Conductive Skin Warming and Hypothermia: An Observational Study

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Most surgical patients receiving regional or general anesthesia experience perioperative hypothermia unless effective preventive measures are used. Patient positioning poses a challenge for clinicians using existing technology. The purpose of this study is to describe outcomes of hypothermia after a combination of preoperative and intraoperative conductive skin warming (CSW). This retrospective observational study included 972 adult surgical patients receiving general or neuraxial anesthesia. Clinicians were provided an alternative for perioperative warming, an underbody conductive warming mattress using resistive ink technology (VitaHEAT UB3, VitaHEAT Medical), or the option to use current practice, forced-air warming (FAW). The primary study endpoint was temperature on arrival in the postanesthesia care unit.

Active warming was provided preoperatively with CSW (81.5%) or FAW (0.6%) and intraoperatively with CSW (61.1%), FAW (21.8%), or both (12.1%). Hypothermia occurred in 3.5% of patients overall and in 16.7% of patients when active warming was not used. When CSW was used preoperatively and intraoperatively, 4.1% of patients became hypothermic. When CSW was used preoperatively and FAW was used intraoperatively, 2.3% of patients became hypothermic. When clinicians used active warming methods based on individual patient needs, nearly all patients (96.5%) remained normothermic.

Keywords: Anesthesia, body temperature, hypothermia, intraoperative complication, perioperative care.

Most patients undergoing surgical procedures with regional or general anesthesia will experience perioperative hypothermia unless effective preventive measures are used. The risks of hypothermia to patients are well known. Mild perioperative hypothermia triples the risk of surgical site infection,[1] quadruples the risk of morbid cardiac events,[2] and causes coagulopathy, increasing blood loss.[3,4] Perioperative hypothermia impairs drug metabolism and increases the duration of action of anesthesia and neuromuscular blocking agents,[5] extending postanesthesia recovery.[6] In patients who have sustained trauma, perioperative hypothermia is associated with increased mortality.[7]

Passive warming (eg, cotton or reflective blankets) cannot compensate for the anesthesia-induced thermoregulatory impairment experienced by surgical patients and is inadequate to prevent perioperative hypothermia. Blankets reduce heat loss by only 33% in nonanesthetized persons.[8] Applying heated cotton blankets is slightly more effective, but the benefit lasts only 10 minutes.[8] In a randomized clinical trial, applying a heated cotton blanket resulted in mean core temperatures of 35.5°C.[9]

Active warming heats peripheral tissues to minimize the core-to-periphery temperature gradient and is required to prevent perioperative hypothermia. The most common method of active warming is forced-air warming (FAW). Clinical trials have demonstrated that intraoperative FAW is more effective than passive warming (cotton blankets,[9] reflective blankets,[10] or Thermolite [Invista] insulation[11]). Application of FAW preoperatively minimizes heat lost during redistribution of heat and minimizes the incidence of hypothermia.[9,12] Use of FAW preoperatively and intraoperatively is significantly more effective in maintaining normothermia than is use of FAW intraoperatively alone.[12-15]

Despite its demonstrated effectiveness, adherence to preoperative and intraoperative active warming remains inadequate. Challenges to adherence include the variability of types of surgical procedures and surgical positions, and difficulty in integrating the use of FAW technology into the busy perioperative workflow. A newer technology incorporating a reusable, underbody, conductive heating mat using resistive ink is now available for use (from VitaHEAT Medical). This smart technology adjusts the temperature of the mat to ensure even heating and prevent overheating. The mat does not disrupt air flow in the operating room and is reusable. However, little is known about the feasibility of using this technology preoperatively and intraoperatively for patients undergoing

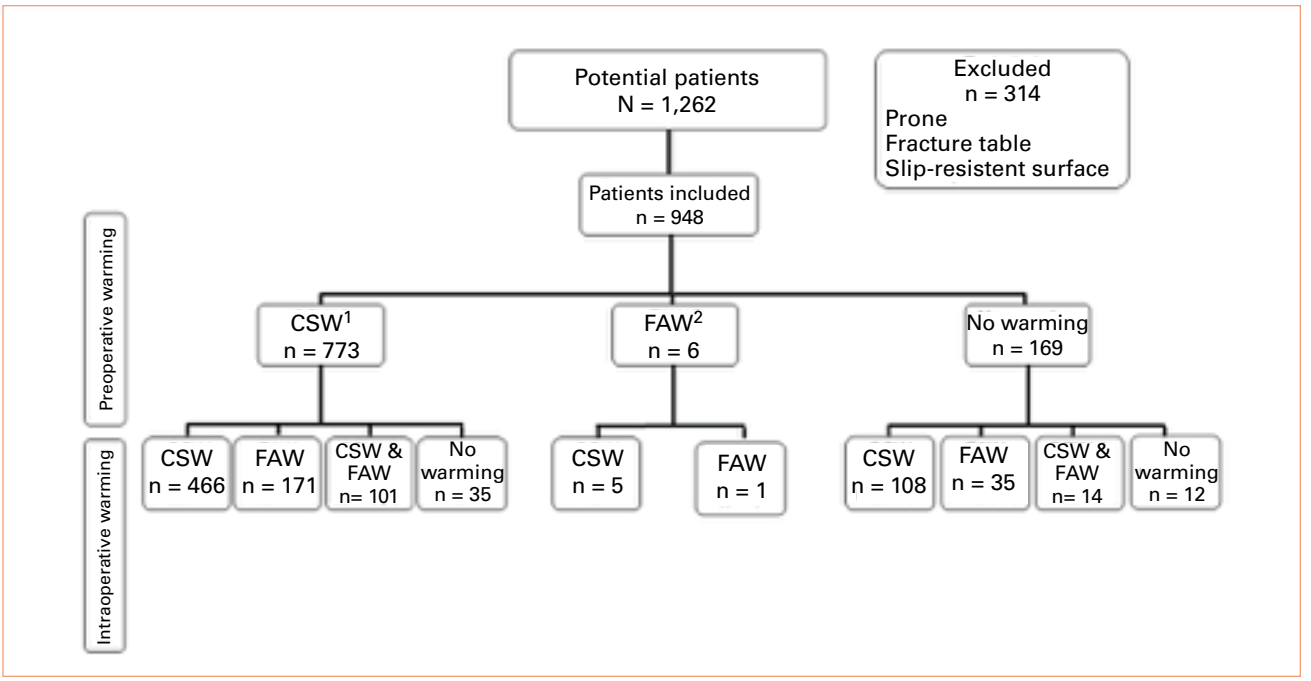

Figure. Type of Active Warming Provided to Patients Preoperatively and Intraoperatively
Abbreviations: CSW, conductive skin warming; FAW, forced-air warming; &, and.

a variety of surgical procedures with different surgical positions seen in an average operating theater.

Our objective in this retrospective observational study was to describe patient outcomes of hypothermia after receiving a combination of preoperative and intraoperative conductive skin warming (CSW) and to identify which patients become hypothermic using CSW in this manner.

Materials and Methods

We reviewed existing data in the health information system of a Midwestern community hospital in the United States, a Level II trauma center. The institutional review board of The University of Iowa determined that this study (No. 201512738) does not meet the regulatory definition of human subjects research.

Staff were encouraged to evaluate the use of a conductive, underbody patient warming mat (VitaHEAT UB3, VitaHEAT Medical) to provide CSW preoperatively and intraoperatively. Alternatively, staff could choose to use the standard of care, an over-the-body FAW blanket. The decision of which technology to use was ultimately determined by the anesthesiologist and the circulating nurse based on the patient's condition, amount of skin surface area exposed, and the surgical position.

We used a convenience sample of all adult patients undergoing surgery with general or neuraxial anesthesia between March 1, 2016, and May 31, 2016 (3 months total). This sample size was determined to provide clinically relevant descriptive results. Inclusion criteria were adults receiving general, spinal, or epidural anesthesia; a surgery duration of 30 minutes or greater; and admission to the postanesthesia recovery room. Exclusion criteria were planned hypothermia, preoperative temperature greater than 37.7°C, gastrointestinal endoscopy, and no immediate postoperative temperature recorded. Additionally, patients were excluded if they were positioned with inadequate skin exposure to the conductive mat (prone, fracture table), or on a slip-resistant surface for high lithotomy positioning.

Preoperative warming was applied by either CSW or FAW for at least 30 minutes before transfer to the operating theater. When CSW was used preoperatively, it was also used during transport to the operating theater. Intraoperative warming was provided for the duration of the surgery by CSW, FAW, or a combination of both. The CSW mat includes a patented, conductive silver/carbon ink technology that transfers heat to the patient as well as smart technology to measure the temperature in 6 zones. The skin was warmed to 40°C. If the temperature of any of the 6 zones reached over 40°C, the heat to that zone stopped. The equipment was preset by the manufacturer and tested by the Bioengineering Department before use. One layer of cotton fabric (sheet) was placed between the patient and the mat.

During the evaluation, nursing personnel measured the patient's temperature preoperatively (before the 30 minutes of active warming) and postoperatively (immediately on arrival and as per protocol in the recovery room), using an infrared temporal artery thermometer (Exergen TAT-5000, Exergen Corp) calibrated by the thermometer manufacturer. This temperature reading provided a consistent method of measurement and is a

commonly used proxy for core body temperature when no invasive measurement is feasible. All nurses had demonstrated competency in using this type of thermometer.

Nurses recorded the use and type of active warming and the patient temperature in the electronic documentation system. Normothermia was defined as between 36°C and 37.5°C. Investigators retrieved the retrospective data using SAP BusinessObjects and Crystal Reports (both SAP) and Epic workbench reports (Epic Systems). Patients were identified by a unique numeric identifier coded to link to the patient hospital record number. Investigators did not have access to the patient identifiers. Staff employed by The University of Iowa performed data management. To ensure data integrity, hospital employees verified the accuracy of a sample of data, including all patients who became hypothermic. Investigators used statistical software (SAS 9.4, SAS Institute Inc) to prepare and clean data and to calculate descriptive statistics (means, standard deviations, and percentages).

Results

Between March 1, 2016, and May 31, 2016, a total of 1,262 patients underwent surgery and satisfied inclusion and exclusion criteria. After exclusion of an additional 314 potential subjects due to positioning that resulted in inadequate skin exposure to the conductive mat (prone, fracture table with traction, high lithotomy with a slip-resistant surface), 948 patients were included in this analysis (Figure). For these subjects, there were no missing values on any of the variables studied. The mean age was 56.1 years; 90.3% of subjects were white, and 58.2% were female. Most patients (813 of 948; 85.8%) received general anesthesia. The duration of the surgeries ranged from 30 to 428 minutes (Table 1).

Counts for types of preoperative and intraoperative warming by surgical service are provided in Table 2. Preoperative CSW was provided for 773 (81.5%) of the 948 patients and by FAW for 6 patients (0.6%); no preoperative warming was provided for 169 patients (17.8%). Intraoperative warming was provided for 901 (95.0%) of the 948 patients, with CSW used exclusively for 579 (61.1%), FAW exclusively for 207 (21.8%), and a combination of CSW and FAW for 115 patients (12.1%). Both preoperative and intraoperative warming were provided for 744 (78.5%) of the 948 patients. Preoperative warming alone was provided for 35 (3.7%), intraoperative warming alone was provided for 157 patients (16.6%), and no

Surgical service	All surgeries, No. (%)[a]	Surgeries after exclusion, No. (%)[b]	Type of anesthesia, No. (%)				Duration of surgery, min			
			GA	SA	GA and SA	GA and EDA	Mean	SD	Minimum	Maximum
Cardiothoracic	19 (1.5)	19 (2.0)	13 (1.6)	0 (0)	0 (0)	6 (50.0)	101.7	36.6	44	200
ENT	75 (5.9)	75 (7.9)	75 (9.2)	0 (0)	0 (0)	0 (0)	71.5	41.7	30	183
General	258 (20.4)	220 (23.2)	217 (26.7)	0 (0)	0 (0)	3 (25.0)	69.2	50.9	30	392
Gynecology	179 (14.2)	54 (5.7)	53 (6.5)	1 (1.0)	0 (0)	0 (0)	58.5	27.4	30	133
Neurosurgery	108 (8.6)	30 (3.2)	30 (3.7)	0 (0)	0 (0)	0 (0)	111.3	40.3	56	200
Ophthalmology	2 (0.2)	2 (0.2)	2 (0.3)	0 (0)	0 (0)	0 (0)	54.5	2.1	53	56
Oral surgery	15 (1.2)	15 (1.6)	15 (1.9)	0 (0)	0 (0)	0 (0)	115.1	64.5	42	261
Orthopedics[c]	468 (37.1)	427 (45.0)	307 (37.8)	96 (98.0)	24 (96.0)	0 (0)	72.0	33.3	30	241
Plastics	67 (5.3)	60 (6.3)	60 (7.4)	0 (0)	0 (0)	0 (0)	139.5	86.6	31	428
Urology	38 (3.0)	13 (1.4)	10 (1.2)	1 (1.0)	1 (4.0)	1 (8.3)	87.1	77.5	30	303
Vascular	33 (2.6)	33 (3.5)	31 (3.8)	0 (0)	0 (0)	2 (16.7)	89.1	40.3	32	166
All	1,262 (100.0)	948 (100.0)	813 (100.0)	98 (100.0)	25 (100.0)	12 (100.0)				

Table 1. Anesthesia Type and Duration of Surgery by Surgical Service

Abbreviations: EDA, epidural anesthesia; ENT, ear, nose, and throat; GA, general anesthesia; SA, spinal anesthesia.

[a]All surgeries 30 minutes or longer, excluding surgeries with planned hypothermia or in which the hypothermia status was unknown, surgeries in which the patient was not admitted to the postanesthesia care unit, surgeries in which the patient's last preoperative temperature was greater than 37.7°C, and surgeries performed in subjects under age 18 years. Percentages are based on all surgical services.

[b]Surgeries after prone positioning, positioning on fracture table, and positioning on a slip-resistant surface were excluded. Percentages are based on all surgical services after exclusion.

[c]Orthopedics includes podiatry.

Surgical service	n[b]	Preop warming		Intraop warming			No warming preop or intraop	Only preop warming	Only intraop warming	Preop and intraop warming
		CSW	FAW	CSW only	FAW only	FAW and CSW				
Cardiothoracic	19	17 (89.5)	0 (0)	8 (42.1)	10 (52.6)	1 (5.3)	0 (0)	0 (0)	2 (10.5)	17 (89.5)
ENT	75	70 (93.3)	1 (1.3)	53 (70.7)	8 (10.7)	3 (4.0)	1 (1.3)	10 (13.3)	3 (4.0)	61 (81.3)
General	220	150 (68.2)	1 (0.5)	167 (75.9)	18 (8.2)	27 (12.3)	4 (1.8)	4 (1.8)	65 (29.5)	147 (66.8)
Gynecology	54	49 (90.7)	0 (0)	17 (31.4)	28 (51.9)	4 (7.4)	1 (1.9)	4 (7.4)	4 (7.4)	45 (83.3)
Neurosurgery	30	24 (80.0)	0 (0)	3 (10.0)	22 (73.3)	3 (10.0)	1 (3.3)	1 (3.3)	5 (16.7)	23 (76.7)
Ophthalmology	2	2 (100.0)	0 (0)	1 (50.0)	0 (0)	0 (0)	0 (0)	1 (50.0)	0 (0)	1 (50.0)
Oral surgery	15	9 (60.0)	0 (0)	9 (60.0)	1 (6.7)	5 (33.3)	0 (0)	0 (0)	6 (40.0)	9 (60.0)
Orthopedics[c]	427	358 (83.8)	2 (0.5)	252 (59.0)	114 (26.7)	44 (10.3)	4 (0.9)	13 (3.0)	63 (14.8)	347 (81.3)
Plastics	60	58 (96.7)	0 (0)	36 (60.0)	0 (0)	24 (40.0)	0 (0)	0 (0)	2 (3.3)	58 (96.7)
Urology	13	11 (84.6)	1 (7.7)	5 (38.5)	5 (38.5)	1 (7.7)	0 (0)	2 (15.4)	1 (7.7)	10 (76.9)
Vascular	33	25 (75.8)	1 (3.0)	28 (84.8)	1 (3.0)	3 (9.1)	1 (3.0)	0 (0)	6 (18.2)	26 (78.8)
All	948	773 (81.5)	6 (0.6)	579 (61.1)	207 (21.8)	115 (12.1)	12 (1.3)	35 (3.7)	157 (16.6)	744 (78.5)

Table 2. Preoperative and Intraoperative Warming by Surgical Service[a]

Abbreviations: CSW, conductive skin warming; ENT, ear, nose, and throat; FAW, forced-air warming; intraop, intraoperative; preop, preoperative.
[a]Values are number (percent), with percentages based on number of surgeries for relevant services.
[b]Surgeries after prone positioning, positioning on fracture table, and positioning on a slip-resistant surface were excluded.
[c]Orthopedics includes podiatry.

Surgical service	Surgeries, No.[a]	Hypothermia, No. (%)[b]
Cardiothoracic	19	4 (21.1)
ENT	75	1 (1.3)
General	220	6 (2.7)
Gynecology	54	0 (0)
Neurosurgery	30	1 (3.3)
Ophthalmology	2	1 (50.0)
Oral surgery	15	0 (0)
Orthopedics[c]	427	14 (3.3)
Plastics	60	1 (1.7)
Urology	13	1 (7.7)
Vascular	33	4 (12.1)
All	948	33 (3.5)

Table 3. Overall Hypothermia

Abbreviation: ENT, ear, nose, and throat.
[a]Surgeries after prone positioning, positioning on fracture table, and positioning on a slip-resistant surface were excluded.
[b]Percentages are based on number of surgeries for relevant services.
[c]Orthopedics includes podiatry.

preoperative or intraoperative warming was provided for 12 patients (1.3%).

Overall, hypothermia was observed in 33 (3.5%) of 948 patients (Table 3). Table 4 summarizes hypothermia cases when conductive warming was used preoperatively (n = 773). Two (5.7%) of the 35 patients who received preoperative CSW and no intraoperative warming became hypothermic. Of the 466 patients who received preoperative and intraoperative CSW, 19 (4.1%) became hypothermic, 4 (2.3%) of the 171 patients who received preoperative CSW and intraoperative FAW became hypothermic, and 2 (2.0%) of 101 patients who received preoperative CSW and a combination of CSW and FAW intraoperatively became hypothermic.

Table 5 shows results for patients who were not provided preoperative warming. Among these, 2 (16.7%) of the 12 patients who also received no intraoperative warming became hypothermic; 3 (2.8%) of the 108 patients who received CSW intraoperatively and 1 (2.9%) of 35 patients who received intraoperative FAW became hypothermic. None of the 14 patients who received a combination of intraoperative CSW and FAW became hypothermic.

Nearly all (95.9%) of the 466 patients who received both preoperative and intraoperative CSW remained normothermic, including 100% of the patients undergoing gynecology (n = 15), neurosurgery (n = 2), oral surgery (n = 6), and plastic surgery (n = 35). Ninety-eight percent of 51 patients undergoing ENT procedures stayed normothermic. Of patients undergoing general surgery (n =113), 96.5% remained normothermic; of patients undergoing orthopedic

Surgical service	Overall Hypothermia, Surgeries, No.[a]	Overall Hypothermia, No. (%)[b]	No intraop warming Hypothermia, Surgeries, No.[a]	No intraop warming Hypothermia, No. (%)[b]	CSW intraop Hypothermia, Surgeries, No.[a]	CSW intraop Hypothermia, No. (%)[b]	FAW intraop Hypothermia, Surgeries, No.[a]	FAW intraop Hypothermia, No. (%)[b]	Both CSW and FAW intraop Hypothermia, Surgeries, No.[a]	Both CSW and FAW intraop Hypothermia, No. (%)[b]
Cardiothoracic	17	3 (17.7)	0	NA	7	1 (14.3)	9	2 (22.2)	1	0 (0)
ENT	70	1 (1.4)	10	0 (0)	51	1 (2.0)	6	0 (0)	3	0 (0)
General	150	5 (3.3)	4	0 (0)	113	4 (3.5)	11	1 (9.1)	22	0 (0)
Gynecology	49	0 (0)	4	0 (0)	15	0 (0)	27	0 (0)	3	0 (0)
Neurosurgery	24	0 (0)	1	0 (0)	2	0 (0)	18	0 (0)	3	0 (0)
Ophthalmology	2	1 (50.0)	1	0 (0)	1	1 (100.0)	0	NA	0	NA
Oral surgery	9	0 (0)	0	NA	6	0 (0)	0	NA	3	0 (0)
Orthopedics[c]	358	13 (3.6)	13	2 (15.4)	208	9 (4.3)	97	1 (1.0)	40	1 (2.5)
Plastics	58	1 (1.7)	0	NA	35	0 (0)	0	NA	23	1 (4.4)
Urology	11	1 (9.1)	2	0 (0)	5	1 (20.0)	3	0 (0)	1	0 (0)
Vascular	25	2 (8.0)	0	NA	23	2 (8.7)	0	NA	2	0 (0)
All	773	27 (3.5)	35	2 (5.7)	466	19 (4.1)	171	4 (2.3)	101	2 (2.0)

Table 4. Hypothermia by Intraoperative Warming Type: Conductive Skin Warming Used Preoperatively (N = 773)

Abbreviations: CSW, conductive skin warming; ENT, ear, nose, and throat; FAW, forced-air warming; intraop, intraoperative; NA, not available.

[a]Surgeries after prone positioning, positioning on fracture table, and positioning on a slip-resistant surface were excluded, and conductive skin warming was used preoperatively.

[b]Percentages are based on the number of surgeries for relevant services.

[c]Orthopedics includes podiatry.

surgery (n = 208), 95.7% remained normothermic; and of patients undergoing vascular procedures (n = 23), 91.3% remained normothermic. Among cardiothoracic surgical patients, 85.7% stayed normothermic. Only 8% of 5 patients undergoing urology surgeries remained normothermic, and the 1 patient undergoing ophthalmology (eyelid) surgery did not stay normothermic (0%).

Table 6 provides additional information for the 33 patients who became hypothermic. The majority (n = 26, 78.8%) received general anesthesia. Fifteen (45.5%) of the 33 patients were undergoing orthopedic surgery, including total knee arthroplasty (n = 6; 18.2%), total hip arthroplasty (n = 3; 9.1%), and shoulder arthroscopy (n = 3; 9.1%). Twenty-five (75.8%) of the 33 patients with hypothermia were actively warmed both preoperatively and intraoperatively. Twenty-seven (81.8%) received preoperative CSW. Two patients (6.1%) received preoperative CSW and a combination of CSW and FAW intraoperatively.

Discussion

Perioperative hypothermia is a major problem leading to negative patient outcomes. Passive warming (eg, a cotton or reflective blanket) merely retains heat and is inadequate to prevent perioperative hypothermia. Active warming minimizes the core-to-periphery temperature gradient, minimizing the risk of perioperative hypothermia. Yet, adherence to preoperative and intraoperative active warming has remained challenging, in part because of workflow considerations with FAW and the variability of types of surgical procedures and surgical positions. Unfortunately, the period during which active warming should be initiated to have maximum benefit is very busy, with competing demands of personnel. An alternative to FAW is CSW. This reusable mat can be placed on the bed before patient arrival, minimizing the time required to initiate warming. To our knowledge, this is the first study published about this conductive silver/carbon ink technology and the utility of this technology for the variety of surgeries performed with different surgical positions. We encouraged clinicians to participate in identifying clinical applications in which this technology might be appropriately used.

- ***Key Findings.*** Providing clinicians with options for preoperative and intraoperative warming resulted in a high rate of adherence to active warming and normothermia for most patients (96.5%). When staff elected to use CSW both preoperatively and intraoperatively, 95.9% of patients remained normothermic. When CSW was used preopera-

Surgical service	Overall Hypothermia,		No intraop warming Hypothermia,		CSW intraop Hypothermia,		FAW intraop Hypothermia,		Both CSW and FAW intraop Hypothermia,	
	Surgeries, No.[a]	No. (%)[b]	Surgeries, No.[a]	No. (%)[b]	Surgeries, No.[a]	No. (%)[b]	Surgeries, No.[a]	No. (%)[b]	Surgeries, No.[a]	No. (%)[b]
Cardiothoracic	2	1 (50.0)	0	NA	1	1 (100.0)	1	0 (0)	0	NA
ENT	4	0 (0)	1	0 (0)	1	0 (0)	2	0 (0)	0	NA
General	69	1 (1.5)	4	0 (0)	53	1 (1.9)	7	0 (0)	5	0 (0)
Gynecology	5	0 (0)	1	0 (0)	2	0 (0)	1	0 (0)	1	0 (0)
Neurosurgery	6	1 (16.7)	1	1 (100.0)	1	0 (0)	4	0 (0)	0	NA
Ophthalmology	0	0 (0)	0	NA	0	NA	0	NA	0	NA
Oral surgery	6	0 (0)	0	NA	3	0 (0)	1	0	2	0 (0)
Orthopedics[c]	67	1 (1.5)	4	0 (0)	42	0 (0)	17	1 (5.9)	4	0 (0)
Plastics	2	0 (0)	0	NA	1	0 (0)	0	NA	1	0 (0)
Urology	1	0 (0)	0	NA	0	NA	1	0 (0)	0	NA
Vascular	7	2 (28.6)	1	1 (100.0)	4	1 (25.0)	1	0 (0)	1	0 (0)
All	169	6 (3.6)	12	2 (16.7)	108	3 (2.8)	35	1 (2.9)	14	0 (0)

Table 5. Hypothermia by Intraoperative Warming Type: No Preoperative Warming Used (N = 169)

Abbreviations: CSW, conductive skin warming; ENT, ear, nose, and throat; FAW, forced-air warming; intraop, intraoperative; NA, not available.

[a]Surgeries after prone positioning, positioning on fracture table, and positioning on a slip-resistant surface were excluded, and no preoperative warming was used.

[b]Percentages are based on the number of surgeries for relevant services.

[c]Orthopedics includes podiatry.

tively and FAW used intraoperatively, 97.7% of patients remained normothermic. When CSW was used preoperatively and the combination of CSW and FAW used intraoperatively, 98.0% of patients remained normothermic.

• ***Limitations.*** This study has 2 limitations. By using an observational design, we could capture the comprehensive nature of the variety of surgeries and surgical positions used in an average operating theater. However, the design does not permit a direct comparison of outcomes related to the use of CSW and FAW. Second, core temperature was approximated using a temporal artery thermometer, a commonly used measurement in many hospitals. This thermometer is not as accurate as invasive measures of core body temperature.[16] However, invasive temperature measurement is not the standard of practice and is not feasible for many surgeries, particularly when regional anesthesia or general anesthesia with a laryngeal airway mask is used.

• ***Interpretation.*** Our results identify opportunities when CSW with silver/carbon ink technology might have a positive impact. For example, in this study, none of the patients undergoing gynecology, neurosurgery, oral surgery, or plastic surgery who received CSW both preoperatively and intraoperatively were hypothermic on admission to the postanesthesia care unit. We also identified patients for whom maintaining normothermia is especially challenging (eg, plastic surgery patients undergoing breast reconstruction). Using a combination of CSW and FAW intraoperatively resulted in 98% of these patients remaining normothermic. Thus, it appears that using both technologies for patients at higher risk of hypothermia may be the best alternative.

We used an observational design in which clinicians were presented with the option of using CSW as an alternative to FAW. The rationale for using this design was to integrate the individual clinical expertise of practitioners into decision making for the heterogeneous population of surgical patients found in a midsized hospital. The decision to use CSW or FAW, which was the standard of practice in the setting, was based on clinicians' assessments of patient risk, surgical procedure, and surgical position. The determination of which positions would provide inadequate skin exposure to the conductive mat (prone, fracture table) was made through consensus reached by perioperative staff who conducted simulations for a variety of surgical positions. Staff also identified that the conductive mat interfered with use of a slip-resistant surface for high lithotomy positioning. Consequently, these conditions were identified as exclusions to the study sample.

Sex/ Age, y	BMI, kg/m^2	Anesthesia	Surgical procedure	Preop temp, °C	Duration, min	Preop warming	Intraop warming	Postop temp, °C
F/35	32.3	GA	AV fistula, upper extremity	Missing	40	None	CSW	35.7
M/73	40.1	SA	Arthroplasty, hip, total	36.8	134	CSW	CSW	35.9
M/83	37.9	SA	Arthroplasty, hip, total	36.5	94	CSW	CSW	35.4
F/61	24.4	GA	Arthroplasty, hip, total	35.9	52	CSW	FAW	35.8
M/30	41.8	GA	Arthroscopy, knee	36.2	78	CSW	CSW	35.9
M/62	26.9	GA, SA	Arthroplasty, knee, total	36.7	71	CSW	CSW	35.5
F/61	36.7	GA	Arthroplasty, knee, total	36.6	122	CSW	CSW	35.6
M/62	39.6	SA	Arthroplasty, knee, total	36.5	74	CSW	CSW	35.8
F/68	29.3	SA	Arthroplasty knee, total	36.7	74	CSW	None	35.9
F/70	29.6	GA	Arthroplasty, knee, total	37.0	38	CSW	CSW	35.7
M/58	22.5	SA	Arthroplasty, knee, total	36.4	77	None	FAW	35.9
M/26	27.7	GA	Arthroscopy, shoulder	Missing	34	CSW	CSW	35.9
M/26	21.9	GA	Arthroscopy, shoulder	36.9	77	CSW	None	35.9
M/62	32.5	GA	Arthroscopy, shoulder	36.5	68	CSW	CSW, FAW	35.5
M/61	18.5	GA	Bypass, FP/femoral tibial	36.1	105	CSW	CSW	35.7
M/64	29.7	GA	Defibrillator lead removal	36.3	149	None	CSW	35.7
F/0	21.9	GA	Endarterectomy, carotid	36.6	161	CSW	CSW	35.9
F/67	34.4	GA	Endarterectomy, carotid	37.4	75	None	None	35.9
M/88	34.0	GA	Eyelid reconstruction with flap	36.0	56	CSW	CSW	35.9
F/45	38.4	GA	Fusion spine, cervical anterior	36.4	101	None	None	35.9
M/65	22.8	GA	Inguinal hernia repair, laparoscopic	36.2	59	None	CSW	35.3
F/57	34.5	GA	Laparoscopy	35.9	56	CSW	CSW	35.9
F/47	46.3	GA	Laparoscopy	36.1	34	CSW	CSW	35.9
F/56	30.1	GA	Mastectomy, bilateral; reconstruction	36.2	392	CSW	CSW	35.8
F/78	28.1	GA	Mastectomy; excision sentinel nodes	36.5	102	CSW	FAW	35.8
M/82	20.8	GA	Penectomy, partial	36.5	51	CSW	CSW	35.9
M/58	34.8	GA	Peritoneal dialysis catheter insertion	36.0	93	CSW	CSW	35.7
F/65	31.2	GA	Reconstruction breast, bilateral	37.0	80	CSW	CSW, FAW	35.8
F/40	30.0	GA	Repair distal lower extremity	36.0	163	CSW	CSW	35.8
M/47	27.8	GA	Thoracoscopy; lobectomy	Missing	60	CSW	FAW	35.8
F/74	17.0	GA	Thoracotomy	36.2	100	CSW	CSW	35.7
F/59	42.5	GA, EDA	Thoracotomy; wedge resection	36.3	66	CSW	FAW	35.7
F/59	32.2	GA	Thyroidectomy/parathyroidectomy	36.4	72	CSW	CSW	35.9

Table 6. Characteristics of Patients With Postoperative Hypothermia (N = 33)

Abbreviations: AV, arteriovenous; BMI, body mass index; CSW, conductive skin warming; EDA, epidural anesthesia; FAW, forced-air warming; FP, femoropopliteal; GA, general anesthesia; intraop, intraoperative; preop, preoperative; postop, postoperative; SA, spinal anesthesia; temp, temperature.

Staff provided preoperative warming for most patients (773 of 948; 81.5%). Adherence to preoperative warming was much easier when patients were admitted to the preoperative care unit rather than when cared for in any of a number of different inpatient wards or the emergency department. Some of these latter patients were either in traction or transported in a bed, preventing placement of the mat under the patient. The CSW technology was readily adopted into the workflow patterns in the preoperative care unit, where it was placed on the bed before patient arrival. Adherence to using CSW was further supported by numerous unsolicited positive comments from patients.

In addition to active warming, adjunct measures may also be incrementally beneficial in preventing perioperative hypothermia. In the study setting, intravenous fluids are room temperature and blood products are warmed with an in-line warmer. A systematic review reported that warming intravenous fluids results in a slightly higher core temperature than using fluids at room temperature.[17] However, it remains to be seen whether this difference in core temperature is also present when active warming is used. In the study setting, irrigation fluids were room temperature for shoulder arthroscopies, total hip arthroplasties, and total knee arthroplasties. However, 2 studies have found that the decrease in patient temperature is greater when room-temperature irrigation fluids are used during shoulder arthroscopy.[18,19]

This observational study provides beginning knowledge of the potential value of adding CSW as an option for clinicians to use for preventing perioperative hypothermia. Additional research should compare processes in preoperative workflow using CSW vs FAW to determine if these technologies result in different rates of adherence to preoperative warming. Next, research should compare the relative effectiveness of the conductive silver/carbon ink technology, FAW, and the combination of both for patients undergoing certain surgeries, specifically total hip arthroplasty, total knee arthroplasty, and shoulder arthroscopy. Research should also evaluate the use of warmed irrigation fluids in conjunction with active warming during shoulder arthroscopy and total hip arthroplasty.

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