Perioperative Cost-finding Analysis of the Routine Use of Intraoperative Forced-air Warming during General Anesthesia

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Background: Despite the well-documented ability of forced-air warming (FAW) to maintain normothermia, it is unclear whether this technique results in a net increase or decrease in costs. The authors did a prospective cost-finding study comparing FAW with routine thermal care in patients at low risk for perioperative complications who were undergoing general anesthesia.

Methods: After institutional review board approval was received, 100 patients were studied who were having elective surgery scheduled for more than 2 h during general endotracheal anesthesia. Patients were randomly assigned to one of two groups: FAW or routine thermal care. All patients received a standardized anesthetic. Anesthesia providers were blinded to core temperatures and the use of FAW. Primary outcomes were those associated with perioperative costs.

Results: The time from completion of surgical dressing until tracheal extubation was significantly reduced in the FAW group (10 ± 1 min compared with 14 ± 1 min; mean $\pm$ SEM; $P < 0.01$). There was no demonstrable difference in attainment of postanesthesia care unit discharge criteria between the two groups, although the FAW group used one less cotton blanket there. The net savings related to the use of the FAW depends on the percentage of the intraoperative costs that are fixed rather than variable ($15 additional for FAW if all costs are fixed compared with $29 savings if all costs were variable).

Conclusions: Routine intraoperative FAW significantly reduced time until extubation and use of cotton blankets in the postanesthesia care unit. These results suggest that the influence of FAW on net total perioperative costs depends on patient and surgical characteristics and institutional factors related to cost accounting. (Key words: Economics; hypothermia; randomized clinical trial; sensitivity analysis; technology assessment.)

NEW technology is constantly being developed for introduction into clinical practice. As part of the initial approval process, a new medical device must be shown to be safe and efficacious (*i.e.*, perform its stated purpose under ideal conditions). Further, before a new medical technology is adopted into clinical practice, its cost-effectiveness for improving clinical care should be determined.

Among the new technologies introduced into anesthesia practice to maintain normothermia is the forced-air warmer. It efficacy in maintaining normothermia has been well demonstrated.[1] Forced-air warming (FAW) improves outcome in several clinical scenarios, such as for patients having major bowel surgery, treatment for cardiac diseases, and total hip arthroplasty.[2-4] However, none of these studies evaluated the cost of implementing the technology itself. When determining overall costs, the potential savings related to the new device (*i.e.*, forced air warmers) must also be included. Cost-finding analysis (also called observational cost studies) offers a way to identify the cost of different available diagnostic or therapeutic strategies.[5,6] Once a cost-finding analysis is completed, a full economic evaluation can be performed. For example, if the outcomes of two strategies are equivalent, then the cost-finding analysis is the same as a cost-minimization study in which the goal is to find the least expensive way to achieve the outcome.[7]

In attempting to assess all potential costs and savings related to FAW, we hypothesized that maintenance of normothermia with the routine use of FAW may prolong the emergence time from anesthesia as a result of decreased drug metabolism. In addition, postanesthesia care unit (PACU) discharge may be prolonged in patients at greatest risk for hypothermia to develop, such

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as the elderly population and those undergoing surgery associated with exposure of a large body surface area. We did a prospective cost-finding analysis from a societal perspective that compared FAW with routine thermal care (RTC) in patients at low risk for perioperative cardiac complications who were having general anesthesia for a surgical procedure. We also tried to determine those factors, other than the use of intraoperative FAW, that predict the time in the PACU and therefore resource use.

Materials and Methods

With institutional review board approval and written informed patient consent, patients were enrolled who were classified as American Society of Anesthesiologists (ASA) physical status I, II, or III, who ranged in age from 18 to 85 yr, and who were scheduled for gynecologic, plastic, orthopedic, or general surgery and for postsurgical admission to one PACU location. One hundred patients were randomly assigned to one of two groups: FAW or RTC. Patients were randomized to group assignment using a random-number generator that blocked every 10 patients. Inclusion criteria included elective surgery scheduled for at least 2 h and the use of general endotracheal anesthesia. Because the study was designed prospectively to assess economic outcomes in patients with a low probability of adverse perioperative complications, patients with coronary artery disease were excluded. Exclusion criteria also included combined general and regional anesthesia, preoperative fever (>38°C oral), minor peripheral procedures, and factors that precluded the use of a lower body FAW blanket (*i.e.,* use of leg stirrups or lower extremity surgery). Demographics were assessed including weight and ASA physical status classification.

Thermal Management

The thermostat in the operating room was set at approximately 21°C. Both groups received prewarmed crystalloid, passive airway humidification, and a lower extremity warming blanket (Mallinckrodt Medical, St. Louis, MO) that was completely covered by one cotton blanket and surgical drapes. Those patients randomized to receive RTC had their blankets connected to the warming unit, which was turned on but not programmed to deliver air. Those patients randomized to receive warm air (FAW) had their units turned to high temperature and high flow settings after drapes were placed. Because the warming units fit under the foot of the bed, and the forced-air blankets were completely covered by surgical drapes, the anesthesia providers and PACU staff were blinded to the use of FAW and to body temperature data. Success of the blinding protocol regarding the use of FAW was assessed by a questionnaire given to the anesthesiologist in a subset of cases. The questionnaire asked the provider to guess which modality was being used or to say "not sure."

Temperature Monitoring

Sublingual temperatures were measured before operation. Intraoperative and postoperative core temperatures were measured using a tympanic membrane thermocouple probe (Mon-a-Therm; Mallinckrodt). When a urinary bladder catheter was indicated, a second core temperature thermocouple probe was used in the urinary bladder catheter (Mon-a-Therm). Body temperature was monitored with these probes using an isothermex monitor (Columbus Instruments, Columbus, OH) every 2.5 min until discharge from the PACU. If the tympanic probe could not be placed because of surgical needs or it became dislodged during operation, the bladder temperature was substituted for tympanic temperature. The anesthesia provider was blinded to intraoperative temperature measurements, which were monitored by a member of the research team not involved in the anesthetic care. In all patients, core temperatures were maintained between 34.5°C and 38°C, which are currently accepted allowable temperature extremes in our hospital. If the RTC patient temperature decreased to <34.5°C, FAW was to be initiated by a member of the research team to prevent further decrease in core temperature without the knowledge of the anesthesia team. The FAW was discontinued once the temperature increased to >34.5°C. If core temperature increased to >38°C, the anesthesiology and surgical teams were notified. In the PACU, temperature was provided to the nursing staff when the patient was determined to be ready for discharge from the PACU.

Anesthetic Technique

All patients received general endotracheal anesthesia. Patients received a standardized anesthetic premedication with midazolam (up to 2 mg), fentanyl (up to 3 μg/kg), or both. General anesthesia was induced with thiopental (3-5 mg/kg) or propofol (1.5-2.5 mg/kg) and fentanyl (2-10 μg/kg total for case). Rocuronium was used to facilitate endotracheal intubation and to maintain muscle relaxation. Anesthesia was maintained

with isoflurane (0.5–1.5%) and nitrous oxide (50–70%) in oxygen. Fresh gas flows were kept <3 l/min. Ventilation was controlled to keep the end-tidal carbon dioxide level at approximately 35 mmHg. Neuromuscular blockade was monitored so that one twitch of a train-of-four was present, and it was reversed at the end of surgery with neostigmine (0.05–0.07 μg/kg) and glycopyrrolate (0.01 μg/kg).

The decision to extubate was based on criteria that included adequate spontaneous ventilation, return of airway reflexes, and a sustained head lift for 5 s, as determined by the anesthesiologist. Extubation was performed without knowledge of body temperature. Time from completion of surgical dressing until extubation was measured in both groups. This time was used as a measure of postsurgical emergence time from anesthesia.

Care in the Postanesthesia Care Unit

Care in the PACU was performed according to established protocols. Discharge criteria used in our institution include blood pressure and pulse rate within 20% of baseline, oxygen saturation >95% on <6 l oxygen *via* face mask, pain scores ≤5 of 10, and responsiveness to verbal stimuli. These criteria were assessed by the nursing staff every 10 min, and time to attainment of discharge criteria was measured. Analgesia in the PACU consisted of intravenous morphine sulfate patient-controlled analgesia, unless otherwise specified by the surgeon. Warm blankets were applied to the patient based on the subjective complaint of being cold or the observation of shivering by the nursing staff. No active FAW was used in the PACU.

Economic Assessment

A societal cost perspective was used that included hospital and physician costs. All resources related to the use or potential use of FAW were assessed prospectively, and costs were determined at the end of the study period. The cost of FAW was determined using retail costs for the blankets and costs for the warming units amortized over 5 yr and assuming use in 10 cases per week based on current use at our hospital and estimated longevity of the unit based on manufacturer information. The PACU costs included warmed cotton blankets, the cost of which was calculated based on laundry and acquisition costs. The cost of medications to manage postoperative pain, nausea, and vomiting were calculated based on pharmacy drug acquisition and delivery system costs.

The costs of intraoperative and PACU care include fixed semivariable and variable costs and incorporate the costs of basic supplies, equipment, and institutional overhead. Assuming that all costs are variable, then the per-minute-cost for the operating room and PACU time can be calculated based on resource use and labor requirements for the period when the study was conducted. Specifically, intraoperative costs reflect total nursing cost plus the institutional overhead costs divided by total operating room minutes billed for the 1-yr period when the study was conducted. The PACU costs were based on calculations of staffing and resource allocations in the PACU. The PACU per-minute nursing cost was determined by dividing total PACU staff salaries by total PACU minutes billed for the study period. Anesthesia provider costs were assessed based on the Medicare payment fee schedule on a per-minute basis.

Assessment of Patient Satisfaction

Patient satisfaction was assessed through a personal interview with the patient on the morning after surgery. This instrument assessed satisfaction of anesthetic care using a five-point scoring system of excellent, very good, good, fair, and poor. This scale was used before as part of a study of ophthalmologic anesthetic care, but it had not been validated in a large cohort of general anesthesia patients. In addition, patients were asked to mark the degree of satisfaction on a horizontal visual analog scale, which was converted subsequently to a score. Patients were also queried as part of a free-form interview regarding any potential improvements in their care.

Statistical Analysis

Data related to costs, including time to extubation and discharge from the PACU, were compared in the two groups using an unpaired Student's *t* test. To test the effectiveness of randomization, patient demographics, temperature, and satisfaction were compared for the two groups using an unpaired Student's *t* test or Fisher's exact test when appropriate. Data are expressed as mean ± SEM. As part of the secondary hypotheses, determinates of one of the economic outcomes (min in the PACU) were assessed by multiple linear regression. All analyses were performed on an intent-to-treat basis.

A sensitivity analysis of the effect of varying the fixed rather than the variable costs was performed to determine the influence of this factor on the optimal decision.

Table 1. Patient Demographics

	Routine Thermal Care	Forced-air Warming	P
n	47	48	
Age (yr)	47 ± 2	43 ± 2	NS
Female sex	39 (83%)	38 (79%)	NS
Weight (lb)	156.9 ± 5.2	162.1 ± 5.9	NS
Height (cm)	64.7 ± 0.6	65.7 ± 0.5	NS
Postinduction core temperature (°C)	36.6 ± 0.1	36.5 ± .1	NS
Postsurgical core temperature (°C)	35.4 ± 0.1	36.8 ± 0.1	<0.001
Duration of surgery	222.0 ± 13.7	250.6 ± 15.1	NS

NS = not significant.

Results

One hundred anesthetics delivered to 99 patients were studied. The procedures included general, gynecologic, plastic, and orthopedic surgeries. Fifty patients were randomized to each treatment group. Five patients were excluded from the analysis based on the inability to extubate in the operating room or unexpected admission to the intensive care unit, leaving a total of 95 cases of anesthesia, with 47 patients in the RTC group and 48 in the FAW group.

There were no significant demographic differences between the two groups with regard to age, sex distribution, weight, and height (table 1). Seventy-three percent of patients in the RTC group were classified as ASA physical status I or II, compared with 81% in the FAW cohort. The duration of surgery from incision until application of the dressing was similar in both groups. Postinduction core temperatures did not differ between the two groups. In the routine care group, temperatures declined progressively during the operative period. At the end of surgery, the mean core temperatures were significantly lower than baseline in the RTC group (35.5 ± 0.1°C). In contrast, the actively warmed group was slightly warmer than baseline (36.8 ± 0.1°C). The temperature difference between the two groups at the end of surgery was significant ($P < 0.05$). Forced-air warming was used to prevent further hypothermia in two patients in the RTC group whose core temperature decreased to <34.5°C.

Time from the end of surgery until extubation was measured in the two groups. Postsurgical emergence time (from completion of surgical dressing until extubation) was significantly reduced in the FAW group. Emergence time was 14 ± 1 min in the RTC group and 10 ± 1 min in the FAW group ($P < 0.01$).

When they arrived in the PACU, RTC patients had significantly lower temperatures than FAW patients did (fig. 1). However, there was no demonstrable difference in the time to attainment of PACU discharge criteria between the two groups (80 ± 6 min in the RTC group compared with 80 ± 6 min in the FAW group; $P = $ NS). There was no significant difference among any of the surgical subgroups.

The inverse correlation between temperature at the end of surgery with postsurgical emergence time was significant. The initial temperature in the PACU did not correlate with time in the PACU ($P = 0.22$). Interestingly, temperature at the end of their care in the PACU inversely correlated with time in the PACU ($P = 0.01$), although weakly ($R^2 = 0.07$). In addition to temperature, the total fentanyl dose administered during the last hour of surgery also significantly correlated with the length of stay in the PACU.

The ability to successfully blind the anesthesiology providers to the use of the FAW blankets was examined in 66 cases. For those anesthesiologists who expressed an opinion about the method of thermal warming, there was no correlation between randomization group and their opinions ($P = 0.78$). The anesthesiologists were not sure 43.8% of the time in patients in the FAW group and 50% of the time in the RTC group. Of those who
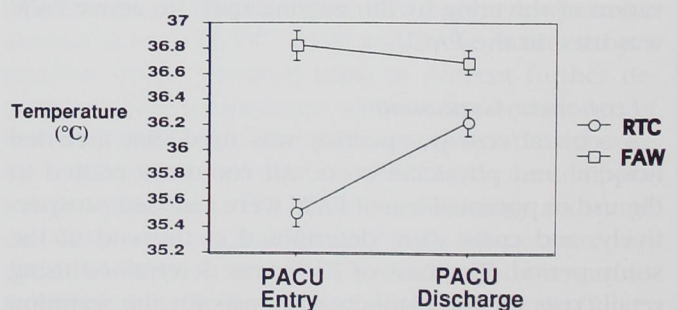

Fig. 1. Mean and standard error of the postanesthesia care unit (PACU) entry and readiness-to-discharge temperatures for the forced-air warming (FAW) and routine thermal care (RTC) cohorts. Patients in the FAW group entered the PACU warm (36.8 ± 0.1°C) and remained warm (36.7 ± 0.1°C). Patients in the RTC group entered the PACU at a significantly lower temperature than the FAW group (35.5 ± 0.1°C) and were discharged at a significantly higher temperature than at entry (36.2 ± 0.1°C; $P < 0.01$), which was also significantly lower than the discharge temperature in the FAW group ($P < 0.01$). Importantly, the temperatures of some of the patients (10 of 45) in the RTC group remained <35.5°C even when they were ready for discharge.

expressed an opinion and worked with the patients who received routine care, the response was correct in 59% of the cases. Among the physicians who worked with the patients who received FAW, their responses were correct in 44% of the cases.

Resource Use

Patients in the routine care group used two blankets, whereas patients in the warmed group used one blanket in the PACU, in addition to the standard one blanket given before they left the operating room ($P < 0.001$). There was no significant difference in the incidence of postoperative nausea between the two groups. In addition, there were no significant differences between medication use in the PACU between the two groups, including morphine for analgesia and ondansetron and metoclopramide for postoperative nausea.

Patient Satisfaction Scores

There was no significant difference in patient satisfaction scores. Based on the five-point assessment of anesthesia care, there was no difference between the two groups (95% of the patients thought their care was good or excellent in the RTC group, compared with 86% of patients with this opinion in the FAW group). There was no statistical difference in the number of patients who suggested that their care could have been improved (25% in the RTC group compared with 18% in the FAW group; $P = 0.43$). In addition, the 100-point satisfaction score was (91 ± 2) for the RTC group and (91 ± 2) for the FAW group.

Economic Analysis

Immediate perioperative costs related to the use of the FAW included the amortized costs of the warming unit ($0.82 per use) and the blankets themselves ($15). Potential resources that could be saved include cotton blankets ($0.95 per blanket based on laundering and replacement costs) and time. The Medicare payment for anesthesia is $1.14 per min. Assuming that all intraoperative costs are variable (*i.e.*, additional costs exactly match additional units of production), then each intraoperative minute in our institution costs $9.20. Similarly, PACU costs during the study were $1.04 per min. Therefore, the net savings related to the use of the FAW depends on the percentage of the operating room costs that are fixed rather than variable (fig. 2).

Discussion

Our cost-finding study of routine intraoperative FAW showed that this technology significantly reduced the time until extubation and the use of cotton blankets in the PACU. In addition, patients who remained cold in the PACU had a delayed time until discharge, which may have been further improved by FAW. With respect to the potential cost savings related to the use of FAW, our results suggest that its influence on net total perioperative costs depends on patient and surgical characteristics and institutional factors related to cost accounting.

The findings of a reduction in the time to extubation in warmer patients is consistent with the known effects of hypothermia. Hypothermia has been previously associated with prolongation or potentiation of the action of drugs used by anesthesiologists.[8–10] For example, Vitez *et al.*[11] found that the minimum alveolar concentrations of halothane and isoflurane were decreased approximately 5% for each degree of reduction in body temperature.

As Sperry[12] described in a recent review, hospital costs are fixed and variable. If we theoretically assume all costs as variable, when the additional expenditure for FAW is compared with the measured savings in labor and supplies, FAW decreases overall cost at our institution. However, in reality, most OR costs are fixed (*i.e.*, costs do not depend on the product produced) or semivariable, and savings would only be realized if staff could be reduced or additional cases performed as a result of the use of FAW.[13] Although the small reduction in OR time was statistically significant, in most cases, it would not be financially significant. Ideally, fixed and marginal costs should be calculated, as demonstrated by Macario *et al.*[14] At a similar academic institution, they suggested that 44% of operating room costs are variable.[14] Even if marginal costs were determined, Dexter *et al.*[13] suggest that a true cost savings could not be achieved in the operating room or PACU unless staffing was reduced or additional cases were performed. However, such studies have focused on academic medical centers with their inherent cost inefficiencies. If, for example, substantial time was saved in the PACU resulting in reduced overtime or staff, then such financial savings might be realized.

The primary costs of FAW are the blankets. When amortized over 5 yr, the costs of the warming units were less than the costs of the additional blanket used in the PACU. In addition, the warming units are frequently given to the hospitals at no costs.[15] In our analysis, we chose to use the retail costs of the warming blankets ($15), which may be higher than that actually expended by most hospitals. We also standardized the number of cotton blankets used during operation. If fewer cotton
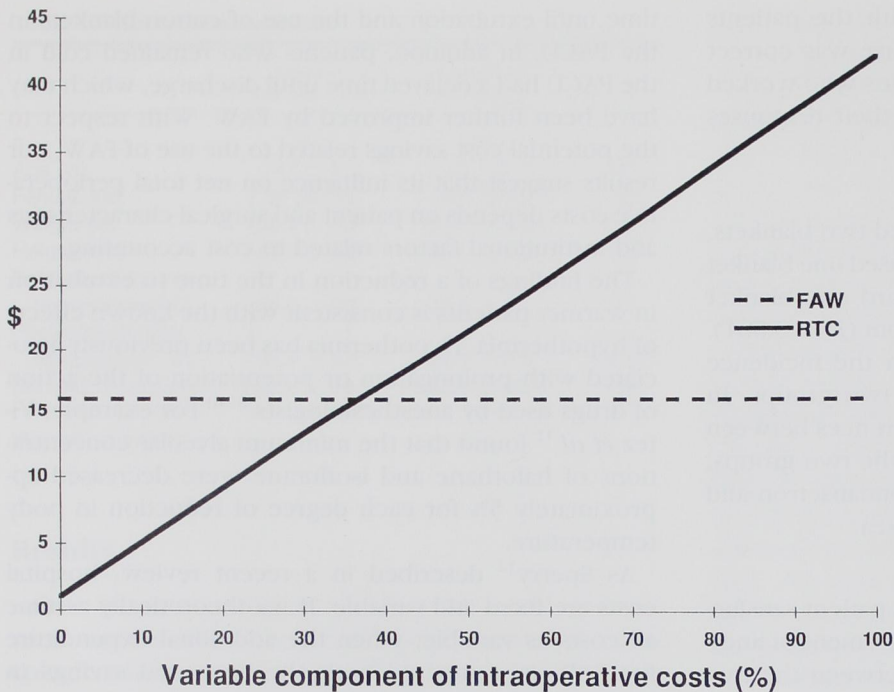
Fig. 2. The net costs associated with the use of and potential savings from forced-air warming. The average costs of the warming unit and blanket is $15.82 per case (*horizontal dashed line*). Potential perioperative savings are related to decreased operating room use and the costs of an extra blanket in the postanesthesia care unit. As the percentage of the variable portion of operating room costs increases, the costs of the additional time of extubation increases (*diagonal solid line*). The use of forced air warming is the strategy with the lower cost compared with routine thermal care if the percentage of operating room costs that vary is >36%. If the variable component of OR costs is <36%, then forced-air warming adds additional costs on average to a given surgical procedure.

blankets were used with FAW, then FAW may have resulted in smaller increases in cost. Therefore, the actual additional expense or savings from FAW varies greatly depending on clinical practice and cost accounting.

In our study, time until readiness for discharge from the PACU did not differ significantly between the two groups. In addition, there was no significant difference in patient temperature at the end of surgery between the various categories of surgical procedures. However, the time to meet discharge criteria inversely correlated with patient temperature in the PACU at discharge, with those patients who remained cold having a longer time until readiness for discharge. Patients in the RTC group generally required more time to reach the PACU nursing criteria of being awake enough for discharge (table 2).

Table 2. Time to Reach Each of the Discharge Criteria

	Routine Thermal Care (min)	Forced-air Warming (min)	P
Arousable	46 ± 6	39 ± 5	
Pain <5/10	49 ± 6	61 ± 6	
Vitals 20% baseline	33 ± 5	34 ± 5	
Oxygen saturation >94%	24 ± 5	22 ± 4	
Ready for discharge (all criteria met)	79 ± 6	78 ± 6	0.9

This was possibly a result of continued slower metabolism and redistribution of intraoperative anesthetics. The strongest independent predictors of temperature at the time of readiness to discharge include PACU admission temperature, total intraoperative fluids, and surgical procedure. Previous studies have also documented the influence of advancing age on thermoregulation and a prolonged return to normothermia.[16,17] Therefore, in trying to further define the population in whom FAW offers the greatest potential clinical and therefore cost benefit, these factors should be considered. For example, FAW ultimately may prove to save costs in elderly patients having surgical procedures associated with large fluid requirements.

Although core temperature is frequently used as one of several discharge criteria from the PACU, it has never been determined whether core temperature is necessarily important or related to other discharge criteria. In our study, only a small group of patients would not have met discharge criteria based on temperature when all other criteria were met. Therefore, not delaying discharge until a set temperature threshold was reached would not have resulted in any significant savings.

Intraoperative FAW has the potential to reduce overall perioperative cost primarily through decreased postoperative emergence time. If we had taken the payer per-

spective, then costs would only include operating room and anesthesia charges. In a fee-for-service environment, longer operating room and anesthesia times would generate more charges; shortening these times by using FAW would actually have a negative effect on revenue to the anesthesiologist and hospital. However, higher charges may lead to decreased referral from the payers if a significant percentage of patients are in managed care organizations, and this could result in an overall reduction in revenue.

Although patients frequently report shivering and thermal discomfort in the PACU, we did not find any difference in patient satisfaction when we queried them the following morning. This shows that many of the issues of immediate postoperative concern may not be remembered after discharge from the PACU, probably because of the residual effects of the anesthetic agents. In addition, nonmedical factors such as timeliness of care frequently affect satisfaction. Therefore, it is important also to determine patient satisfaction after the period when the anesthetic drugs are exerting a strong effect. Importantly, we did not directly question the patients regarding their thermal comfort. If the RTC group had an increased sensation of being cold, then the intangible costs of being cold could be included in an analysis from the patient's or society's perspective. Finally, our patient satisfaction instruments have not been validated in a large cohort of patients having general anesthesia, so further research is required to determine the implications of our findings.

Our cost-finding analysis focused on patients at low risk for perioperative adverse cardiac events. Two recent studies have shown a reduced incidence of perioperative morbidity in patients who received FAW, such as infection rates in patients having colon surgery and cardiac morbidity in patients with known or risk factors for coronary artery disease, which would result in reduced perioperative costs.[2,3] Incorporating the results of our cost-finding study with additional savings from reducing perioperative morbidity suggests that this technology would be highly cost-effective or cost saving in selected subgroups of patients.

Limitations of our study include our method for calculating OR and PACU cost and the determination of the variable portion of costs. Although we tried to standardize our population and used only one PACU location, we included a population undergoing diverse surgical procedures. We could not determine if FAW would reduce overall expenditures in specific patient groups. The study population was relatively young, and there-

fore we may not be able to generalize our results to an older population, because, in fact, we observed a prolonged time to rewarm in older patients. In calculating net costs, we assumed that the variable *versus* fixed portion of the costs were equal across the operating room and anesthesia personnel costs. As Macario *et al.*[14] described, the variable portion of costs is not constant across all hospital services. In addition, we used the point estimate of 4 min difference between the two groups, whereas the actual number could vary. Because precise cost data are unavailable at our institution and would vary greatly among institutions, the sensitivity analysis illustrates the potential net benefits or costs that require adaptation to the local environment. Finally, we did not assess the dynamic level of nursing requirements in the PACU between the two groups. It is possible that hypothermic patients required more intensive and longer care in the PACU.

In conclusion, our cost-finding study of FAW shows that although this new technology adds a finite cost to perioperative patient care, it can result in a decreased cost from a societal perspective by shortening postsurgical emergence time. This work suggests that in those subgroups of patients in whom there is a marked improvement in outcome, such as decreased cardiac morbidity and wound infection, the technology would be cost-effective.

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