmed fluid should be used for elective Caesarean delivery.

Key words: anaesthesia; body temperature, hypothermia; caesarean section; obstetric; temperature

The benefits of maintaining normothermia in the perioperative period include reductions in: postoperative wound infection,[1 2] myocardial ischaemia,[3] the risk of perioperative coagulopathy, blood loss and transfusion requirement.[4] Although maintenance of normothermia before, during and after surgery in order to help prevent surgical site infection has been recommended for adults undergoing surgery under general or regional anaesthesia,[1 5 6] the benefits of preventing hypothermia in women undergoing Caesarean delivery remain unclear. There are currently no European or American national recommendations regarding the use of perioperative warming for elective Caesarean delivery. Consequently routine warming of patients during Caesarean delivery is not widely practiced, despite almost all obstetric operating rooms having the capability to do so.[7]

Despite several studies investigating active warming during Caesarean delivery, there is still no consensus regarding whether

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Editor's key points

- Perioperative warming is recommended practice but rarely used for Caesarean section.
- This meta-analysis evaluated 13 randomized control trials of warming in 789 patients undergoing elective Caesarean section with neuraxial anaesthesia.
- Warming reduced temperature change, improved thermal comfort and other measures.
- Active warming for Caesarean delivery is suggested.

it improves maternal or neonatal outcomes. Studies have used different warming or anaesthetic techniques, variable ambient room temperatures, different durations of patient warming, diverse temperature measurement devices and various temperature measurement intervals, making interpretation of the effects of active warming difficult. This meta-analysis aimed to determine the effects of active warming (either fluid warming or forced air warming) on maternal temperature change and other maternal (temperature at the end of surgery, shivering, thermal comfort, hypothermia, vomiting, vasopressor use) and neonatal (temperature, umbilical cord pH and Apgar scores at 1 and 5 min) outcomes during and immediately after elective Caesarean delivery.

Methods

For this meta-analysis, we analysed randomized controlled trials comparing active warming techniques (specifically forced air warming or warmed fluid) to no warming before and during elective Caesarean delivery, and followed PRISMA guidelines.[8] We conducted a literature search with no language restriction on January 16, 2014 and repeated the search on August 27 and December 3, 2014. Searches were performed in PubMed (1950 to August 2014), Ovid EMBASE (1970 to December 2014), Ovid MEDLINE (1950 to December 2014), Scopus (1960 to December 2014), EBM Reviews Cochrane Central Register of Controlled Trials 2nd Quarter 2014, clinicaltrials.gov, and CINAHL (December 2014). We consulted the clinical trials registry (www.clinicaltrials.gov) on August 27, 2014 to identify any unpublished studies. The search strategy consisted of a combination of subject headings (obstetric, Caesarean) and keywords/ key phrases (temperature, warming, Caesarean) for each of MEDLINE, EMBASE, and CINAHL searched in specified fields (such as ti=title/ab=abstract). In the event that a database did not index articles, we conducted keyword searching in the entire record (see Appendix 1 for detailed PubMed search criteria). Reference lists of all identified studies were also checked.

All randomized controlled trials utilizing forced air warming or warmed fluid were considered. We included studies comparing groups that commenced warming from within 30 min of neuraxial anaesthesia placement up to and including warming in the post anaesthetic care unit. We excluded studies using general anaesthesia and other methods that may minimize perioperative hypothermia including various intrathecal opioid doses, leg wrapping, warmed intrathecal drugs, different anaesthetic techniques, and increased ambient temperature. Studies were also excluded if they did not report maternal or neonatal outcomes. The quality of studies included in the meta-analysis was reviewed using the Cochrane Collaboration's tool for assessing risk of bias.[9] Areas of methodological quality assessed included concealment of allocation, random sequence generation, blinding of the assessors and participants, and accounting for all subjects. Overall quality was graded as low (high risk of bias), high (low risk of bias), or unclear risk of bias for each domain entry using a standardized tool.[9] At least two individuals extracted the study data independently utilizing a standardized review protocol and recorded the information on a data collection sheet. Differences were resolved by re-examination of the original manuscripts and by discussion with a third investigator. The data were then entered into a computer by one of the authors (Y.C.) and checked by a second investigator (P.S.).

The primary outcome was the maximum temperature change in the perioperative period. For the purposes of this study, the perioperative period was defined as the time from 30 min before anaesthesia to 15 min after arrival on the post anaesthetic care unit.[10] Secondary outcomes included (1) temperature at the end of surgery or on admission to the post anaesthetic care unit (2) shivering (3) nausea and vomiting (4) thermal comfort (5) hypothermia (6) hypotension (7) vasopressor use (8) neonatal temperature at delivery (9) umbilical cord blood pH and (10) Apgar scores at 1 and 5 min.

Data were analysed using the Review Manager software (RevmanVersion 5.3.5 Copenhagen: the Nordic Cochrane Centre, The Cochrane Collaboration, 2014), CMA (comprehensive meta-analysis, Version 2, 2005),[11] and R routine metacont (R package Meta). We calculated pooled estimates for all studies combined and also performed a subgroup analysis according to warming modality used (forced air warming or fluid warming). We compared subgroups using the Q test. For dichotomous outcomes, the risk ratio (RR) and 95% confidence interval (CI) were calculated (a RR<1 favoured warming). In addition, the number needed to treat (NNT) was calculated for statistically significant dichotomous outcomes. For continuous data, the standardized mean difference (SMD) or mean difference (MD) and 95% CI were determined. The MD was used for all continuous outcomes except when the data available from the included studies were in different formats. This applied to the outcome of temperature change, where data was available either as a mean (SD) temperature change or as baseline temperature and post intervention temperature, and the outcome of thermal comfort where two different scales were used by the included studies. The percentage of heterogeneity was assessed with the I^2 statistic. Significant heterogeneity was assumed to be present if I^2>50%. For the primary outcome we explored significant heterogeneity, by performing sensitivity analyses, excluding studies with methodological differences according to type of neuraxial technique or site of forced air warming. Publication bias for the primary outcome was assessed using funnel plots and Egger's test. In case of funnel plot asymmetry, a contour-enhanced funnel plot was examined to further assess for publication bias. A P value <0.05 was considered statistically significant. All data were combined and analysed using the DerSimonian-Laird random effects model.

Results

The flow diagram of the study selection is provided in Fig. 1. We retrieved all 34 shortlisted articles that were identified from the literature search. Six additional publications found from reference lists of retrieved articles were added to the literature search results, only one of which was included in the final meta-analysis.[12] No additional unpublished positive or negative trials were identified on clinicaltrials.gov. The retrieved articles were examined by two authors (P.S. and B.C.) to assess eligibility for inclusion in the meta-analysis. Excluded studies are listed in Appendix 2. Thirteen articles met our inclusion criteria. Of the studies that met the inclusion criteria: 2 evaluated forced air warming;[13 14] 8 evaluated fluid warming;[12 15–21] 1 study utilized

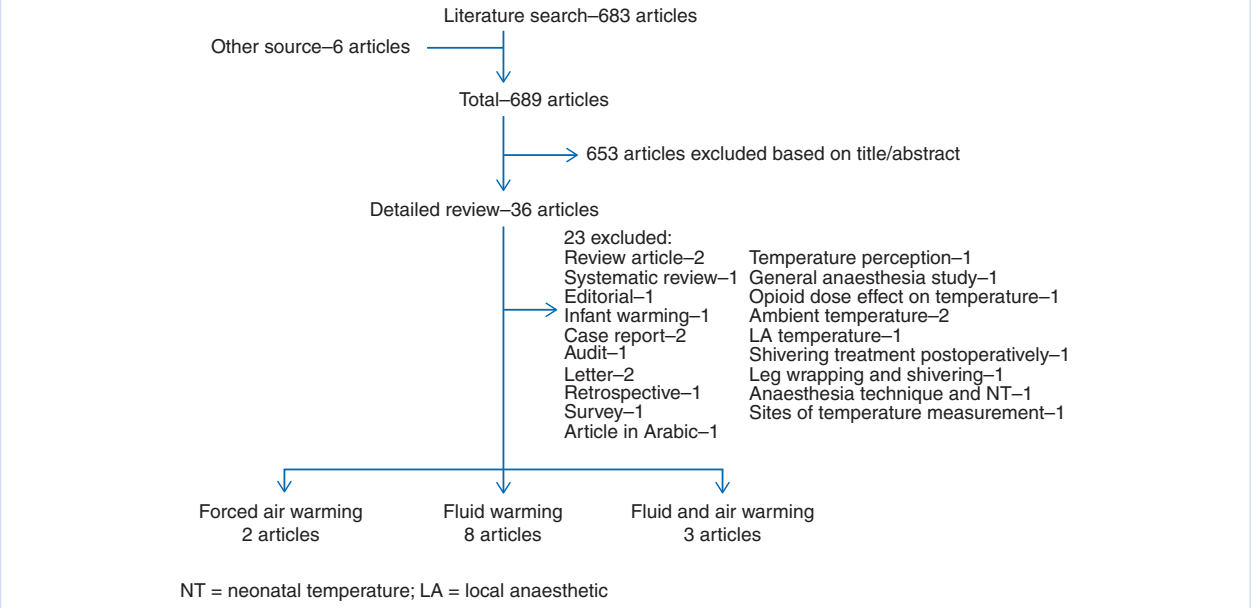

Fig 1 Literature search outlining included and excluded studies.

forced air warming for 15 min before anaesthesia with or without fluid warming;[22] and 2 studies utilized warmed fluids with or without forced air warming.[23 24] A total of 789 patients were recruited in all study groups (320 in the warmed fluids group, 96 patients in the forced air warming group, and 373 patients in the control groups). The methodology utilized in each study is summarized in Table 1. Temperatures of the warmed fluid groups among the studies ranged from 30 to 42°C.

Primary outcome

394 patients in the warmed groups and 366 patients in the control groups from 12 studies were analysed for the primary outcome (298 warmed fluid and 96 forced air warming *vs* 270 and 96 controls respectively). Overall warming significantly reduced maximum temperature change compared with control (SMD −1.27° C [−1.86, −0.69]; P=0.00002; Fig. 2). The risk-of-bias graph and contour-enhanced funnel plot for the primary outcome are shown in Figs 3 and 4 respectively. There was significant heterogeneity for the primary outcome (I^2=92%). The Egger's test suggests risk of publication bias (P=0.001). Examination of the contour-enhanced funnel plot also suggests that publication bias might be a plausible explanation for the funnel plot asymmetry.

Subgroup analysis according to method of warming (fluid warming or forced air warming) for the primary outcome

Fluid warming and forced air warming were both associated with a reduced temperature change compared with control groups receiving no warming (Fig. 2). There was no significant difference between the two warming modalities for this outcome (P=0.511).

In subgroup analysis according to warming method, there was significant heterogeneity in the fluid warming studies (I^2=94%) and the forced air warming studies (I^2=85%). The heterogeneity remained even when restricting analysis to only spinal anaesthesia in the fluid warming studies (I^2=88%) and forced air warming studies (I^2 80%).

For the forced air warming studies, excluding the epidural anaesthesia study[24] resulted in loss of statistical significance (SMD −0.7 [−1.4, 0.002]; P=0.05; I^2=78%), however, exclusion of the lower body warming study[14] (SMD −1.3 [−2.2, −0.36]; P=0.006; I^2 85%) or analysing studies utilizing only spinal anaesthesia resulted in statistical significance (SMD −0.9[−1.8, −0.09]; P=0.03; I^2 80%) being maintained.

Secondary maternal outcomes

Temperature at the end of surgery (or on arrival to the post anaesthetic care unit) was assessed in 10 studies (Table 2) and was found to be significantly higher in the warmed fluid group compared with the control group. Results for the effect of warming on shivering, hypothermia and thermal comfort are also demonstrated in Table 2. Twelve studies explored the incidence of shivering. Warming was associated with significantly less shivering (NNT=7) and a reduced incidence of hypothermia (NNT=5). Most studies defined hypothermia as <36°C, except for one which defined it as ≤35.5° C.[14] Thermal comfort was improved with forced air warming. Thermal comfort was measured in most studies as a VAS 0–100 scale (100=insufferably hot, 50=thermoneutral and 0=unimaginably cold), and one study utilized a −50 to +50 scale (−50=worst imaginable cold, 0=thermally neutral, +50=insufferably hot).[13] The study by Chung utilized a 0–100 scale (0 mm insufferably hot, 50 mm as thermally neutral and 100 mm as worst imaginable cold).[22] Two studies utilized a 0–10 scale,[18 23] but were not included in the analysis because of a lack of reporting of SD in one study[23] or only reporting the outcome in dichotomized form.[18] Both those studies reported improved thermal comfort with warming.

The remaining maternal outcomes and side effects are summarized in Table 2. Hypotension was evaluated in six studies. Two of these studies found no difference between groups but did not present the data.[13 14] Three studies neither presented nor commented on whether hypotension differed between groups.[12 16 22] Woolnough[18] defined intraoperative hypotension as >30% decrease from baseline systolic pressure;

Table 1 Summary of studies included in meta-analysis, OR operating room.

Author	Groups and method of warming	Other heating methods	Anaesthetic technique/dose	Temperature device
Butwick and colleagues[14]	Forced air warming (n=15) - placed over the upper thighs just distal to the inguinal fold (set to 43°C) Control group (n=15) - warming blanket only (switched off)	Both groups have cotton blanket covering warmer	Spinal: 12 mg bupivacaine + fentanyl 10 mcg + morphine 200 mcg	Oral digital thermometer (Medichoice, Portsmouth, VA)
Chan and colleagues[21]	Warmed fluid (n=21) - through a Fenwal blood warmer set at 36.5°C (no preload in either group), warmed cleaning solutions (38–42°C) and extra gowns, socks, blankets, covered as much as possible during epidural insertion and for the following 20 min Control group (n=19) – room temperature crystalloids, prep solution and single hospital gown. Epidural medications were room temperature		Epidural: 3 ml lidocaine with 1:200000 adrenaline test dose followed by titrated doses to T4-T6	Aural canal thermistors (Mon-A-Therm, Inc., St. Louis, MO) and temperature sensing Foley catheter in bladder
Chung and colleagues[22]	Forced air warming (n=15) - Bair hugger set at 43°C to upper body 15 min before spinal and room temperature fluid pre-load with 10 ml kg^{-1} Hartmann's solution pre-spinal. Warmed fluid (n=15) - from warming cabinet set at 37–38° C. Preload of 10 ml kg^{-1} Hartmann's solution Control group (n=15) – 10 ml kg^{-1} Hartmann's solution pre spinal at room temperature		Spinal: 10 mg hyperbaric bupivacaine	Core temp-thermoscan® (infrared tympanic thermometer IRT 4020; Braun, Bethlehem, PA, USA)
Fallis and colleagues[23]	Forced air warming (n=32) - Bair hugger set at 43°C to upper body until mother exited operating room Control group (n=30) warmed cotton blankets as needed	Both groups had warmed fluid from the warming cupboard set at 39°C.	Spinal: Local anaesthetic not stated; Intrathecal morphine 150 mcg Fentanyl 32±39 mcg in control; 14±4 mcg in warmed group	IVAC TempPLUS II electronic thermometer (Alaris Medical Systems, San Diego, CA)
Goyal and colleagues[15]	Warmed fluid (n=32) - through a Asotherm plus AP220 Futuremed fluid warmer set at 39°C Control (n=32) – fluids at OR temperature (22°C) Both groups preloaded with 10 ml kg^{-1} 0.9% Normal Saline		Spinal: 2.5 ml heavy bupivacaine 0.5%	Tympanic membrane thermometer - model not presented
Horn and colleagues[24]	Forced air warming (n=15) - Bair hugger set to 43°C over upper body 15 min before epidural insertion. Control group (n=15) - Single cotton blanket	All patients received warmed fluids to 37°C (device not stated)	Epidural: 3 ml ropivacaine 0.75% test dose then 4 ml boluses until block to T4 bilaterally (no opioids)	Tympanic membrane temp Mon-a-Therm thermocouples (Mallinckrodt Anesthesiology Product, Inc., St. Louis, MO)

Continued

Table 1 *Continued*

Author	Groups and method of warming	Other heating methods	Anaesthetic technique/dose	Temperature device
Horn and colleagues[14]	Forced air warming (n=19) - Level 1 Equator warmer over upper body immediately set to 44°C after spinal Control group (n=21) – pre warmed cotton blankets taken from 40°C heating cabinet		Spinal: 1.4 to 1.6 ml 0.5% bupivacaine + sufentanil 5 mcg	Skin temperature on chest of mother (Infrared Temperature Scanner, Model Dermatemp DT-1001, Exergen Corporation, Watertown, MA). Sublingual temperature probe (Temp-Plus II, Model 2080, Alaris™; Carefusion, San Diego, CA) into posterior sublingual pocket
Jorgensen and colleagues[17]	Warmed fluid (n=57) – 37°C stored in thermostat control. Preload (20 ml kg^{-1} during the 15 min preceding spinal injection) and maintenance (10 ml kg^{-1} during the 20 min after spinal injection) Control group (n=56) - 21°C fluid. Volumes as with warmed group		Spinal: 2.7 ml bupivacaine 0.5%	Not described
Paris and colleagues[16]	Warmed fluid (n=73) - fluid warmed to 41°C via infusion pump and fluid warmer. Three fluid warmers utilized for study (type and manufacturer not stated) Control group (n=76) - one warm blanket applied to lower extremities and one warm blanket applied across maternal upper chest and arms		Not stated	Temperature sensing Foley catheters (make and manufacturer not stated)
Smith and colleagues[12]	Warmed fluid (n=35) - via Hotline, set point 42°C Control group (n=32) – room temperature fluids at 20–22°C		Spinal lidocaine or bupivacaine or epidural lidocaine to achieve block to T4-T6 (technique not dictated by protocol)	Mon-a-therm thermocouple temperature probes (Mallinkrodt Medical Inc, St Louis MO) at tympanic membrane
Woolnough and colleagues[7]	Warmed fluid - either from: a) Warmed cabinet (n=25) set at 45°C (distal end 37–38°C) b) Hotline (n=25; Smiths Medical) set to 42°C Control group (n=25) - fluid through Hotline warmer switched off		Spinal: 2.3 ml bupivacaine 0.5% + diamorphine 350 mcg	Infrared tympanic thermometer (ThermoScan Exac-Temp, Braun, Weybridge, UK)
Workhoven and colleagues[19]	Warmed fluid (n=22) – from heated cabinet and administered immediately 30–33.9°C Control group (n=22) – fluid at room temperature Both groups received 1Litre Hartmann's solution over 10–15 min		Epidural: 2% lidocaine with epinephrine 1:200000. 3 ml test dose + 17–22 ml, small doses of fentanyl and thiopental or both given pre and post-delivery for sedation as necessary	Oral temperature (device not stated)
Yokoyama and colleagues[20]	Warmed fluid (n=15) – heated for 3 days at 41°C and then infused through i.v. tube warmer coil at 38°C Control group (n=15) - fluid maintained at room temperature (25°C) Both groups received preload of 400 mls Hydroxyethlated starch	All patients had reflective blanket on shoulders, upper extremities and lower extremities	Spinal: 12.5 mg hyperbaric bupivacaine; 0.5 mg midazolam after delivery	Thermocouple probe (Monatherm; Covidien, Mansfield, MA)

Temperature Change

Group by Subgroup within study	Study name	Std diff in means	Warming Method	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value	Active Warming	Control
Fluid	Chung	−0.750	Fluid	0.378	0.143	−1.490	−0.010	−1.985	0.04711	15	15
Fluid	Goyal	−0.587	Fluid	0.255	0.065	−1.087	−0.086	−2.297	0.02159	32	32
Fluid	Woolnough	−0.919	Fluid	0.256	0.066	−1.421	−0.417	−3.587	0.00033	50	25
Fluid	Yokoyama	−3.922	Fluid	0.624	0.390	−5.146	−2.699	−6.283	0.00000	15	15
Fluid	Chan	−1.806	Fluid	0.376	0.141	−2.542	−1.070	−4.809	0.00000	21	19
Fluid	Jorgensen	−0.142	Fluid	0.188	0.035	−0.511	0.228	−0.752	0.45227	57	56
Fluid	Smith	−4.000	Fluid	0.423	0.179	−4.830	−3.170	−9.448	0.00000	35	32
Fluid	Paris	−0.170	Fluid	0.164	0.027	−0.491	0.152	−1.033	0.30161	73	76
Fluid		−1.428		0.381	0.145	−2.175	−0.682	−3.751	0.00018		
Forced Air	Butwick	−0.000	Forced Air	0.365	0.133	−0.716	+0.716	−0.000	1.00000	15	15
Forced Air	Chung	−1.131	Forced Air	0.393	0.155	−1.902	−0.361	−2.877	0.00402	15	15
Forced Air	Fallis	−0.222	Forced Air	0.255	0.065	−0.721	0.278	−0.870	0.38451	32	30
Forced Air	Horn 2002	−2.374	Forced Air	0.477	0.227	−3.309	−1.440	−4.980	0.00000	15	15
Forced Air	Horn 2014	−1.537	Forced Air	0.360	0.130	−2.243	−0.831	−4.267	0.00002	19	21
Forced Air		−1.023		0.485	0.236	−1.974	−0.071	−2.107	0.03514		
Overall		−1.274		0.300	0.090	−1.861	−0.687	−4.251	0.00002		

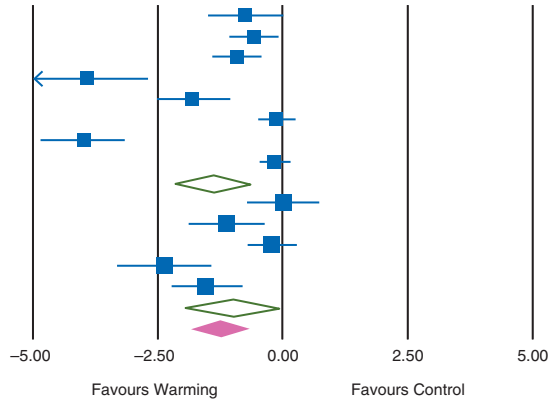

Fig 2 Forest plots of the primary outcome of maximum core temperature change.

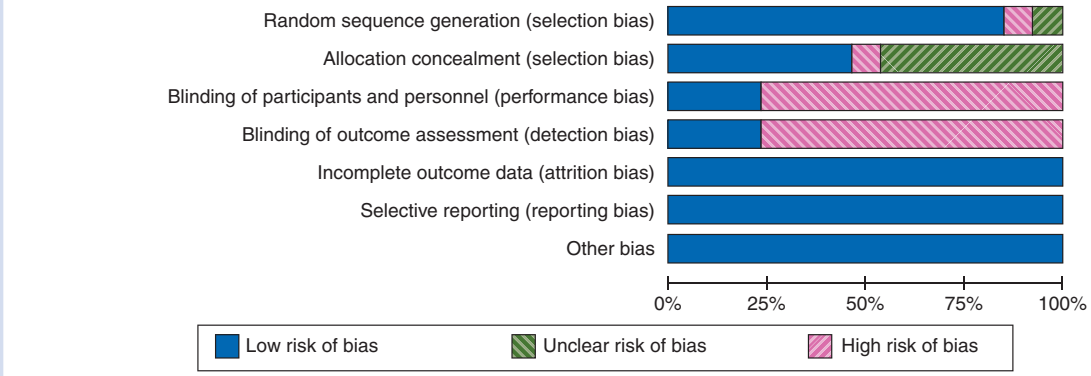

Fig 3 Risk of bias figure for primary outcome of maximum temperature change.

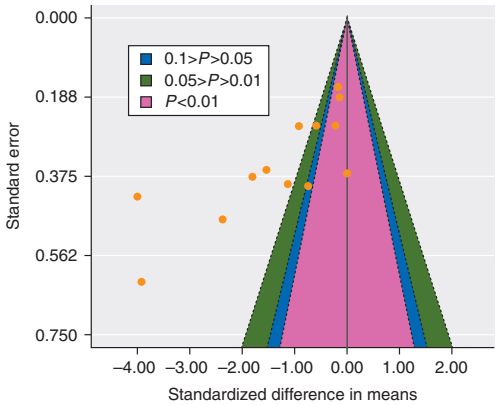

Fig 4 Contour-enhanced funnel plot for primary outcome of maximum temperature change.

Yokoyama[20] defined hypotension as SBP below 90 mm Hg; Workhoven[19] defined hypotension as <20% of preoperative baseline or SBP <100 mm Hg; and Jorgensen[17] defined hypotension as SBP less than 30% of baseline or <100 mm Hg. For the studies analysed in this meta-analysis, warming did not significantly reduce the incidence of hypotension, vomiting or requirement for vasopressor.

Neonatal outcomes

Neonatal outcomes are shown in Table 2. Neonatal temperature at delivery was not significantly higher with active maternal warming. Umbilical vein blood pH was not significantly different in the warmed groups, however umbilical artery pH was significantly higher in the warmed group with a mean difference in pH of 0.02 [0.00–0.05]. Apgar scores at 1 and 5 min were not significantly higher in the warmed groups and incidence of Apgar score <7 was not significantly different in the warmed group.

Subgroup analysis according to method of warming (fluid warming or forced air warming) for secondary outcomes

Temperature at the end of surgery was significantly higher with the use of fluid warming (0.46°C), but not forced air warming (0.39°C) when compared with control groups ($P<0.00001$ and 0.09 respectively). Fluid warming was associated with significantly less shivering (NNT=7), whereas forced air warming did not result in significant reduction of shivering incidence compared with controls. Hypothermia was significantly reduced in fluid warming (NNT=5) group but not forced air warming group compared with control. Neonatal outcomes were not different with either warming method compared with controls.

Forest plots of maternal shivering, maternal thermal comfort, maternal hypothermia and umbilical artery pH are available as supplementary material online.

Discussion

The main finding of this study is that the magnitude of the perioperative decrease in temperature was smaller when active warming was used for elective Caesarean delivery (SMD –1.27°C [–1.86, –0.69]; $P=0.00002$). We feel that this effect size is clinically significant because a mean temperature change of 1.27 degrees is more than two times greater than normal physiological variation in temperature (plus or minus 0.5 degrees). A change in temperature of this magnitude would therefore result in a greater number of patients becoming hypothermic (perioperative hypothermia is usually defined as core temperature less than 36 degrees).[5] Active warming also decreases the incidence of hypothermia, reduces shivering, increases the temperature at the end of surgery or on arrival to the post anaesthetic care unit, and improves thermal comfort when compared with no active warming.

The maximum change in temperature was chosen as our primary outcome for several reasons. The maximum temperature decrease is likely to be the most important clinical outcome linked to the harmful effects of hypothermia, such as perioperative coagulopathy, blood loss, and myocardial ischaemia. We also felt that this outcome would be measured in the majority of studies included in the analysis. The difference in starting or baseline temperature and the duration of surgery were also accounted for, by using this outcome rather than temperature at the end of surgery, or on admission to the post anaesthetic care unit. Maximum temperature decrease as an outcome also accounts for any further temperature changes from the end of surgery to admission to the post anaesthetic care unit. Additionally the temperature in the postoperative care unit reflects the Association of Anaesthetists of Great Britain and Ireland (AAGBI)[25] and Centers for Medicare and Medicaid Services (CMS) guidelines of when temperature should be measured. Key related maternal secondary outcomes such as temperature at the end of surgery, incidence

Table 2 Summary of maternal and neonatal outcomes. F, Fluid warming; A, Forced air warming; C, combined results; N, number of studies analysed; MD, mean difference; RR, risk ratio; n/a, not applicable; *statistically significant ($P<0.05$)

Outcome	Fluid/Air/Combined	N	MD/RR	Value [95% CI]	P-value	Heterogeneity (I^2)
End of surgery temperature	F	6	MD	0.46 [0.28, 0.64]	<0.00001*	88
	A	4		0.39 [−0.06, 0.84]	0.09	90
	C	10		0.43 [0.27, 0.59]	<0.00001*	88
Shivering	F	8	RR	0.60 [0.42, 0.85]	0.004*	40
	A	5		0.50 [0.25, 1.00]	0.05	30
	C	12		0.58 [0.43, 0.79]	0.0004*	32
Thermal comfort	F	0				
	A	4	SMD	0.90 [0.36, 1.45]	0.001*	54
	C					
Hypothermia	F	3	RR	0.68 [0.55, 0.86]	0.001*	23
	A	2		0.35 [0.03, 3.56]	0.37	81
	C	5		0.66 [0.50, 0.87]	0.003*	41
Vomiting	F	1	RR			
	A	1				
	C	2		1.57 [0.20, 12.14]	0.67	0
Hypotension	F	4	RR	1.06 [0.79, 1.44]	0.69	0
	A	0				
	C					
Vasopressor use	F	3	MD	4.44 [−2.62, 11.50]	0.22	0
	A	0				
	C					
Neonatal temperature at delivery	F	2	MD	0.06 [−0.12, 0.25]	0.49	52
	A	3		0.19 [−0.24, 0.62]	0.39	92
	C	5		0.11 [−0.09, 0.31]	0.27	84
Umbilical artery pH	F	2	MD	0.02 [−0.01, 0.05]	0.11	60
	A	1		0.04 [−0.17, 0.25]	0.7	n/a
	C	3		0.02 [0.00, 0.05]	0.04*	20
Umbilical vein pH	F	2	MD	0.00 [−0.04, 0.04]	0.87	73
	A	4		0.02 [−0.04, 0.07]	0.57	86
	C	5		0.01 [−0.02, 0.04]	0.57	79
Apgar 1 min	F	2	MD	−0.11 [−0.80, 0.59]	0.76	0
	A	3		−0.25 [−0.59, 0.10]	0.17	0
	C	4		−0.22 [−0.53, 0.09]	0.17	0
Apgar 5 min	F	0				
	A	2	MD	−0.03 [−0.13, 0.07]	0.54	0
	C					
Apgar <7 at 1/5 min	F	2	RR	0.35 [0.01, 8.38]	0.51	n/a
	A	1		0.33 [0.01, 7.58]	0.49	n/a
	C	3		0.34 [0.04, 3.16]	0.34	0

of hypothermia and shivering demonstrated similar improvements with the use of warming.

Subgroup analysis showed that both fluid and forced air warming significantly reduced the maximum change in temperature. The aim of the meta-analysis was to examine the benefit of both active warming modalities. Although only fluid warming (not forced air warming) showed a statistically significant reduction in the incidence of hypothermia, shivering and temperature at the end of surgery in the studies evaluating these outcomes, we cannot definitively conclude that fluid warming is better than forced air warming, as they were not directly compared with each other in this meta-analysis. The temperature results at the end of surgery for forced air warming should be interpreted with caution as the confidence intervals for this outcome are wide and the effect size is small (0.39°C). The lack of statistical significance with forced air warming might be as a result of the small number of patients included in this comparison. The results of these subgroup analyses should be regarded as observational in nature and interpreted with caution. The only study that included fluid warming and air warming arms did not demonstrate a difference between the groups.[22] Future studies are needed to explore the optimal warming technique (fluid or air warming) and to evaluate whether utilizing a combination of techniques offers an advantage over a single modality. This meta-analysis suggests that either warming technique offers some benefit compared with no warming.

Heat loss during Caesarean delivery performed under regional anaesthesia occurs through several mechanisms. In the first hour, vasodilation below the level of the sensory block results in heat loss, secondary to decrease of core-periphery temperature gradient and subsequent redistribution of blood.[26 27] Neuraxial anaesthesia also results in a reduction of thermoregulatory vasoconstriction and shivering thresholds above the level of the block by approximately 0.5°C.[28–30] Vasoconstriction above the level of the dermatomal block does not appear to prevent decreases in core temperature.[31] Air warming acts through peripheral conduction and convection by increasing skin temperature, whereas fluid warming acts through peripheral and central conduction and is

associated with a shorter distribution time throughout the body. Unless utilized for a sufficient period of time preoperatively (as utilized in study by Horn and colleagues[24]), air warming may not be effective at preventing the initial temperature decrease, caused by redistribution of blood associated with neuraxial anaesthesia. After spinal anaesthesia we would expect vasoconstriction above the sensory block level and vasodilation below the level of sympathectomy. Therefore lower body air warming may theoretically be more effective at preventing heat loss than upper body warming, because of its action on the areas of the body with greatest loss of core-periphery temperature gradient and redistributive heat loss. However the only study investigating lower body warming did not show a benefit with warming.[14] Subgroup analysis of forced air warming in using only spinal anaesthesia studies, demonstrated significant differences when only upper body warming studies were analysed.

Fluid warming would be expected to reduce the magnitude of any decrease in core temperature and reduce the degree of heat loss from core-periphery redistribution. Women undergoing Caesarean delivery often receive greater volumes of i.v. fluid when compared with the intraoperative requirements of patients from other surgical specialities. As a result of the common practices of preloading or co-loading to minimize spinal hypotension, patients undergoing Caesarean delivery may receive between 2–3 litres of crystalloid intra-operatively. Fluid warming may therefore be particularly effective in the Caesarean delivery setting because of the relatively high fluid volumes infused. Further studies are required to compare a combination of air warming and fluid warming against single modalities, to determine the optimal protection strategy of preventing hypothermia in the setting of Caesarean delivery under spinal anaesthesia.

In terms of thermal comfort, only forced air warming studies were analysed, as no fluid warming studies reported this outcome. Thermal comfort score is a subjective measure of patient comfort related to perioperative temperature, unlike actual temperature measurement or observation of shivering. The psychological effect of the use of forced air warming on thermal comfort scores warrants further exploration. Some regard forced air warming as intrusive and anxiety provoking,[18] whereas our results suggest that patients report improved thermal comfort with its use. Subgroup analysis of thermal comfort with the exclusion of the lower body warming study for example, resulted in reduced heterogeneity (I^2 from 67 to 0%), and the result remained statistically significant.

We found no significant differences in neonatal outcomes when comparing active warming to no warming, with the exception of umbilical artery blood pH. The pH in the combined warmed groups was modestly different (0.02 [0.00–0.05]). However as it is a mean effect demonstrated in over 209 patients, it could potentially be important for some individual patients. For example neonates with pre-existing fetal compromise (borderline arterial acidaemia) at the time of elective Caesarean delivery may benefit from maternal active warming. The mechanism for the difference demonstrated in umbilical artery pH is unclear, but may be as a result of maternal decreases in pH generated from shivering which are subsequently transferred to the fetus. Several studies did not measure neonatal outcomes, and most studies were underpowered to demonstrate these differences. Therefore neonatal outcome results in this meta-analysis should be interpreted with caution. Larger studies specifically powered to observe differences in neonatal outcomes are still required.

A survey in 2009 demonstrated that while approximately 95% of departments within the UK have the equipment to warm patients, only 8% of departments have specific guidelines for temperature management during elective Caesarean delivery, and only 16% of units actually warm women (utilizing a variety of methods including warmed mattress, forced air warming and fluid warming).[7] As only a minority of departments currently warm patients during Caesarean delivery, the introduction of routine active warming would require a widespread change of practice.

There are several limitations to this study. There was significant heterogeneity for many of the study outcomes. In order to explore this heterogeneity we conducted subgroup analyses in an attempt to account for different methods of anaesthesia and techniques of warming. Comparing lower and upper body warming to control groups, did not appear to significantly alter the heterogeneity or statistical significance of results. Similarly the fluid warming groups revealed high heterogeneity whether or not the analysis was spinal or epidural anaesthesia, although overall results remained the same in these sensitivity analyses.

There were also differences between studies with regards to warming equipment used to achieve warming. The temperature at the point of fluid entry to patient was also not always recorded in studies. There were a variety of anaesthesia techniques, neuraxial local anaesthetic agents and opioid combinations administered (Table 1). The thresholds utilized for vasopressor therapy administration, fluid volumes given, and ambient temperatures within operating room and the post anaesthetic care unit, also varied among the included studies. There were a variety of temperature measurement techniques used and different sites of measurement which are known to affect temperature readings.[32] There are little data comparing the method of temperature measurement on readings so the impact of this on our results is not clear. Timing and duration of warming also varied among studies including warming, pre-anaesthesia, post-anaesthesia and throughout anaesthesia and surgery. Variations also existed between studies with regards to the definition of hypothermia. The heterogeneity observed in this meta-analysis suggests that research methodology and measurement standardization is required for future studies evaluating the impact of perioperative warming. Publication bias as already outlined should also be considered as a potential confounding factor in this meta-analysis. The positive result from the Egger's test must however be interpreted with caution, as the number of studies was limited and there was significant heterogeneity.[33] While there are other reasons for funnel plot asymmetry, examination of the contour-enhanced funnel plot suggests that publication bias is a plausible explanation for this asymmetry. Blinding in warming studies is inherently difficult. While blinding was attempted in several studies,[14 18 20] the warming device may have been audible or visible to participants and outcome assessors, making true blinding almost impossible. An advantage of assessing temperature as a primary outcome, however, is that temperature is an objective rather than subjective measure which reduces interpretation bias.

In summary, based on the results from this meta-analysis we recommend that active warming should be used for elective Caesarean delivery in order to minimize decreases in maternal temperature, reduce the incidence of hypothermia and shivering, and improve thermal comfort. Despite clear differences in maternal temperature and shivering outcomes, active warming does not seem to impact neonatal outcome. Publication bias could be a confounding factor influencing the findings of this study. Further studies are needed to determine which warming modality is more effective, and whether the combination of warming techniques is more effective than utilizing a single method. The optimal method of fluid and air warming (lower or upper

body) warming, and the duration and optimum time to initiate these interventions also warrant further study.

Authors' contributions

Study design/planning: P.S., A.S.H., Y.C., B.C.
Study conduct: P.S., A.S.H., Y.C., B.C.
Data analysis: A.S.H.
Writing paper: P.S., A.S.H., Y.C., B.C.
Revising paper: all authors

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online.

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Declaration of interest

None declared.

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Appendix 1 – PubMed search strategy

1. ('temperature'[Supplementary Concept] OR 'warming'[Mesh])
2. ('obstetric'[Mesh] OR 'caesarean' [Mesh] OR 'cesarean'[Mesh])
3. (((random*[tiab] OR placebo*[tiab] OR controls[tiab] OR control [tiab] OR controlled[tiab] OR trial[ti] OR 'double blind'[tiab] OR blinded[tiab] OR 'single blind'[tiab] OR 'clinical trial'[tiab] OR 'clinical trials'[tiab] OR ((singl*[tiab] OR doubl*[tiab] OR trebl* [tiab] OR tripl*[tiab]) AND (mask*[tiab] OR blind*[tiab])) OR 'latin square'[tiab] OR prospectiv*[tiab] OR volunteer*[tiab]) NOT medline[sb]) OR ((randomized controlled trial[pt] OR controlled clinical trial[pt] OR random*[tiab] OR placebo [tiab] OR 'clinical trials as topic'[mesh] OR trial[ti])).

Appendix 2 – List of excluded studies (from Figure 1)

Review article (2) – Carpenter 2012[34], Baston 2001,[32]
Systematic review (1) – Munday 2014[35]
Editorial (1) – Halloran 2009[36]
Infant warming (1) – Boo 2005[37]
Case report (2) – Usman 2007,[38] Valente 2008[39]
Audit (1) – Chakladar 2010[40]
Letter (2) – Petsas 2009,[41] Sims 1993[42]
Retrospective (1) – Munn 1998[43]
Survey (1) – Woolnough 2009[7]
Temperature perception (1) – Glosten 1992[44]
Opioid dose effect on temperature (1) – Hui 2006[45]
Ambient temperature (2) – Kent 2008,[46] Pribylova 1970[47]
Local anaesthetic temperature (1) – Ponte 1986[48]
Shivering treatment postoperatively (1) – Sharkey 1993[49]
Leg wrapping and shivering (1) – Sun 2004[50]
Anaesthesia technique and neonatal temperature (1) – Yentur 2009[51]
Sites of temperature measurement (1) – Larue 1991[52]
General anaesthesia study (1) – Oshvandi 2014[53]
Article in Arabic (1) – Oshvandi 2011[54]

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