Meta-analysis: effectiveness of forced-air warming for prevention of perioperative hypothermia in surgical patients

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Abstract

Aim. The aim of this study was to evaluate the effectiveness of forced-air warming for preventing perioperative hypothermia.

Background. Perioperative hypothermia commonly occurs in patients receiving anaesthesia during surgeries. However, the effectiveness of warming systems requires verification.

Design. Systematic review incorporating meta-analysis.

Data sources. We searched OVID, PubMed, Cochrane Library, Medline, CINAHL, CETD and CEPS databases (2001-2015) for randomized controlled trials published in English and Chinese. Outcome measures of interests were body temperature and thermal comfort.

Review methods. Cochrane methods, Quality of evidence (GRADE) assessments and Jadad Quality Score were used.

Results. Twenty-nine trials (1875 patients) met inclusion criteria, including seven trials (502 patients) related to thermal comfort. Results showed that: (1) forced-air warming was more effective than passive insulation and circulating-water mattresses; (2) there was no statistically significant difference among forced-air warming, resistive heating blankets, radiant warming systems and circulating-water garments; and (3) that thermal comfort provided by forced-air warming was superior to that of passive insulation, resistive heating blankets and radiant warming systems, but inferior to that of circulating-water mattresses.

Conclusions. Forced-air warming prevents perioperative hypothermia more effectively than passive insulation and circulating-water mattresses, whereas there is no statistically significant difference in its effectiveness compared with circulating-water garments, resistive heating blankets and radiant warming systems.

Keywords: body temperature, forced-air warming, hypothermia, meta-analysis, nursing, perioperative care, systematic review, thermal comfort
Perioperative hypothermia, defined as a body core temperature lower than 36°C (Al-Qahtani & Messahel 2011) remains common, occurring in up to 70% of patients undergoing anaesthetic surgical procedures. In particular, perioperative hypothermia is frequently observed in association with skin, thoracic, abdominal and bone marrow cavity surgeries, because these parts/organs contain a great number of peripheral thermal receptors (Long et al. 2013).

Perioperative hypothermia may be caused by multiple factors, such as low ambient temperature in the operating room, inhibition of thermoregulation induced by anaesthesia, exposure of the patient’s body cavities to a cold environment and a lack of pre-warming processes for injection and flushing/lavage solutions (Al-Qahtani & Messahel 2011, Hart et al. 2011, Horosz & Malec-Milewska 2013). Perioperative hypothermia commonly occurs among patients who are older than 70 years; who have a preoperative systolic blood pressure < 140 mmHg, low basic mass index, diabetes, or immune deficiency; and whose surgeries require a long operation time. However, insufficient warming may result in core body temperature falling by 2–6°C (Horosz & Malec-Milewska 2013) and surgical complications (Chiang et al. 2014, Harder et al. 2013, Long et al. 2013), which are caused by reduced thermal comfort in patients (Benson et al. 2012). Therefore, it is essential to use sufficient insulation and warming devices for perioperative patients (Alderson et al. 2014).

In clinical practice, passive insulation and active warming systems have been often used to prevent hypothermia during anaesthesia in surgery. The perioperative hypothermia guidelines of the National Institute for Health and Clinical Excellence (2011) indicated that forced-air warming (FAW) can be used to prevent perioperative hypothermia in patients under surgical procedures (Radauceanu et al. 2009). Previous systematic studies on the effectiveness of warming systems (Galvão et al. 2009, Poveda et al. 2012, de Brito Poveda et al. 2013, Roberson et al. 2013) stated that circulating-water garments (CWG) are more effective than FAW during surgeries (Galvão et al. 2009, Poveda et al. 2012), but others have argued that preoperative application of FAW is more effective than other methods at preventing perioperative hypothermia (de Brito Poveda et al. 2013). However, no recent meta-analysis has been conducted to verify the effectiveness of various warming systems. Indeed, most previous studies did not examine the thermal comfort of patients who used warming devices. Without providing proper warming intervention or equipment during preoperative process, hypothermia will last for several hours and result in more complications and discomfort. Therefore, nurses should help warm the patient’s temperature to at least 36°C and carefully consider the comfort of patients undergoing surgical procedures (Vallet et al. 2013).

To address these questions, we examined the effectiveness and thermal comfort of FAW for prevention of perioperative hypothermia through a systematic literature review and meta-analysis. We hope this review can be a reference for clinical nurses in providing more effective, safe and comfortable perioperative warming methods for patients undergoing surgical procedures. It may also useful for nurses in increasing the quality of perioperative patient care and improving their discomfort.

### Background

Core temperature is controlled by the hypothalamic thermoregulatory centre, which is regulated by a negative feedback mechanism. The normal core temperature of adults is maintained at 37 (± 0.5)°C at the head and trunk, with a fluctuation of 0.2°C (Sessler 2013). The effect of general anaesthesia on core body temperature can be divided into three stages: Phase I, the redistribution phase; Phase II, the heat loss phase and Phase III, the plateau phase (Horosz & Malec-Milewska 2013). Previous research has indicated that perioperative hypothermia may lead to surgical wound
infection, poor prognosis, myocardial ischaemia, extended metabolism of anaesthetics, prolonged bleeding, prolonged shivering and discomfort (Benson et al. 2012, Chiang et al. 2014, Harder et al. 2013, Jeyadoss et al. 2013, Long et al. 2013); accordingly, perioperative hypothermia requires close attention. Thermal comfort includes a subjective sensation of feeling secure or protected when an individual has meaningful relationships, successful maintenance of body functions and relief from physiological discomforts (Md Din et al. 2014). Thermal comfort can be achieved when pain, vomiting, hypothermia and shivering are relieved; when individuals can fully express their feelings and receive proper care; and when feelings of complications, anxiety and uncertainty are alleviated (Md Din et al. 2014, Krinsky et al. 2014). A recent study reported that 71% of surgical patients expressed that they felt very cold in the operation room and requested warming support in the postanaesthesia care unit (PACU). This indicates that the majority of patients feel cold during anaesthesia and surgery. Therefore, healthcare workers should actively provide insulation/warming devices to improve patients’ thermal comfort and satisfaction (Wasfie & Barber 2015).

To prevent hypothermia, Al-Qahtani and Messahel (2011) recommend using multiple active warming techniques, such as FAW, circulating-water mattresses (CWM), CWG, resistive heating blankets (RHB), radiant warming systems (RWS) and pre-warming of intravenous infusions or lavage solutions (John et al. 2014). The mechanisms underlying these methods vary considerably. FAW prevents heat loss on the basis of radiation and conduction; hot air is generated by a motor and delivered to the forced-air blanket through a hose, thus raising peripheral tissue temperature and reducing core heat loss and blood cooling rate (Bräuer & Quintel 2009). The RHB system is based on the principle of metal electrical conduction; a heating element directly converts the electrical current into heat energy (Tanaka et al. 2013). In RWS, heat from a light source is radiated to a particular site and warms the surrounding air; a safe distance for RWS use is 80 cm (Kadam et al. 2009). CWM involves a pad connected to a circulating pump and electric heating chamber, which maintains temperature using hot water circulation. The underlying mechanism of CWG is similar to that of CWM; however, CWG uses a water-circulating garment that allows coverage of different parts of the body.

According to the literature, there is a long history of using warming devices to prevent perioperative hypothermia (Warntig et al. 2014). Recently, several randomized studies reported varying effectiveness of different warming techniques. Two trials suggested that FAW is superior to passive insulation (PI) warming (De Witte et al. 2010, Pu et al. 2013), while three trials showed no difference between these two methods (Negishi et al. 2003, Fallis et al. 2006, Nicholson 2013). No difference between FAW and RHB was detected in three trials (Negishi et al. 2003, Ng et al. 2003, Brandt et al. 2010, Egan et al. 2011, Tanaka et al. 2013). Only one trial demonstrated that FAW was superior to RWS (Lee et al. 2004) and two trials found no difference between the two methods (Wong et al. 2004, Torrie et al. 2005). In addition, four trials reported that FAW is superior to CWG (Melling et al. 2001, Matsuzaki et al. 2003, Negishi et al. 2003, Ihn et al. 2008), while another trial found no difference between the two methods (Hasegawa et al. 2012). Two trials proposed that FAW is superior to CWG (Janicki et al. 2002, Insler et al. 2008), whereas Zangrillo et al. (2006) concluded that CWG is superior to FAW.

To date, there is only one published meta-analysis evaluating the performance of different warming systems (FAW, PI, RWS and CWG) in surgical patients during the perioperative period (Galvão et al. 2010); however, it did not include RHB and CWM. Based on analysis of 23 trials (1749 patients), this previous study concluded that the effectiveness of FAW was superior to that of PI (mean difference: 0.29°C; 95% confidence interval [CI]: 0.02-0.59; three trials, 292 patients) and RWS (mean difference: 0.16°C; 95% CI: 0.01-0.33; three trials, 161 patients), but inferior to that of CWG (mean difference: 0.73°C; 95% CI: 1.51-0.05, I² = 97%; four trials, 198 patients). However, due to a lack of robust data comparing the effectiveness and thermal comfort provided by different insulation/warming techniques, the most effective techniques have not yet been identified. Therefore, it is necessary to conduct a meta-analysis to evaluate the overall effect of various insulation/warming systems, thus assisting practitioners in making an appropriate selection in clinical practice.

The review

Aim

The aim of this meta-analysis was to analyse the data regarding the effectiveness of FAW compared with other methods of preventing perioperative hypothermia and providing thermal comfort in surgical patients.

Design

We followed the procedures of the Cochrane Collaboration meta-analysis proposed by Higgins and Green (2006). The analysis included five steps: identifying a clinical topic for
retrogressive analysis, searching databases for relevant literature, establishing inclusion and exclusion criteria, systematically extracting relevant data and conducting meta-analyses/drawing conclusions. Two investigators were independently involved in each step and cross-checked the quality of the included trials to ensure accuracy.

Search methods

The searched English and Chinese databases included OVID, PubMed, Cochrane Library, Medline, CINAHL, Chinese Electronic Theses and Dissertations Service (CETD) and Chinese Electronic Periodical Services (CEPS). The search terms were ‘perioperative hypothermia’ and ‘active warming system’ or ‘warming devices’ and ‘comfort’. The relevant hard copies and reports were manually screened.

The relevant literature was screened for randomized experimental studies. Other inclusion criteria were as follows: (1) all participants were older than 18 years of age and had perioperative hypothermia; (2) description of the insulation/warming intervention used, such as cotton blankets, FAW, CWM, CWG, RHB or RWS; (3) measurement of core temperature (tympanic, oesophageal, anal or oral) and thermal comfort. Studies irrelevant to perioperative hypothermia, monographs or literature review articles were excluded.

Search outcome

Among 751 papers obtained through database searching, 36 trials (Table 1) were selected for analysis after excluding 627 non-clinical or non-human trials, 27 trials with participants younger than 18 years, 39 trials irrelevant to the insulation/warming intervention used, such as cotton blankets, FAW, CWM, CWG, RHB or RWS; (3) measurement of core temperature (tympanic, oesophageal, anal or oral) and thermal comfort. Studies irrelevant to perioperative hypothermia, monographs or literature review articles were excluded.

Quality appraisal

To avoid literature selection bias, two trained independent reviewers assessed the quality of trials using the evaluation table of Campbell et al. (2015) and JQS (Jadad et al. 1996). The quality of trials was assessed based on three aspects: (1) randomized trial study; (2) double-blinded and (3) full information of reasons for withdrawals and dropouts during the follow-up period. The minimum and maximum scores of each aspect were 0 and 2, respectively. Consistency between the two reviewers was evaluated through Kappa analysis using SPSS 22 software.

Data abstraction

Data were abstracted by two reviewers using a validated data extraction form according to the standard of Cochrane Collaboration and Meta-Analysis guidelines (Stroup et al. 2000). These data included details of the study methods, participants, authors’ countries, intervention groups and control groups, intervention time, type of surgery, temperatures during the perioperative period, PACU thermal comfort, type of anaesthesia and risk of bias (Table 1); the mean intraoperative (operating room oesophageal, nasopharyngeal or rectal) and postoperative (PACU tympanic, oral or rectal) temperature was calculated and presented by quality of evidence (GRADE) assessments (Table 2).

Synthesis

Comprehensive Meta-Analysis V2 software was used for systematic data meta-analyses. Prior to analysis and data pooling, the heterogeneity and homogeneity of trials were tested using the Cochrane Q statistic, $t^2$ test, or $I^2$ test. A heterogeneity value less than 25% indicated high homogeneity and a fixed-effects model was applied after direct data pooling. If the heterogeneity value was higher than 50%, a random-effects model was applied for analysis (Newman et al. 2003). A narrative description was used for the data that could not be pooled. Categorical data were expressed using odds ratios (ORs), continuous data were expressed using standardised mean differences (SMDs) and 95% confidence intervals (CI) were calculated using a statistical test. CI is a type of interval that estimates a population parameter and 95% CI is calculated from the sample data out of an interval to ensure that among all samples, 95% will contains the real population parameters among the interval (Hoekstra et al. 2014). Publication bias was detected using funnel plots and regression tests (Murad et al. 2014). A $P < 0.05$ was regarded as statistically significant.

Results

Core temperature

Comparison of FAW and PI

Five trials that compared FAW and PI with regard to patients’ core body temperatures were included in this
<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Interventions</th>
<th>Outcomes</th>
<th>Risk of bias</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kabbara et al. (2002) / America</td>
<td>Participants: 41 (14) years old, ASA I–III.</td>
<td>I: FAW cover with 43°C (n = 44), C: 1 cotton blanket (n = 39).</td>
<td>Distal esophageal temperatures were monitored at the end of surgery.</td>
<td>Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
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<tr>
<td>Ng et al. (2003) / Singapore</td>
<td>Participants: 66-27 (0-91) years old, ASA I-II, TKR</td>
<td>I: FAW cover with 38°C (n = 100), C: 2 cotton blankets (n = 100).</td>
<td>Tympanic temperature was measured at PACU and every 10 min until discharge from the recovery room.</td>
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<tr>
<td>Vanni et al. (2003) / Brazil</td>
<td>Participants: 34 (12) years old, ASA I-II, abdominal surgery.</td>
<td>I: FAW cover with 42°C (n = 10), C: 2 cotton blankets (n = 10).</td>
<td>Tympanic temperature were recorded every 15 min intraoperatively</td>
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<tr>
<td>Fallis et al. (2006) / Canada</td>
<td>Participants: 30 (5) years old, caesarean delivery.</td>
<td>I: FAW cover with 43°C (n = 32), C: 2 cotton blankets (n = 30).</td>
<td>Mothers: oral temperature, degrees of shivering, scores of thermal comfort and pain, were measured.</td>
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<tr>
<td>Wagner et al. (2006) / America</td>
<td>Participants: 50 (13) years old, ASA I–III.</td>
<td>I: FAW cover with 38°C (n = 58), C: 2 cotton blankets (n = 60).</td>
<td>Patient’s thermal comfort was measured by visual analogue scale (NVAS) and thermal comfort inventory (TCI).</td>
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<tr>
<td>D’Angelo Vanni et al. (2007) / Brazil</td>
<td>Participants: 35 (13) years old, ASA I-II, abdominal surgery</td>
<td>I: FAW cover with 42°C (n = 10), C: 1 cotton blanket (n = 10).</td>
<td>Tympanic temperature were recorded every 15 min intraoperatively</td>
<td>Incomplete outcome data addressed all outcomes: Lost in Time 2 follow-up (n = 6).</td>
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</tr>
<tr>
<td>Andrzejowski et al. (2008) / England</td>
<td>Participants: 19-80 years old, ASA I-II, spinal surgery</td>
<td>I: FAW cover with 38°C (n = 31), C: cotton blanket (n = 37).</td>
<td>The oesophagus core temperature was recorded immediately after induction and then at 20 min intervals for the duration of the surgery.</td>
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</table>
### Table 1 (Continued)

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Interventions</th>
<th>Outcomes</th>
<th>Risk of bias</th>
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</thead>
<tbody>
<tr>
<td><strong>De Witte et al. (2010)/America</strong></td>
<td>59 (10) years old, ASA I-III, laparoscopic colorectal surgery.</td>
<td>FAW cover with 42°C ($n = 8$) for 30 min, C: 2 cotton blankets ($n = 9$).</td>
<td>Tympanic and distal oesophageal temperatures were measured 10 min before pre-warming and measured every 10 min until discharge from the PACU.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: eight patients were excluded due to surgical cancellations.</td>
</tr>
<tr>
<td><strong>Leeth et al. (2010)/America</strong></td>
<td>18 -75 years old, ASA I–III, outpatient surgery patients</td>
<td>FAW cover with 38°C ($n = 56$), C: 1 cotton blanket ($n = 49$).</td>
<td>Oral temperatures and thermal comfort were measured every 30 min before operation and in the PACU.</td>
<td>Selection bias: Not described. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td><strong>O’Brien et al. (2010)/America</strong></td>
<td>36 (14) years old, ASA I-II, orthopaedic surgery.</td>
<td>FAW cover with 42°C ($n = 58$), C: 2 warm cotton blankets ($n = 72$).</td>
<td>Patient’s thermal comfort was measured by NVAS and their anxiety level was measured by State-Trait Anxiety Inventory (STAI).</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: 142 subjects consented to participate in this study, but only 105 patients completed.</td>
</tr>
<tr>
<td><strong>Benson et al. (2012)/Canada</strong></td>
<td>68 years old, ASA I–III, TKA.</td>
<td>FAW cover with 42°C ($n = 15$), C: 2 cotton blanket ($n = 15$).</td>
<td>Oral temperature was measured before surgery and PACU. Patients’ thermal comfort was assessed using a Likert-5 rating scale in the PACU.</td>
<td>Selection bias: Randomly assigned simple random draw. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td><strong>Horn et al. (2012)/America</strong></td>
<td>54 (11) years old, ASA I-III, surgery for 30-90 min.</td>
<td>FAW Pre-warming with 44°C ($n = 50$), No pre-warming ($n = 55$).</td>
<td>Tympanic temperatures were measured every 15 min in the PACU. Thermal comfort was evaluated with a 100-mm visual analogue scale in 15-min intervals.</td>
<td>Selection bias: Randomly assigned simple random draw. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td><strong>Fettes et al. (2013)/America</strong></td>
<td>18-85 years old, ASA I–III, undergoing outpatient surgery</td>
<td>FAW cover with 37.5°C ($n = 54$), C: 1 cotton blanket ($n = 74$).</td>
<td>Tympanic temperature was measured while admitting to the outpatient department, leaving from the preoperative waiting area, and arriving to the PACU.</td>
<td>Selection bias: Randomly assigned. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: 3 participants cancelled their surgeries, and the admission nurse did not recorded 10 participants in the project.</td>
</tr>
<tr>
<td><strong>Nicholson (2013)/Canada</strong></td>
<td>18-85 years old, ASA I–IV, undergoing colorectal surgery.</td>
<td>FAW cover with 38°C ($n = 32$), C: 2 cotton blankets ($n = 34$).</td>
<td>Oral temperatures were measured before and after the surgery in 15-min intervals. Oesophageal temperatures were measured during surgery.</td>
<td>Selection bias ‘Randomly assigned by a computer’. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
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Table 1 (Continued).

<table>
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<tr>
<th>Study</th>
<th>Participants</th>
<th>Interventions</th>
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<th>Characteristics of included studies: Comparing FAW and RHB</th>
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</thead>
<tbody>
<tr>
<td>Pu et al. (2013)/China</td>
<td>68 (11) years old, ASA I-III, laparoscopic surgery</td>
<td>Interventions: I: FAW cover with 41°C (n = 55), C: 1 cotton blanket (n = 55).</td>
<td>Nasopharyngeal temperature was measured during surgery and every 10 min until the end of anaesthesia.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: single-blinded trial to evaluate the feasibility. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
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<tr>
<td>Ng et al. (2003)/Singapore</td>
<td>66-27 (0-91) years old, TKR, ASA I-II.</td>
<td>Interventions: I: FAW cover with 38°C (n = 100), C: RHB (n = 100).</td>
<td>Tympanic temperature was measured before surgery in the induction room, at PACU, and at 10-min intervals until discharge from the recovery room.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: single-blinded trial to evaluate the feasibility. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
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<tr>
<td>Negishi et al. (2003)/Japan</td>
<td>62 (14) years old, open abdominal surgery, ASA I-II.</td>
<td>Interventions: I: FAW cover with 43°C (n = 8), C: RHB 42°C (n = 8).</td>
<td>Tympanic temperature was measured before the induction of anaesthesia and continually measured at 15-min intervals throughout surgery.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
<td></td>
</tr>
<tr>
<td>Ng et al. (2006)/Singapore</td>
<td>60-3 (9-1) years old, TKR, ASA I-III.</td>
<td>Interventions: I: FAW cover with 43°C (n = 30), C: RHB 42°C (n = 30).</td>
<td>Rectal temperature was measured every 5 min until the end of anaesthesia. NVAS for thermal comfort (0-10) was assessed before anaesthesia and in PACU.</td>
<td>Selection bias: Randomly assigned. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
<td></td>
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<tr>
<td>Fanelli et al. (2009)/America</td>
<td>75 (16) years old, THR, ASA I-III.</td>
<td>Interventions: I: FAW cover with 43°C (n = 28), C: RHB 41°C (n = 28).</td>
<td>Patient’s basal temperature (T0) was measured before anaesthesia and every 15 min during at least 120 min-surgery.</td>
<td>Selection bias: Randomly assigned. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
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<tr>
<td>Brandt et al. (2010)/Switzerland</td>
<td>39 (16) years old, orthopaedic surgery, ASA I-II.</td>
<td>Interventions: I: FAW cover with 43°C (n = 8), C: RHB 42°C (n = 8).</td>
<td>Oesophageal temperature was measured every 5 min until the end of surgery. Patient’s thermal comfort was evaluated by 0-100 NVAS at PACU.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
<td></td>
</tr>
<tr>
<td>Egan et al. (2011)/America</td>
<td>51 (13) years old, open abdominal surgery, ASA I-III.</td>
<td>Interventions: I: FAW cover with 43°C (n = 34), C: RHB 40°C (n = 40).</td>
<td>Oesophageal temperature was measured every 15 min until the end of surgery.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
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<tr>
<td>Study Details</td>
<td>Participants</td>
<td>Interventions</td>
<td>Outcomes</td>
<td>Risk of bias</td>
<td>Incomplete outcome data addressed all outcomes</td>
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<tr>
<td>Tanaka et al. (2013)/Japan</td>
<td>55 (13) years old, open abdominal surgery, ASA I-III.</td>
<td>Interventions I: FAW cover with 43°C ($n = 31$), C: RHB 42°C ($n = 33$).</td>
<td>Oesophageal temperature was measured every 15 min until the end of surgery.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described.</td>
<td>six patients were excluded for the reasons of change in surgical plans.</td>
</tr>
<tr>
<td>Lee et al. (2004)/Australia</td>
<td>56 (15) years old, non-cardiac surgery, ASA I-III.</td>
<td>Interventions I: FAW cover with 43°C ($n = 30$), C: RWS ($n = 29$).</td>
<td>Oesophageal temperatures were measured every 15 min until the end of surgery. Patient’s thermal comfort was evaluated by a (0-5) NVAS scale.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described.</td>
<td>One patient was excluded (RWS 1) for the following reasons: change in surgical plan.</td>
</tr>
<tr>
<td>Wong et al. (2004)/New Zealand</td>
<td>40-5 (9-8) years old, laparoscopic cholecystectomy, ASA I-III.</td>
<td>Interventions I: FAW cover with 43°C ($n = 21$), C: RWS ($n = 21$).</td>
<td>Rectal core temperatures were measured during operations. Patient’s thermal comfort was evaluated by VAS scale (0-10).</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described.</td>
<td>No loss to follow-up.</td>
</tr>
<tr>
<td>Torric et al. (2005)/New Zealand</td>
<td>72-5 (9) years old, TURP, ASA I-III.</td>
<td>Interventions I: FAW cover with 43°C ($n = 32$), C: RWS ($n = 26$).</td>
<td>The oesophageal core temperatures were record during operations.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described.</td>
<td>two patients were excluded (RWS 1, FAW 1) for the reasons: change in surgical plan.</td>
</tr>
<tr>
<td>Motamed et al. (2000)/France</td>
<td>56 (15) years old, abdominal surgery, ASA I-II.</td>
<td>Interventions I: Upper body with 43°C ($n = 13$), C: lower body with 43°C ($n = 13$).</td>
<td>Oesophageal temperature was measured every 20 min until the end of surgery.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described.</td>
<td>No loss to follow-up.</td>
</tr>
<tr>
<td>Wagner et al. (2008)/America</td>
<td>46 (14) years old, abdominal and orthopaedic surgery, ASA I-III.</td>
<td>Interventions I: Upper body with 43°C ($n = 95$), C: lower body with 43°C ($n = 89$).</td>
<td>Oesophageal temperature were measured preoperatively and admission to the PACU.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described.</td>
<td>12 patients were excluded, for the following reasons: five patients had their anaesthesia method changed, (from general to nerve block, spinal or epidural), five patients changed their surgical plans or operation duration &lt;60 min, and two patients were ASA &gt;3.</td>
</tr>
<tr>
<td>Matsuzaki et al. (2003)/England</td>
<td>20-80 years old, laparoscopic cholecystectomy, ASA I-II.</td>
<td>Interventions I: FAW cover with 41°C ($n = 8$), C: CWM 38°C ($n = 8$).</td>
<td>Oesophageal temperature was measured every 15 min until the end of surgery.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described.</td>
<td>No loss to follow-up.</td>
</tr>
</tbody>
</table>

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Table 1 (Continued).

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Interventions</th>
<th>Outcomes</th>
<th>Risk of bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negishi et al. (2003)/Japan</td>
<td>62 (14) years old, open abdominal surgery, ASA I–II.</td>
<td>I: FAW cover with 43°C ($n = 8$), C: CWM 42°C ($n = 8$).</td>
<td>Tympanic temperature was measured before the induction of anaesthesia and continually measured throughout surgery every 15-min intervals.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td>Kim et al. (2006)/Korean</td>
<td>64-1 (8-1) years old, CABG, ASA I–III.</td>
<td>I: FAW cover with 40°C ($n = 20$), C: CWM 38°C ($n = 20$).</td>
<td>Temperature (pulmonary artery), and core temperature were measured before anaesthesia and every 30-min intervals until 90 min after anaesthesia.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td>Ihn et al. (2008)/Korean</td>
<td>48 (6) years old, ATH, ASA I–II.</td>
<td>I: FAW cover with 42°C ($n = 30$), C: CWM 42°C ($n = 30$).</td>
<td>Tympanic temperature were measured before the induction of anaesthesia and continually measured throughout surgery at 15-min intervals.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td>Hasegawa et al. (2012)/Japan</td>
<td>20-80 years old, open abdominal surgery, ASA I–II.</td>
<td>I: FAW cover with 43°C ($n = 12$), C: CWM 42°C ($n = 12$).</td>
<td>Tympanic temperature were measured before the induction of anaesthesia and continually measured throughout surgery at 30-min intervals.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td>Comparing FAW and CWG Janicki et al. (2001)/America</td>
<td>52-9 (15) years old, open abdominal surgery, ASA II–IV.</td>
<td>I: FAW cover with 43°C ($n = 25$), C: CWG 41°C ($n = 28$).</td>
<td>Rectal, distal oesophageal, tympanic, forearm, and fingertip temperatures were measured preoperatively and within 2 hours after surgery.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Not described. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td>Janicki et al. (2002)/America</td>
<td>18-65 years old, open abdominal surgery.</td>
<td>I: FAW cover with 43°C ($n = 12$), C: CWG 36-8°C ($n = 12$).</td>
<td>Distal oesophageal temperatures were recorded perioperatively and within 2 hours after surgery.</td>
<td>Selection bias: Randomly assigned by a computer. Allocation concealment: Using the sealed-envelope method. Performance bias: Not described. Detection bias: Not described. Incomplete outcome data addressed all outcomes: No loss to follow-up.</td>
</tr>
<tr>
<td>Zangrillo et al. (2006)/Italy</td>
<td>67-3 (9-6) years old, CABG, ASA I–II.</td>
<td>I: FAW cover with 38°C ($n = 15$), C: CWG 38°C ($n = 16$).</td>
<td></td>
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</tr>
</tbody>
</table>
analysis, including 338 patients who underwent abdominal surgery. High homogeneity was found among samples (Q-value = 3.528, P = 0.474, I² = 0%). Funnel plot and regression analyses indicated no publication bias (Egger’s regression intercept = 1.13349, P = 0.55534). Under a fixed-effects model, the forest plot showed an overall SMD of 0.461°C (95% CI: 0.244-0.678; P < 0.001; Figure 2), indicating that FAW was superior to PI in the prevention of perioperative hypothermia.

Comparison of FAW and RHB
Five trials that compared FAW and RHB with regard to patients’ core body temperatures were included in this study. Insler et al. 2008/America
Participants 67.3 (5-6) years old, nonemergency cardiac surgery, ASA I–II. Interventions I: FAW cover with 43°C (n = 30), C: CWG 42°C (n = 30).
Outcomes Bladder core body temperature and oesophageal and pulmonary artery temperatures were measured. Temperatures were recorded every 15 min, including arrival in the OR, immediately after induction of anaesthesia, initiation and termination of CPB, departure from the OR, arrival in the ICU.

Table 1 (Continued).

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Rectum temperature was continuously recorded every 30 min.</th>
</tr>
</thead>
</table>

Insler et al. 2008/America
Participants 67.3 (5-6) years old, nonemergency cardiac surgery, ASA I–II. Interventions I: FAW cover with 43°C (n = 30), C: CWG 42°C (n = 30).
Outcomes Bladder core body temperature and oesophageal and pulmonary artery temperatures were measured. Temperatures were recorded every 15 min, including arrival in the OR, immediately after induction of anaesthesia, initiation and termination of CPB, departure from the OR, arrival in the ICU.

Figure 1 Flow diagram of the screening process.
Table 2  Summary of findings for the main comparison.

To evaluate effectiveness of forced-air warming in preventing perioperative hypothermia

Patient or population: adults with perioperative hypothermia
Settings: heating during perioperative period
Intervention: forced-air warming
Comparison: control (PI: passive insulation; CWM: circulating-water mattress; CWG: circulating-water garment; RWS: radiant warming system; RHB: resistive heating blanket)

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Illustrative comparative risks* (95% CI)</th>
<th>SMDs/Odds (95% CI)</th>
<th>Number of participants/studies</th>
<th>Quality of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison of FAW and PI regard to patients' core body temperatures.</td>
<td>Mean temperature of PI group was 35.5°C</td>
<td>SMDs of the FAW group were 0.461°C higher than PI group, indicating that FAW was better than PI in preventing perioperative hypothermia.</td>
<td>SMD of 0.461°C (95% CI: 0.244-0.678; ( P &lt; 0.001 ))</td>
<td>338 (five studies)</td>
</tr>
<tr>
<td>Comparison of FAW and RHB regard to patients' core body temperatures.</td>
<td>Mean temperature of RHB group was 35.9°C</td>
<td>SMDs of the FAW group were −0.144°C lower than RHB group, indicating that both had no difference in preventing perioperative hypothermia.</td>
<td>SMD of −0.144°C (95% CI: −0.677 to 0.390; ( P = 0.598 ))</td>
<td>430 (five studies)</td>
</tr>
<tr>
<td>Comparison of FAW and RWS regard to patients' core body temperatures.</td>
<td>Mean temperature of RWS group was 35.85°C</td>
<td>SMDs of the FAW group were −0.253°C lower than RWS group, indicating no difference between groups in preventing perioperative hypothermia.</td>
<td>SMD of −0.253°C (95% CI: −0.547 to 0.535; ( P = 0.535 ))</td>
<td>158 (five studies)</td>
</tr>
<tr>
<td>Comparison of FAW use on the lower and upper body regard to patients' core body temperatures.</td>
<td>Mean temperature of groups was 35.95°C</td>
<td>SMDs of low body FAW group were 0.371°C higher than upper group, indicating both had no difference in preventing perioperative hypothermia.</td>
<td>SMD of 0.371°C (95% CI: −0.234 to 0.977; ( P = 0.229 ))</td>
<td>210 (two studies)</td>
</tr>
<tr>
<td>Comparison of FAW and CWM regard to patients' core body temperatures.</td>
<td>Mean temperature of CWM group was 35.45°C</td>
<td>SMDs of the FAW group were 0.966°C higher than CWM group, indicating that FAW was better than CWM in preventing perioperative hypothermia.</td>
<td>SMD of 0.966°C (95% CI: 0.531-1.400; ( P &lt; 0.001 ))</td>
<td>92 (three studies)</td>
</tr>
</tbody>
</table>

†High homogeneity was found in the samples (Q-value = 3.528, \( P = 0.474, I^2 = 0\% \)).
‡Moderate heterogeneity was found in the samples (Q-value = 11.401, \( P = 0.003, I^2 = 82.458\% \)).
§High homogeneity was found in the samples (Q-value = 2.284, \( P = 0.131, I^2 = 56.215\% \)).
Table 2 (Continued).

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Control group</th>
<th>Intervention group</th>
<th>SMDs/Odds (95% CI)</th>
<th>Number of participants/studies</th>
<th>Quality of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison of FAW and CWG regard to patients’ core body temperatures.</td>
<td>Mean temperature of CWG group was 35.9°C</td>
<td>SMDs of the FAW group were −1.186°C lower than CWG groups, indicating that FAW and CWG had similar effectiveness in preventing perioperative hypothermia.</td>
<td>SMD of −1.186°C (95% CI: −3.774 to 1.402; (P = 0.369))</td>
<td>121 (three studies)</td>
<td>⊗⊗⊗⊗ Low†‡</td>
</tr>
<tr>
<td>Comparison of FAW PI, RHB, RWS, and CWM regard to patients’ thermal comfort</td>
<td>Mean thermal comfort of numeric visual analogue scale (NVAS) was 3.975</td>
<td>The ORs showed that FAW had better thermal comfort than PI, RHB and RWS. Only one trial suggested that CWM had better thermal comfort than FAW.</td>
<td>ORs of 2.919 (95% CI: 1.293-6.588, (P = 0.010))</td>
<td>502 (seven studies)</td>
<td>⊗⊗⊗ Moderate§</td>
</tr>
</tbody>
</table>

GRADE Working Group grades of evidence.
High quality: Further research is very unlikely to change our confidence in the estimate of effect.
Moderate quality: Further research is likely to have an important impact on our confidence in the estimate of effect and may change the estimate.
Low quality: Further research is very likely to have an important impact on our confidence in the estimate of effect and is likely to change the estimate.
Very low quality: We are very uncertain about the estimate.

*The basis for the assumed risk (e.g. median control group risk across studies) is provided in the footnotes. The corresponding risk (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).
†Blinding was not possible, unclear what effect this has. Not downgraded.
‡Serious risk of imprecision, downgraded 1 place: wide confidence intervals where clinical action would differ if the extreme ends of the confidence interval were true.
CI, Confidence interval; SMDs, standardized mean temperature difference; ORs, odds ratios; °C, degrees Celsius.

JAN: REVIEW PAPER
Effectiveness of FAW for preventing perioperative hypothermia

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analysis, including 430 patients who underwent abdominal surgery. High heterogeneity was found among samples (Q-value = 22.186, \(P < 0.001\), \(I^2 = 81.970\%\)). Funnel plot and regression analyses indicated no publication bias (Egger’s regression intercept = 1.83, \(P = 0.59\)). Under a random-effects model, the forest plot showed an overall SMD of \(-0.144^\circ\text{C} (95\%\text{ CI}: \(-0.677\) to 0.390; \(P = 0.598\); Figure 3), indicating there was no difference in the effectiveness of FAW and RHB for prevention of perioperative hypothermia.

Comparison of FAW and RWS
Five trials that compared FAW and RWS with regard to patients’ core body temperatures were included in this study, including 158 patients who underwent laparoscopic or prostate surgery. High heterogeneity was found among

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**Figure 2** Forest plot of the core temperature for forced-air warming (FAW) vs. passive insulation (PI) only. +, standard mean difference (SMD) and confidence interval (CI) in the individual trial; ◆, the overall effect derived from a pooled analysis; \(P < 0.05\) as statistically significant.

**Figure 3** Forest plot of the core temperature for forced-air warming (FAW) vs. resistive heating blanket (RHB) only. +, standard mean difference (SMD) and confidence interval (CI) in the individual trial; ◆, the overall effect derived from a pooled analysis; \(P < 0.05\) as statistically significant.

**Figure 4** Forest plot of the core temperature for forced-air warming (FAW) vs. radiant warming system (RWS) only. +, standard mean difference (SMD) and confidence interval (CI) in the individual trial; ◆, the overall effect derived from a pooled analysis; \(P < 0.05\) as statistically significant.
**Comparison of FAW use on the lower and upper body**

Two trials that compared patients' core body temperatures with FAW use for the upper vs. lower body were included in this analysis, including 210 patients who underwent surgery. Moderate heterogeneity was found among samples (Q-value = 2.284, P = 0.131, $I^2 = 56.215\%$). As only two trials were included, publication bias could not be assessed. Under a random-effects model, the forest plot showed an overall SMD of $-0.253^\circ C$ (95% CI: $-1.054$ to 0.547; $P = 0.535$; Figure 4), indicating that there was no difference in the effectiveness of FAW and RWS for prevention of perioperative hypothermia.

**Table 1**

<table>
<thead>
<tr>
<th>Study name</th>
<th>Subgroup within study</th>
<th>Sample size</th>
<th>Statistics for each study</th>
<th>Weight (Fixed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Std diff in means</td>
<td>Lower limit</td>
</tr>
<tr>
<td>Motamed 2000</td>
<td>FAW(up)</td>
<td>13 13 26</td>
<td>0.810 0.010</td>
<td>1.609</td>
</tr>
<tr>
<td>Wagner 2008</td>
<td>FAW(up)</td>
<td>95 89 184</td>
<td>0.154 -0.136</td>
<td>0.443</td>
</tr>
<tr>
<td></td>
<td></td>
<td>108 102 210</td>
<td>0.371 -0.234</td>
<td>0.977</td>
</tr>
</tbody>
</table>

Heterogeneity: $\tau^2 = 0.412$, Chi2 = 2.284, df = 1 ($P = 0.131$); $I^2 = 56.215\%$

Test for overall effect: $Z = -1.203$ ($P = 0.229$)

**Figure 5**

Forest plot of the core temperature for forced-air warming (FAW) (lower) vs. FAW (upper). +, standard mean difference (SMD) and confidence interval (CI) in the individual trial; ◆, the overall effect derived from a pooled analysis.

**Figure 6**

Forest plot of the core temperature for forced-air warming (FAW) vs. circulating-water mattress (CWM) only. +, standard mean difference (SMD) and confidence interval (CI) in the individual trial; ◆, the overall effect derived from a pooled analysis; $P < 0.05$ as statistically significant.

**Figure 7**

Forest plot of the core temperature for forced-air warming (FAW) vs. CWM only. +, standard mean difference (SMD) and confidence interval (CI) in the individual trial; ◆, the overall effect derived from a pooled analysis; $P < 0.05$ as statistically significant.

samples (Q-value = 11.401, $P = 0.003$, $I^2 = 82.458\%$). Funnel plot and regression analyses indicated no publication bias (Egger’s regression intercept = 1.83, $P = 0.59$). Under a random-effects model, the forest plot showed an overall SMD of $-0.253^\circ C$ (95% CI: $-1.054$ to 0.547; $P = 0.535$; Figure 4), indicating that there was no difference in the effectiveness of FAW and RWS for prevention of perioperative hypothermia.
overall SMD of 0.371°C (95% CI: −0.234 to 0.977; \( P = 0.229 \); Figure 3), indicating there was no difference in the use of FAW on the upper vs. lower body for prevention of perioperative hypothermia.

**Comparison of FAW and CWM**

Four trials comparing patients' core body temperatures with use of FAW vs. CWM, including 116 patients who underwent abdominal surgery, were included in this analysis. High heterogeneity was found among samples (Q-value = 16.571, \( P = 0.001 \), \( I^2 = 81.896\% \)); therefore, the study that had heterogeneous standard residuals (Hasegawa et al. 2012) was removed (Figure 6). The remaining three trials (92 patients) were subjected to meta-analysis and showed high homogeneity (Q-value = 2.043, \( P = 0.360 \), \( I^2 = 2.095\% \)). Funnel plot and regression analyses indicated no publication bias (Egger’s regression intercept = 0.839, \( P = 0.87 \)). Using a fixed-effects model, the forest plot showed an overall SMD of 0.966°C (95% CI: 0.531-1.400; \( P < 0.001 \); Figure 7), indicating that FAW had effectiveness superior to that of CWM for the prevention of perioperative hypothermia.

**Comparison of FAW and CWG**

Three trials comparing FAW and CWG with regard to patients' core body temperatures, including 158 patients who underwent surgery, were included in this analysis. High heterogeneity was found among samples (Q-value = 61.281, \( P < 0.001 \), \( I^2 = 96.736\% \)). Funnel plot and regression analyses indicated no publication bias (Egger’s regression intercept = −14.564, \( P = 0.10054 \)). Using a random-effects model, the forest plot showed an overall SMD of −1.186°C (95% CI: −3.774 to 1.402; \( P = 0.369 \); Figure 8), indicating that FAW and CWG had similar effectiveness for the prevention of perioperative hypothermia.

**Thermal comfort**

Seven trials that compared patients’ thermal comfort with use of various warming techniques were included in this analysis; these trials included 502 patients who underwent surgery. High heterogeneity was found among samples (Q-value = 28.458, \( P < 0.001 \), \( I^2 = 78.92\% \)). Funnel plot and regression analyses indicated no publication bias (Egger’s regression intercept = −0.069, \( P = 0.979 \)). Using a random-effects model, the forest plot showed an OR of 2.919 (95% CI: 1.293-6.588, \( P = 0.010 \); Figure 9), indicating that FAW improved thermal comfort more effectively than PI, RHB and RWS. Only one trial suggested that CWM had thermal comfort superior to FAW; however, the test for overall effects indicated superior thermal comfort with use of FAW (\( \text{Z} = 2.579; \text{P} = 0.010 \)).

**Discussion**

On the basis of a careful systematic review with meta-analysis, we found that FAW was superior to PI and CWM in preventing perioperative hypothermia, but no statistical difference was found in effectiveness compared with CWG, RHB and RWS. There was no temperature difference between FAW use for the top half vs. the lower half of the body. Moreover, FAW offered thermal comfort superior to that of other insulation/warming techniques.

Evaluation of the effectiveness of FAW should take into account the type of surgery, anaesthesia method, timing of insulation/warming intervention, insulation/warming method, temperature setting and core temperature measurement sites (Horosz & Malec-Milewska 2013). The present analysis showed that FAW has a better thermal insulation effect than PI during general anaesthesia; this is supported by the studies of Galvão et al. (2010) and Alderson et al.
Effectiveness of FAW for preventing perioperative hypothermia

In this study, three trials were included in the meta-analysis comparing the effectiveness of FAW and RHB. The trials included patients undergoing orthopaedic (Ng et al. 2003, Brandt et al. 2010) and abdominal surgeries (Negishi et al. 2003, Egan et al. 2011, Tanaka et al. 2013). The sample size greatly varied among the trials, ranging from 16-200 participants. Despite the high heterogeneity among the trials, there was no evidence of publication bias. Our results are consistent with those of Galvão et al. (2009). FAW and RHB have similar effectiveness in warming and temperature preservation during surgery; however, close attention should be paid to temperature control to help avoid burn injury from RHB due to direct skin contact (John et al. 2014).

In this study, three trials were included in the meta-analysis comparing the effectiveness of FAW and RWS. The intervention was applied during surgery, the anaesthesia methods included general (Lee et al. 2004, Wong et al. 2004) and epidural anaesthesia (Torrie et al. 2005) and oesophageal (Lee et al. 2004, Wong et al. 2004) or anal temperature (Torrie et al. 2005) was measured after surgery. The results showed no statistically significant difference in warming effectiveness between FAW and RWS. Our results contradicted those of Galvão et al. (2010), who argued that the effectiveness of FAW was superior to that of RWS. A possible reason for this discrepancy could be the different indicators used for single trial analysis. This study used an SMD of −0.253°C (95% CI: −1.054 to 0.547, P = 0.535), which takes into account variations among samples and which was calculated by dividing the mean difference with standard deviation to reduce background effects; however, Galvão et al. (2010) used a mean difference of 0.16 (95% CI: −0.01 to 0.33, P = 0.06). The confidence levels of both studies were greater than 0 and P > 0.05; therefore, an interpretation of no difference between the two groups was suggested (Hodson & Craig 2013, da Silva & Peniche Ade 2014). Our results are consistent with those of Munday et al. (2014), who found no difference between FAW and RWS in insulation/warming performance during abdominal and prostate surgery. Due to an insufficiency of relevant empirical studies, large-scale randomized research is recommended to verify the effectiveness of these two interventions in the future.

This study showed that FAW was superior to CWM in preventing perioperative hypothermia; this result is consistent with that of John et al. (2014), who reported that FAW was more effective than CWM for warming during surgery. In the five trials analysed in this study, all participants underwent abdominal surgery under general anaesthesia, tympanic (Matsuzaki et al. 2003, Negishi et al. 2003) or oesophageal temperature (Ihn et al. 2008) was measured after surgery and the warming intervention was applied prior to (Ihn et al. 2008) or during surgery (Matsuzaki et al. 2003, Negishi et al. 2003). Study samples were homogenous and no publication bias of these trials was detected. Therefore, we suggest that compared with CWM, FAW is more effective in preventing perioperative hypothermia in patients undergoing abdominal surgery.

(2014) that demonstrated core temperature increases of 0.29°C (95% CI: −0.02 to 0.59) and 0.12°C (95% CI: 0.07-0.13), respectively. However, there was no difference between use of FAW and PI during spinal anaesthesia. Five trials included in this study examined patients undergoing abdominal surgery and FAW showed warming performance superior to that of PI, regardless of whether the intervention began before or during surgery. Therefore, compared with PI, we strongly believe that FAW is a more suitable warming approach to prevent hypothermia during the perioperative period in patients who undergo abdominal surgery.

This study did not find any differences in insulation/warming performance between FAW and RHB. The trials included patients undergoing orthopaedic (Ng et al. 2003, Brandt et al. 2010) and abdominal surgeries (Negishi et al. 2003, Egan et al. 2011, Tanaka et al. 2013). The sample size greatly varied among the trials, ranging from 16-200 participants. Despite the high heterogeneity among the trials, there was no evidence of publication bias. Our results are consistent with those of Galvão et al. (2009). FAW and RHB have similar effectiveness in warming and temperature preservation during surgery; however, close attention should be paid to temperature control to help avoid burn injury from RHB due to direct skin contact (John et al. 2014).

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This study showed that FAW was superior to CWM in preventing perioperative hypothermia; this result is consistent with that of John et al. (2014), who reported that FAW was more effective than CWM for warming during surgery. In the five trials analysed in this study, all participants underwent abdominal surgery under general anaesthesia, tympanic (Matsuzaki et al. 2003, Negishi et al. 2003) or oesophageal temperature (Ihn et al. 2008) was measured after surgery and the warming intervention was applied prior to (Ihn et al. 2008) or during surgery (Matsuzaki et al. 2003, Negishi et al. 2003). Study samples were homogenous and no publication bias of these trials was detected. Therefore, we suggest that compared with CWM, FAW is more effective in preventing perioperative hypothermia in patients undergoing abdominal surgery.
In this study, there was no difference between FAW and CWG in avoiding perioperative hypothermia ($P = 0.369$). This result is inconsistent with that of Galvão et al. (2010), who showed that CWG was superior to FAW during surgery. This discrepancy might be attributed to the inclusion of the trial by Janicki et al. (2001) in the study by Galvão et al. (2010), as the former has a low JQS of 2; conversely, this study included three trials, all with a JQS of 3, thereby improving the confidence level. In the three trials included in this study, all participants underwent thoracic/abdominal surgery, the warming intervention was applied during surgery and the temperature was measured at the end of surgery; the temperature settings for FAW ranged from 38°C (Zangrillo et al. 2006)-43°C (Janicki et al. 2002, Insler et al. 2008) and those for CWG ranged from 37°C-38°C. However, considering the high heterogeneity among the trials, a greater number of large-scale and high quality randomized studies are required to increase the sample size and reduce SMD deviations.

Finally, this study revealed that the thermal comfort provided by FAW was superior to that of PI (Fallis et al. 2006, Wagner et al. 2006, O’Brien et al. 2010, Benson et al. 2012), RHB (Ng et al. 2006) and RWS (Lee et al. 2004, Torrie et al. 2005), but inferior to that of FAW (Janicki et al. 2002). In the included trials, the participants underwent thoracic/abdominal (Janicki et al. 2002, Lee et al. 2004, Fallis et al. 2006, Wagner et al. 2006), orthopaedic (O’Brien et al. 2010, Benson et al. 2012) or prostate surgery (Torrie et al. 2005). Furthermore, various tools were used for thermal comfort assessment, including verbal numeric rating scales from 1-10 (Janicki et al. 2002, Torrie et al. 2005, Fallis et al. 2006, O’Brien et al. 2010) or from 1-5 (Lee et al. 2004, Benson et al. 2012) or a thermal comfort inventory from 1-6 (Wagner et al. 2006). Although the overall SMD showed that FAW offers superior thermal comfort over other warming devices, a high heterogeneity was found among the trials. In addition, only one trial involving 37 patients compared thermal comfort between FAW and CWG (Janicki et al. 2002). Thus, the empirical evidence was insufficient. To assess the warming effectiveness and patients’ thermal comfort when using insulation/warming techniques, we suggest that future relevant research should include thermal comfort measurement. Furthermore, our results are in agreement with the proposal of Brauer et al. (2009), namely, that it is appropriate to cover different body parts according to body size and surgery site when using FAW, suggesting that FAW is suitable for all types of surgery. Therefore, we suggest using FAW to prevent perioperative hypothermia, reduce complications and improve thermal comfort during thoracic/abdominal, orthopaedic and prostate surgeries.

This study verified that FAW improves perioperative hypothermia and thermal comfort in surgical patients, which is consistent with the suggestions of Al-Qahtani and Messahel (2011) and Hooper et al. (2009). FAW can be used for skin warming in perioperative patients. However, close attention should be paid to avoid burn injury, surgical wound contamination and the effect of hot airflow on surgical sites (Dasari et al. 2012).

Kellam et al. (2013) assessed the effect of airflow on surgical wound infection when using FAW. Results indicated that hot airflow did not increase the risk of surgical wound infection in vascular and orthopaedic surgeries (1437 patients). In addition, Cobbe et al. (2012) compared the thermal comfort of patients at temperature settings of 43°C and 38°C with preoperative FAW warming; no statistically significant difference was found, but patients showed a preference for 43°C ($P = 0.004$). In addition to core temperature monitoring, healthcare workers should pay close attention to intervention timing and temperature settings to avoid burn injuries. Moreover, the use of FAW should also take into account patients’ thermal comfort and systemic conditions, such as diabetes, thyroid dysfunctions and peripheral vascular diseases, because these might reduce the patient’s sensitivity to low temperatures.

With regard to the cost-benefit aspect, although RHB costs about 500–1000 US dollars, it directly contacts the patient’s skin, which easily leads to burns (Dewar et al. 2004). CWM costs about 2000–3000 US dollars and it is suitable to maintain core temperature during surgery. However, CWM is a non-disposable water mattress which requires sterile material to prevent contamination, thus increasing labour costs (Perez-Protto et al. 2010). FAW costs about 1500–2000 US dollars and is a disposable blanket that allows hot air coming through the numerous holes of warm blanket to equally and continuously warm the patient’s temperature by convection heating (Legg & Hamer 2013, Wu 2013). However, Pikus and Hooper (2010) indicated that perioperative hypothermia causes postoperative complications and mortality that costs 2500-7000 US dollars per patient to treat. Thus, providing appropriate warming equipment to the surgical patients under perioperative nursing is necessary and important.

**Conclusion**

Using a meta-analysis, this study revealed that FAW was superior to PI and CWM in preventing perioperative hypothermia, but there was no statistically significant difference between FAW and CWG, RHB and RWS. FAW allows for a flexible selection of appropriate warming sites.
and provides better thermal comfort than other warming systems. These results can be used as a reference in clinical practice. However, there are some limitations in this study. First, it was a non-blinded meta-analysis and the highest JQS of the trials was only 3, which might affect the assessment of trial quality. In addition, due to the heterogeneity among trials, the comparison of insulation/warming performance between FAW and other warming systems, such as RHB, RWS and CWG, was affected by intervention timing, type of surgery, anaesthesia method and sample size. Therefore, it is necessary to conduct a large-scale and high-quality randomized control trial study to further investigate the performance of various warming techniques.

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- substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data;
- drafting the article or revising it critically for important intellectual content.

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