Clinical Trial/Experimental Study

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Effect of an electric blanket plus a forced-air warming system for children with postoperative hypothermia

A randomized controlled trial

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Abstract

Background: Postoperative hypothermia in children in postanesthesia care unit (PACU) is a well-known serious complication as it increases the risk of blood loss, wound infections, and cardiac arrhythmias. We conducted this prospective randomized controlled trial to evaluate the effect of an electric blanket plus a forced-air warming system on rewarming in children with postoperative hypothermia.

Methods: We recruited 346 children (aged < 3 years) who were admitted to a PACU after surgery and diagnosed with hypothermia between March and August 2016. They were randomly divided into 3 groups: group C (n = 108, rewarmed with only a regular blanket), group E (n = 123, rewarmed with a regular blanket plus an electric blanket), and group EF (n = 115, rewarmed with an electric blanket plus a forced-air warming system). From the beginning of rewarming, the rectal temperature was recorded every 5 minutes for the first half hour, then every 10 minutes up to when the patient left the PACU. The primary outcome was the rewarming time of children (from the beginning of rewarming to recovery of normothermia). The rewarming rate, increase in temperature (compared with the beginning of rewarming), hemodynamics, recovery time, and incidences of adverse effects were recorded.

Results: There were no significant differences among the 3 groups in terms of the baseline clinical characteristics, use of narcotic drugs, intraoperative temperature, and hemodynamics ($P > .05$). Compared with the children in groups C and E, both the heart rate and mean arterial pressure of those in group EF were significantly increased after 10 minutes of arriving at the PACU ($P < .05$). Children in the EF group had the shortest rewarming time (35.61 ± 16.45 minutes, $P < .001$) and highest rewarming efficiency (0.028 ± 0.001 °C/min, $P < .001$), while there was no evidence of a difference in increased rectal temperature among the 3 groups. Children in the EF group had lower incidences of arrhythmia, shivering, nausea, and vomiting ($P < .05$).

Conclusion: The combination of an electric blanket and a forced-air warming system was shown to be an effective rewarming method for children with postoperative hypothermia.

Abbreviations: ASA = American Society of Anesthesiology, BMI = body mass index, HR = heart rate, IQR = interquartile range, MAP = mean arterial pressure, PACU = postanesthesia care unit.

Keywords: children, postanesthesia care unit, postoperative hypothermia, rewarming

1. Introduction

Hypothermia, which may occur during the whole perioperative period, is generally defined as a core temperature <36 °C.[1] Regarding postoperative hypothermia (especially after general anesthesia and surgery), pediatric patients are a high-risk group because of the less effective regulatory capacity of the central nervous system on body temperature, asymmetrical body weight/surface area, and lower levels of subcutaneous fatty tissue.[2,3] Postoperative hypothermia can cause various adverse effects, such as an increased risk of blood loss, wound infections, and cardiac arrhythmia.[4–6] Therefore, a rapid and safe rewarming method, particularly for children in postanesthesia care units (PACUs), is urgently needed.

According to expert consensus, external rewarming methods include forced-air warming systems, electric blankets, and circulating water mattresses, which are considered to be effective for children with mild hypothermia.[7–9] However, no guidelines or recommendations have been issued regarding rewarming methods for the management of postoperative hypothermia in children in PACU. Therefore, we conducted this prospective randomized controlled trial to evaluate the effect of an eclectic blanket plus a forced-air warming system on rewarming among children with postoperative hypothermia.

2. Methods

2.1. Patients

We obtained ethical approval from the Institutional Review Board of Liaocheng People's Hospital, China, for this prospective

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XL, YS, and ZZ conceived and designed the trial. XL, YS, XL collected the data. CR analyzed the data. XL, YS, and ZZ wrote this paper.

The authors have no conflicts of interest to disclose.

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randomized controlled trial. Children who underwent pediatric surgery between March and August 2016 were enrolled in this study, after informed consent had been granted by their parents or guardian. To be enrolled, they had to meet the following inclusion criteria: age <3 years, American Society of Anesthesiologists (ASA) grade I or II, nontracheal intubation general anesthesia used during surgery, transfer to the PACU after their operation, operation time <30 minutes, and rectal temperature <36 °C on arrival at the PACU. The exclusion criteria included a history of congenital disease, neuropsychiatric disease, blood loss >50 mL, reoperation ≤24 hours after surgery, and emergency surgery.

We enrolled 346 children, who were divided into 3 groups using a computerized randomization table by an investigator not involved in patient care: group C (n = 108), group E (n = 123), and group EF (n = 115), which are explained below. Data from electronic charts and a DoCare Clinic electronic anesthesia recording system were utilized.

2.2. Rewarming

The rewarming methods in the 3 groups were as follows. In group C, the children were covered with regular blanket (except for their heads). In group E, the children were rewarmed with a regular blanket plus an electric blanket (Stihler Electronic, Stuttgart, Germany); they were completely covered except for their heads. The electric blanket was prewarmed for 30 minutes and then controlled at 37 °C to 40 °C during the rewarming process. In group EF, the children were rewarmed with an electric blanket plus a forced-air warming system (Bair Hugger 750, Germany). The electric blanket setting was as same as in group E, and the forced-air warming system was controlled at 38 °C during the rewarming process.[10]

All patients with postanesthesia hypothermia were treated using oxygen inhalation with moist oxygen. From the beginning of rewarming, the rectal temperature of each child was recorded every 10 minutes in the first half hour, then every 15 minutes up to the point at which they left the PACU. When the rectal temperature was ≥36 °C, rewarming was considered to be successful. The rewarming rate was calculated using the following formula: rewarming rate (°C·min^{-1}) = increase in rectal temperature (°C)/rewarming time (minutes).[11,12]

2.3. Outcome measures

The primary outcome was the rewarming time (from the beginning of rewarming to recovery of normothermia). The rewarming rate, increase in the rectal temperature (compared with the beginning of rewarming), hemodynamics, recovery time, and incidences of adverse effects were also recorded.

2.4. Data collection

The perioperative hemodynamic data (mean arterial pressure [MAP] and heart rate [HR]) and rectal temperature were obtained using a Phillips IntelVue monitor MP50 at the following timepoints: arrival in the operating room (T0), just before anesthesia induction (T1), 5 minutes after anesthesia induction (T2), at the beginning of the operation (T3), 10 minutes after the start of the operation (T4), 20 minutes after the start of the operation (T5), at the end of operation (T6), and 10 minutes (T7), 20 minutes (T8), 30 minutes (T9), and 45 minutes (T10) after arriving in the PACU. We also recorded the length of the PACU stay based on the Aldretes criteria. The number of adverse effects (such as bradycardia, tachycardia, hypotension, hypertension, nausea, vomiting, agitation, and respiratory depression) was also recorded at the end of the study.

2.5. Statistical analysis

The Kolmogorov–Smirnov test was used to assess the distribution of the variables. Homogeneity of variance was determined using Levene tests. The quantitative data were expressed as means and standard deviations or medians and interquartile ranges (IQRs). Intergroup comparisons were performed using repeated-measures analysis of variance. Bonferroni correction was used for post-hoc multiple comparisons. The nonparametric Wilcoxon–Mann–Whitney test was used for variables that were not normally distributed. Categorical data were expressed as frequencies and percentages, and analyzed using χ^2 tests or Fisher exact tests, when appropriate. Probability (P) values <.05 were considered statistically significant. The statistical analysis was performed with SPSS for Windows version 18.0 (SPSS Inc, Chicago, IL).

3. Results

3.1. Baseline characteristics

The patient enrollment flow diagram is shown in Figure 1. Four hundred eighty children who underwent pediatric surgery between March and August 2016 with the informed consent of their parents or guardian were enrolled in the study. One hundred thirty-four children were excluded because of not meeting the inclusion criteria: 35 required emergency surgery, 24 refused the surgery, 9 had a history of congenital disease, the operation time of 17 was >30 minutes, 35 had hemorrhages >50 mL, and 14 were excluded after surgery due to incomplete clinical data. Consequently, 346 patients were included in the primary analysis and divided into 3 groups: group C (n = 108), group E (n = 123), and group EF (n = 115). The 3 groups were comparable regarding age, sex, body mass index (BMI), ASA grade, type of surgery, and duration of anesthesia and operation (Table 1).

3.2. Perioperative hemodynamic data

The baseline HR and MAP were not significantly different among the 3 groups ($P > .05$, Fig. 2). Compared with groups C and E, the HR in group EF was significantly increased at T7, T8, and T9 (T7: 115 ± 8 vs 118 ± 9 vs 126 ± 9 beats/min, $P < .01$; T8: 123 ± 7 vs 122 ± 9 vs 135 ± 7 beats/min, $P < .01$; T9: 126 ± 9 vs 127 ± 6 vs 138 ± 8 beats/min, $P < .01$; in group C, E, and EF, respectively). Compared with groups C and E, the MAP in group EF was significantly increased at T7, T8, and T9 (T7: 58.64 ± 5.01 vs 59.45 ± 5.21 vs 65.42 ± 4.98 mm Hg, $P < .01$; T8: 58.54 ± 3.97 vs 58.46 ± 4.32 vs 68.76 ± 4.21 mm Hg, $P < .01$; T9: 62.69 ± 5.77 vs 64.34 ± 7.53 vs 70.13 ± 7.47 mm Hg, $P < .01$; in group C, E, and EF, respectively). The lowest HR and MAP in the 3 groups both occurred at T3 (Fig. 2).

There were no significant differences among the 3 groups in terms of the duration of surgery, duration of anesthesia, fluid infusion, and estimated blood loss ($P > .05$, Table 2). The consumption of ketamine and propofol was compared among the 3 groups, and no significant differences were found ($P > .05$, Table 2).

3.3. Effects of different rewarming methods

The mean rewarming time, rewarming rate, and increase in rectal temperature after the administration of different rewarming techniques in children are shown in Table 3.

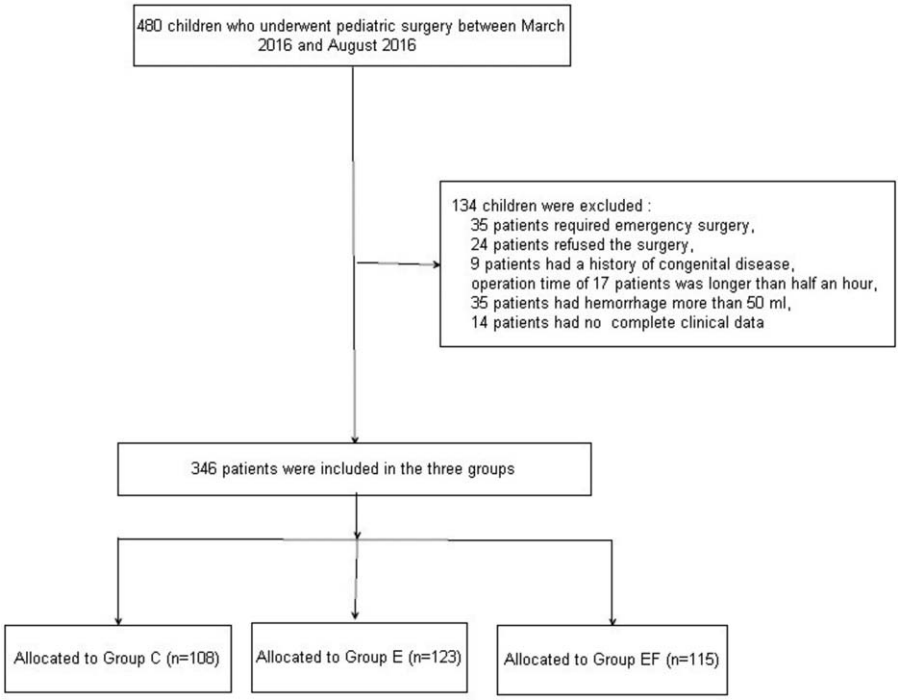

Figure 1. Patient enrolment flow diagram. This illustrates the flow of all the patients screened (including those who were excluded).

The baseline rectal temperature was not significantly different among the 3 groups ($P > .05$, Fig. 3). Compared with groups C and E, the rectal temperature in group EF was significantly increased at T7, T8, and T9 (T7: 35.98 ± 0.45 vs 36.03 ± 0.21 vs 36.35 ± 0.17°C, $P < .01$; T8: 36.23 ± 0.97 vs 36.35 ± 0.45 vs 36.68 ± 0.12°C, $P < .01$; T9: 36.48 ± 0.77 vs 36.65 ± 0.53 vs 36.88 ± 0.74°C, $P < .01$; in groups C, E, and EF, respectively). The lowest rectal temperatures in the 3 groups occurred at T6 (Fig. 3). There was significant difference in the rewarming time in group C compared with groups E and EF (63.47 ± 15.25 vs 54.68 ± 18.53 vs 35.61 ± 16.45 minutes, $P < .01$; in groups C, E, and EF, respectively, Table 3).

Children in groups C and E had a significantly lower rewarming rate than those in group EF (0.022 ± 0.001 vs 0.024 ± 0.001 vs 0.028 ± 0.001 °C/min, $P < .01$; in groups C, E, and EF, respectively, Table 3). There was also significant evidence of a difference in the increase in rectal temperature among the 3 groups (1.61 ± 0.11 vs1.63 ± 0.12 vs 1.72 ± 0.14°C, $P = .028$; in groups C, E, and EF, respectively, Table 3).

3.4. Adverse events

The main adverse events are recorded in Table 4. Compared with the patients in groups C and E, those in group EF had a lower incidence of arrhythmia (16 vs 15 vs 5, $P = .027$, in groups C, E, and EF, respectively), shivering (32 vs 26 vs 12, $P = .002$, in groups C, E, and EF, respectively), nausea (29 vs 27 vs 15, $P = .034$, in groups C, E, and EF, respectively), and vomiting (12 vs 8 vs 2, $P = .016$, in groups C, E, and EF, respectively). In contrast, there was no significant difference among the 3 groups in the incidence of hypoxemia (9 vs 10 vs 11, $P = .915$, in groups C, E, and EF, respectively), hypotension (7 vs 11 vs 9, $P = .785$, in groups C, E, and EF, respectively), and hypertension (16 vs 18 vs 15, $P = .914$, in groups C, E, and EF, respectively).

Table 1

Demographic data of the children with postoperative hypothermia in the 3 groups.

	Group C (n = 108)	Group E (n = 123)	Group EF (n = 115)	*P* values
Age, y	2.35 ± 0.74	2.55 ± 0.68	2.42 ± 0.66	.083
Body weight, kg	12.45 ± 4.22	13.42 ± 4.34	12.85 ± 4.08	.214
Height, m	0.86 ± 0.35	0.84 ± 0.37	0.85 ± 0.38	.918
BMI, kg·m^{-2}	24.57 ± 4.12	25.07 ± 3.98	25.52 ± 4.52	.244
Sex, male/female	65/43	70/53	75/40	.420
ASA I or II, n	92/16	109/14	98/17	.674
Type of surgery, n, %				.991
Inguinal hernia repair	67 (62.04%)	75 (60.98%)	70 (60.87%)	
Cryptorchidopexy	25 (23.15%)	30 (24.39%)	27 (23.48%)	
Hemangioma resection	6 (5.56%)	8 (6.50%)	6 (5.22%)	
Excision of finger	2 (1.85%)	4 (3.25%)	3 (2.61%)	
Others	8 (7.41%)	6 (4.88%)	9 (7.83%)	

The variables are presented as mean ± standard deviation or number of patients, n (%). ASA = American Society of Anesthesiologists, BMI = body mass index.

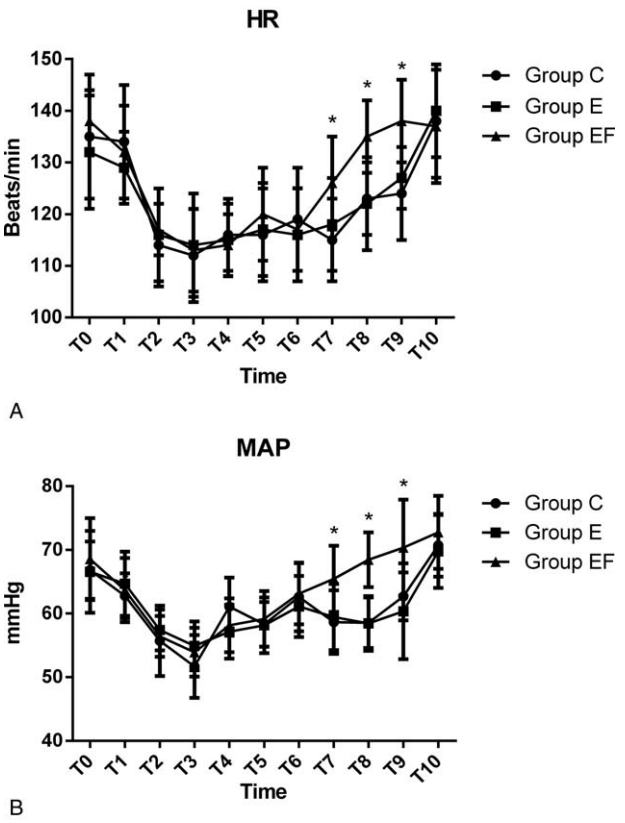

Figure 2. Hemodynamics were monitored in the 3 groups. T0, arrival in the operating room; T1, just before anesthesia induction; T2, 5 min after anesthesia induction; T3, at the start of the operation; T4, 10 min after the start of the operation; T5, 20 min after the start of the operation; T6, at the end of operation; T7 10 min after arriving in the PACU; T8, 20 min after arriving in the PACU; T9, 30 min after arriving in the PACU; T10, 45 min after arriving in the PACU. $^{*}P < .05$ versus group C. PACU = postanesthesia care unit.

4. Discussion

We found that a combination of an electric blanket and a forced-air warming system was an effective rewarming method for children with postoperative hypothermia. At the same time, the incidence of arrhythmia, shivering, nausea, and vomiting was reduced among these patients compared with those in the other 2 groups.

Mild hypothermia, which often occurs during and after operations, developed among the children immediately after the induction of general anesthesia. There are many reasons for this phenomenon, including a combination of anesthetic-induced impairment of thermoregulatory control, a cool operating room environmental temperature, an internal redistribution of heat within the body, inspiration of dry and cool anesthetic gases, evaporation of surgical skin preparations, and infusion of cool fluids.[13–15] To summarize, hypothermia occurs when heat loss exceeds metabolic heat production. Cutaneous heat loss is mainly the result of convection and radiation (which make up 85% of the total heat loss) from the patient to the environment. Heat loss from conduction and evaporation account for < 15% in most circumstances.[16,17] Previous studies have shown that intraoperative hypothermia is minimized by at least 2 hours of active skin-surface warming before anesthesia in volunteers using a forced-air warming system and in surgical patients using an electric blanket.[18,19] However, such prolonged prewarming is impractical for most patients, especially for children undergoing short operations.

Children often have difficulty in maintaining normal body temperatures in environments that would be comfortable for adults, as they regulate their body temperature less efficiently than adults.[20] One study showed that a naked baby exposed to a cool operating room environmental temperature, which is usually set to 23 °C, suffers the same heat loss as a naked adult at 0 °C.[21] Normothermia in infants is an axillary temperature of 36.5 °C to 37.5 °C, as defined by the American Academy of Pediatrics. In

Table 2

Intraoperative data of the children with postoperative hypothermia in the 3 groups.

	Group C (n = 108)	Group E (n = 123)	Group EF (n = 115)	*P* values
Duration of surgery, min	23.43 ± 8.45	24.52 ± 9.55	25.63 ± 6.03	.134
Duration of anesthesia, min	45.35 ± 13.46	42.42 ± 15.98	42.36 ± 14.03	.218
Estimated blood loss, mL	14.57 ± 3.34	15.04 ± 2.52	14.86 ± 3.09	.488
Fluid infusion, mL	66.72 ± 11.64	68.62 ± 12.62	70.23 ± 9.08	.067
Ketamine, mg	38.34 ± 10.92	40.95 ± 12.48	39.82 ± 13.32	.275
Propofol, mg	56.42 ± 13.57	58.33 ± 15.39	55.92 ± 14.02	.394

The variables are presented as mean ± standard deviation.

Table 3

Rewarming effects among children with postoperative hypothermia in the 3 groups.

	Group C (n = 108)	Group E (n = 123)	Group EF (n = 115)	*P* values
Rewarming time, min	63.47 ± 15.25	54.68 ± 18.53*	35.61 ± 16.45*,†	< .001
Rewarming rate, °C/min	0.022 ± 0.001	0.024 ± 0.001*	0.028 ± 0.001*,†	< .001
Increase in rectal temperature, °C	1.61 ± 0.11	1.63 ± 0.12	1.72 ± 0.14*,†	.028

The variables are presented as mean ± standard deviation.

$^{*}P < .05$ versus group C.

$^{\dagger}P < .05$ versus group E.

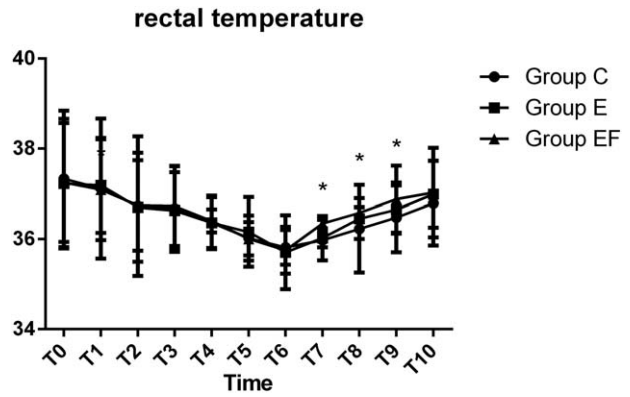

Figure 3. Rectal temperature was monitored in the 3 groups. T0, arrival in the operating room; T1, just before anesthesia induction; T2, 5 min after anesthesia induction; T3, at the start of the operation; T4, 10 min after the start of the operation; T5, 20 min after the start of the operation; T6, at the end of operation; T7 10 min after arriving in the PACU; T8, 20 min after arriving in the PACU; T9, 30 min after arriving in the PACU; T10, 45 min after arriving in the PACU. *$P < .05$ versus group C. PACU = postanesthesia care unit.

addition, the World Health Organization define scold stress as temperatures of 36.0 °C to 36.5 °C and frank hypothermia as all temperatures <36.0 °C.[22] The American Society of PeriAnesthesia Nurses suggests that core temperatures <36 °C cause thermal discomfort, and these temperatures are associated with an increase in the morbidity and mortality rates of the American Society of PeriAnesthesia Nurses.[23] As a result of all these factors, we defined postoperative hypothermia as a core temperature (rectal temperature) <36 °C.

Numerous studies have examined the validity of different rewarming methods for children during anesthesia and surgery.[2,3] However, there have been no guidelines or recommendations issued for rewarming methods for use in PACU for the management of postoperative hypothermia among children. Therefore, we conducted this prospective randomized controlled trial to evaluate the effect of the combination of an electric blanket plus a forced-air warming system on rewarming in children with postoperative hypothermia.

Methods to keep a patient's body temperature at normothermia levels during surgery include covering the patient's head and body with a blanket, increasing the ambient room temperature, warm intravenousor skin irrigation solutions, and using external warming devices. Forced-air warming has been proven to be the most effective method to maintain normothermia among children undergoing surgery.[24,25] Although the cost of a forced-air warming system is more than that of a regular blanket or an electric blanket, it is often worthwhile shortening the patient's stay in the PACU and reducing the risk of the increased costs of treating complications associated with postoperative hypothermia.

Consistent with previous studies,[26,27] we found that the rewarming time, rewarming rate, and increase in rectal temperature in group EF (treated with both an electric blanket and a forced-air warming system) were all significantly increased compared with the children treated with only a regular blanket or only an electric blanket. As a result, both the HR and MAP in group EF were significantly increased at T7, T8, and T9 (T7: 115 ± 8 vs 118 ± 9 vs 126 ± 9 beats/min, $P < .01$; T8: 123 ± 7 vs 122 ± 9 vs 135 ± 7 beats/min, $P < .01$; T9: 126 ± 9 vs 127 ± 6 vs 138 ± 8 beats/min). However, there was no significant difference among the 3 groups in the incidence of hypoxemia (9 vs 10 vs 11, $P = .915$), hypotension (7 vs 11 vs 9, $P = .785$), or hypertension (16 vs 18 vs 15, $P = .914$).

We also found that the children in group EF had lower incidences of arrhythmia (16 vs 15 vs 5, $P = .027$), shivering (32 vs 26 vs 12, $P = .002$,), nausea (29 vs 27 vs 15, $P = .034$), and vomiting (12 vs 8 vs 2, $P = .016$) compared with the patients in groups C and E. However, the incidences of arrhythmia and shivering were still higher than in previous studies.[27] The reasons for this may include the short length of the operations involved in this study and the different types of patients recruited, surgeries performed, and precise methods of rewarming selected.[28]

There are several limitations associated with our study. First, the study is a small prospective randomized controlled trial, and a large multicenter prospective trial is necessary to verify the effect of the combination of an electric blanket plus a forced-air warming system on rewarming among children with postoperative hypothermia. Second, we only included children with short operations (<30 minutes). Operation time varies greatly according to the type of surgical procedure, and further research is required on children undergoing lengthy complex surgery. Third, we failed to consider hyperthermia as a complication during the postoperative period. Although none of the children in our study developed hyperthermia, this variable should be included in future study protocols.

In summary, the combination of an electric blanket and a forced-air warming system was shown to be an effective rewarming method for children with postoperative hypothermia. In addition, the incidences of arrhythmia, shivering, nausea, and vomiting were reduced in these patients compared with those in the other 2 groups. However, further multicenter prospective

Table 4

Postoperative adverse events among children with postoperative hypothermia in the 3 groups.

	Group C (n = 108)	Group E (n = 123)	Group EF (n = 115)	*P* values
Nausea	29 (26.85%)	27 (21.95%)	15 (13.04%)*,†	.034
Vomiting	12 (11.11%)	8 (6.50%)*	2 (1.74%)*,†	.016
Arrhythmia	16 (14.81%)	15 (12.20%)	5 (4.35%)*,†	.027
Hypertension	16 (14.81%)	18 (14.63%)	15 (13.04%)	.914
Shivering	32 (29.63%)	26 (20.33%)	12 (10.43%)*,†	.002
Hypotension	7 (6.48%)	11 (8.94%)	9 (7.83%)	.785
Hypoxemia	9 (8.33%)	10 (8.13%)*	11 (9.57%)	.915

The variables are presented as number of patients, n (%).

* $P < .05$ versus group C.

† $P < .05$ versus group E.

studies are still necessary to verify the effect of this composite technique on rewarming among children with postoperative hypothermia.

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