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Perioperative Thermal Insulation

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To determine the efficacy of passive insulators advocated for prevention of cutaneous heat loss, we determined heat loss in unanesthetized volunteers covered by one of the following: a cloth "split sheet" surgical drape; a Convertors® disposable-paper split sheet; a Thermadrape™ disposable laparotomy sheet; an unheated Bair Hugger® patient-warming blanket; 1.5-mil-thick plastic hamper bags; and a prewarmed, cotton hospital blanket. Cutaneous heat loss was measured using 10 area-weighted thermal flux transducers while volunteers were exposed to a 20.6° C environment for 1 h. Heat loss decreased significantly from 100 ± 3 W during the control periods to 69 ± 6 W (average of all covers) after 1 h of treatment. Heat losses from volunteers insulated by the Thermadrape™ (61 ± 6 W) and Bair Hugger® covers (64 ± 5 W) were significantly less than losses from those insulated by plastic bags (77 ± 11 W). The paper drape (67 ± 7 W) provided slightly, but not significantly, better insulation than the cloth drape (70 ± 4 W). Coverage by prewarmed cotton blankets initially resulted in the least heat loss (58 ± 8 W), but after 40 min, resulted in heat loss significantly greater than that for the Thermadrape™ (71 ± 7 W). Regional heat loss was roughly proportional to surface area, and the distribution of regional heat loss remained similar with all covers. These data suggest that cost and convenience should be major factors when choosing among passive perioperative insulating covers. It is likely that the amount of skin surface covered is more important than the choice of skin region covered or the choice of insulating material. (Key words: Measurement techniques, heat: thermal flux transducers. Temperature, hypothermia: postoperative. Thermoregulation.)

HYPOTHERMIA is a common and potentially serious complication of surgery and anesthesia. Since most metabolic heat is lost through skin[1] (a small fraction is respiratory[2,3]), cutaneous heat loss must be reduced to prevent a decrease in mean body temperature during surgery. Various passive insulators have been advocated for this purpose. To determine the efficacy of six such insulators, we measured cutaneous heat loss in five unanesthetized volunteers exposed to a 20.6° C environment for 1 h.

Although thermal flux[§] across skin is largely determined by skin temperature, heat loss cannot easily be calculated directly from skin temperature. Furthermore, heat transfer cannot be determined only by changes in central body temperature because this temperature is influenced by thermoregulatory responses and redistribution of heat within the body. Therefore, we directly measured cutaneous heat loss using thermal flux transducers.

Materials and Methods

With approval from the University of California, San Francisco, Committee on Human Research and written consent from volunteers, we studied two women and three men aged 22–32 yr. None was obese, was taking medication, or had a history of thyroid disease, dysautonomia, hypertension, or Raynaud's syndrome. Volunteers were minimally clothed and reclined on a standard operating room table covered with a 5-cm-thick foam mattress. They refrained from coffee or alcohol before and during study periods but snacked lightly during the day.

We evaluated the insulating efficiency of six common perioperative coverings: 1) a cloth "split sheet" surgical drape (Superior Surgical, Seminole, FL); 2) a Convertors® disposable-paper split sheet (Baxter Healthcare, Deerfield, IL); 3) a Thermadrape™ disposable laparotomy sheet (O. R. Concepts, Roanoke, TX); 4) an unheated Bair Hugger® patient-warming blanket (Augustine Medical, Eden Prairie, MN); 5) a prewarmed, cotton hospital blanket; and 6) 93 × 110-cm, 1.5-mil-thick plastic hamper bags (Hamper stand bag 306, Winfield, San Diego, CA).

Four of these coverings were modified to ensure that each volunteer was covered neck-down using a single layer of each insulator. The laparotomy opening in the Thermadrape™ was sealed, making it similar in configuration to the paper and cloth drapes. (The Thermadrape™ is similar to a disposable paper drape, but it is made with a reflective metal backing that faces the patient and is intended to minimize heat loss by radiation.) The adult-size Bair Hugger® blanket was lengthened by fastening a pediatric blanket to its foot, and both components were inflated briefly with room temperature air before use and then allowed to deflate passively before application. This allowed for whatever added insulation the residual air would provide. (The Bair Hugger® is a forced-air patient-warming device that injects warm air into a disposable plastic/paper quiltlike blanket. The warm air inflates the blanket and then exits through slits toward the patient, thus providing a shell of warm air around the patient.) We required two cotton blankets to cover each volunteer fully, the second to cover the volunteer's feet while only minimally overlapping the upper blanket. Both blankets were taken from a 48° C blanket warmer and quickly spread over the volunteer in a single

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[§] Net rate of transfer of heat from an organism or object to the environment.

layer. Finally, three hamper bags were taped together, side by side, with minimal overlap. Each bag was initially opened to permit air flow within and then was allowed to deflate passively prior to use.

Control measurements were taken over a 1–2-h period during which subjects lay uncovered in the study room. Each insulator was then placed over the subject for a 60-min period, during which we measured cutaneous heat loss. Volunteers remained supine throughout the study. All six insulators were studied in each volunteer in random order over a period of 1 or 2 study days. Adequate time was allotted between the studies of each insulator (30–90 min) to ensure that cutaneous temperatures and total cutaneous heat loss returned to the baseline values obtained during each volunteer's initial control period.

Heat flux from 10 skin-surface sites was measured in watts per squared meter using thermal flux transducers (Concept Engineering, Old Saybrook, CT) and techniques we have described previously.[4] Transducers were positioned on the back of the hand, the top of the foot, the middle of the forehead, and near the anatomic centers of remaining regions (see below). All probes were exposed to room air during the control period, except for the transducer on the back, which was placed under the volunteer to reflect the insulating properties of the foam mattress. Flux values for each subject were converted into watts per site by multiplying by the calculated body surface area (area $[m^2] = \text{weight}^{0.425}\,[\text{kg}] \times \text{height}^{0.725}\,[\text{cm}] \times 0.0071840$ of each volunteer and assigning the following regional percentages to each site: head = 6%, upper arms = 9%, forearms = 6%, hands = 4.5%, back = 19%, chest = 9.5%, abdomen = 9.5%, thighs = 19%, calves = 11.5%, and feet = 6%.[5] (1 W = 1 J/s = 0.86 kcal/h; the specific heat of humans is $\approx 0.83\ \text{kcal} \cdot \text{kg}^{-1}{}^\circ\ \text{C}^{-1}$ [6]). We defined flux as positive when heat traversed skin to the environment.

Skin temperatures beneath each heat flux transducer, as well as ambient temperature, were monitored using bare-wire Mon-a-Therm® (St. Louis, MO) thermocouple probes. Central temperature was measured using a flexible, cotton-covered Mon-a-Therm® probe placed in contact with the tympanic membrane. All probes were connected to Mallinckrodt® model 8700 (St. Louis, MO) two-channel electronic thermometers having analog output. The manufacturer specifies that these thermometers have an accuracy near 0.1° C. A ten-site average skin-surface temperature[7] was calculated using the same regional percentages as in the heat flux calculations.[5] Analog data from the thermometers and heat flux transducers were acquired using a previously described "virtual instrument" (a computer program that emulates hardware).[4,¶]

For statistical analysis, data were averaged into 10-min observation periods, with −20–0 min representing control measurements and 1–60 min representing the treatment period. Changes in heat flux, average skin-surface temperature, and central temperature over time during each treatment were analyzed using repeated-measures analysis of variance (ANOVA) and Dunnett's tests. Differences among the treatments at each time were evaluated using repeated-measures ANOVA and Scheffé's F tests. Data are expressed as means ± standard deviations; differences were considered statistically significant when $P < 0.05$.

Results

The mean age of volunteers was 27 ± 4 yr; weight was 65 ± 9 kg; and height was 168 ± 8 cm. Average ambient temperature was maintained at 20.6 ± 0.4° C. Results were similar in male and female volunteers. Tympanic membrane temperatures did not differ significantly within or between insulator types at any time during the study. Typical heat flux and average skin-surface temperatures in one volunteer are shown in figure 1. Total cutaneous heat loss and mean skin-surface temperature decreased slightly during each control period, but values before each treatment were similar.

During the last 20 min of each control period, total cutaneous heat loss was 100 ± 3 W and did not vary significantly within or between treatments. At the end of the 60-min treatment period, cutaneous heat loss decreased to 69 ± 6 W (fig. 2). Overall insulator efficiency (after 60 min of treatment) ranked as follows: Thermadrape™ > Bair Hugger® > Convertors® paper

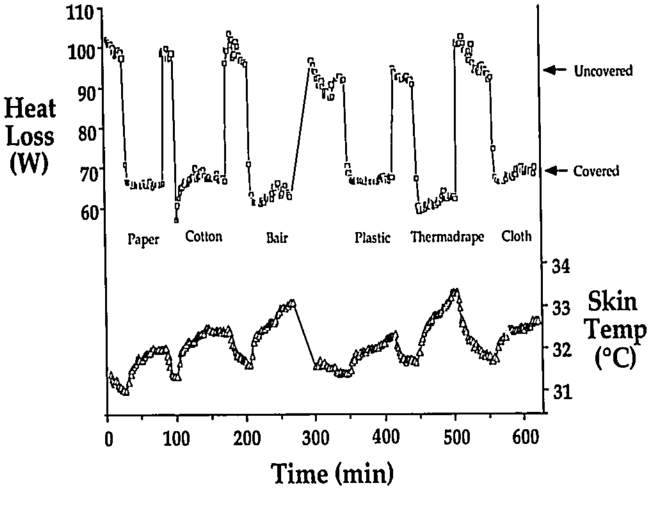

FIG. 1. Typical heat flux and average skin-surface temperatures in one volunteer. Total heat loss and skin temperature decreased slightly during each control period, which is consistent with loss of heat from the peripheral thermal compartment in a cool environment. Skin temperature and heat loss increased only slightly during the 60 min that volunteers were covered, and the increases were greatest when they were covered with the most effective insulators.

[¶] Ponte J, Sessler DI: Quantifying thermoregulatory responses. Scientific Computing and Automation February:35–39, 1989. Dr. D. I. Sessler will make this program available to interested investigators.

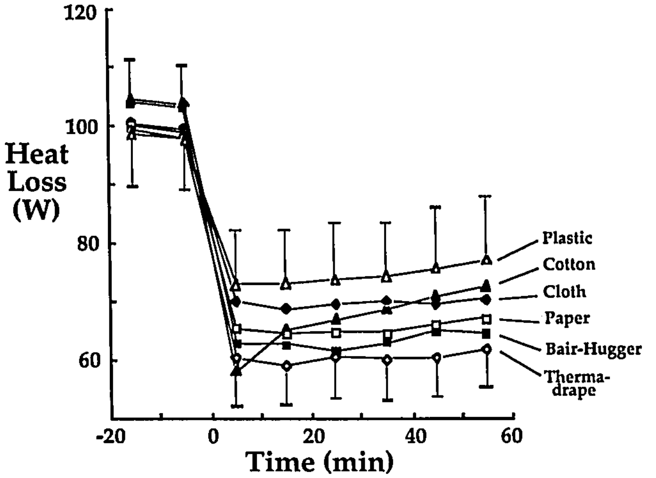

FIG. 2. Total heat loss (W) during the control periods (−20–0 min) and 60 min of treatment (1–60 min) using each insulator. Standard deviations for the best and worst insulators are shown; other are omitted for clarity, but were of similar magnitude.

sheet > cloth surgical drape > prewarmed cotton blankets > plastic bags.

Heat losses from volunteers insulated by the Thermadrape™ (61 ± 6 W) and Bair Hugger® covers (64 ± 5 W) were significantly less than losses during insulation with plastic bags (77 ± 11 W). The paper drape (67 ± 7 W) provided slightly but not significantly better insulation than did the cloth drape (70 ± 4 W). Coverage by prewarmed cotton blankets initially produced the least heat loss (58 ± 8 W), but after 40 min, it resulted in heat loss significantly higher than that with the Thermadrape™ (71 ± 7 W).

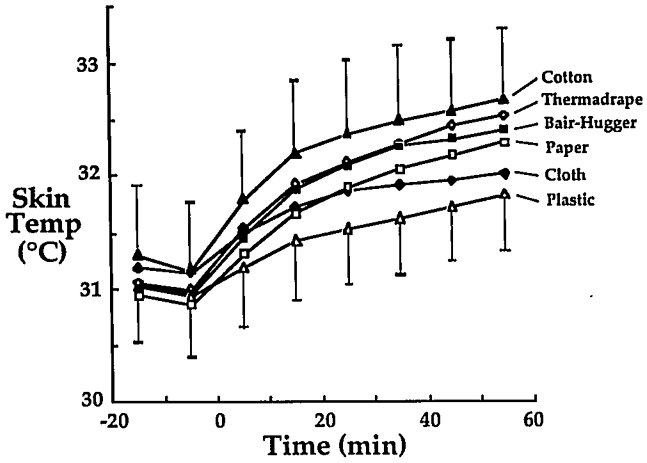

FIG. 3. Average skin-surface temperature (in degrees Celsius) from ten sites during the control periods (−20–0 min) and 60 min of treatment (1–60 min) using each insulator. Skin temperatures were significantly higher than control values with all insulators at all time intervals but did not differ significantly accordingly to insulator type. Standard deviations for the highest and lowest values are shown; other are omitted for clarity, but were of similar magnitude.

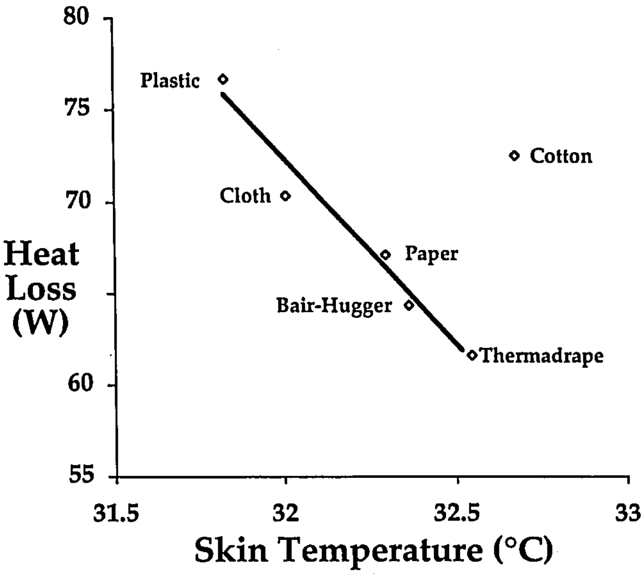

FIG. 4. There was an excellent linear correlation between average skin-surface temperature and total cutaneous heat loss after 60 min with all insulators except the warmed cotton blanket. Heat loss (W) = 715–20 (T_{skin} [°C]), r = 0.98 (excluding data from the cotton blanket trial).

As in our previous studies,[8,9] regional heat loss was approximately proportional to skin-surface area during the control period. The distribution of regional heat loss was similar with all insulators.

Skin temperatures were significantly higher than baseline skin temperatures with all insulators at all time intervals and did not quite differ significantly by insulator type ($P = 0.06$) (fig. 3). There was an excellent linear correlation between average skin-surface temperature and total cutaneous heat loss after 60 min of study with all insulators except the warmed cotton blanket. Heat loss (W) = 715 − 20 (T_{skin} [° C]), r = 0.98 (excluding data from the cotton blanket trial) (fig. 4).

Discussion

Hypothermia during general anesthesia usually develops in two distinct phases. During the initial ≈45 min after induction of anesthesia, central temperature decreases relatively rapidly,[9,10] despite nearly constant heat loss to the environment[11] and minimal decrease in metabolic heat production.[12] Hypothermia appears to result primarily from redistribution of heat from a warm central compartment to cooler peripheral tissues.[13] Because this decrease in central temperature develops without an increase in cutaneous heat loss (*i.e.*, body heat content remains constant), it is unlikely that skin-surface insulation alone can prevent immediate postinduction hypothermia.

After ≈45 min of "redistribution hypothermia," central temperature may continue to decrease at a slower rate. Continuing hypothermia results probably when cutaneous and respiratory heat losses exceed metabolic heat production. Since only about 5 W are lost by respiration (and even active airway heating and humidification transfers little heat), effective prevention of hypothermia requires decreasing cutaneous heat loss.[2,3]

Our data indicate that six passive intraoperative insulators decrease cutaneous heat loss similarly, from 100 ± 3 to 69 ± 6 W after 60 min in a 20.6° C environment. Metabolic heat production in unanesthetized humans at rest is approximately 100 W, but production is near 70 W during general anesthesia in patients whose lungs are mechanically ventilated.[12] Thus, each of the covers, as positioned in this study, decreased heat loss sufficiently to produce thermal steady state.

Differences among insulators were minimal. For example, the specially designed Thermadrape™ was only about 13% more effective than an ordinary cloth surgical drape. These data are consistent with previous studies indicating that "space blankets" provide little extra protection during surgery.[14,15] It is likely that air trapped between the covers and skin surface provided a large fraction of the insulation in all cases.

Surgical considerations frequently make it impossible to cover nearly the entire skin surface, as we did in these volunteers. The use of multiple insulating layers to cover available skin surfaces can help compensate for cutaneous heat lost through uncovered skin under surgical conditions. (We did not test heat retention by multiple layers, but it is not simply additive.) However, up to 50% of total heat loss may result from evaporation within surgical incisions.[16,17] Further heat is lost by respiration and by administration of cold intravenous fluids. Thus, heat loss may continue to exceed heat production during operations, and passive insulation alone cannot ensure thermal balance.

The covers we tested (and the small amount of air trapped between them and the skin surface) did not have sufficient heat capacity to absorb important amounts of metabolic heat. Therefore, heat loss was approximately proportional to the difference between skin and ambient temperature. Skin temperature and heat loss increased only slightly during the 1 h volunteers were covered, and the increases were greatest when volunteers were covered with the most effective insulators (fig. 1).

Cotton blankets differed from the other insulators we tested because they were warmed before use. The heat stored in these blankets decreased initial heat loss slightly, but the effect was short-lived. More importantly, skin-surface warming produced cutaneous vasodilation, which was observed as increases in both skin temperature and heat loss that were out of proportion to the blanket's insulating properties (fig. 4). Consequently, total heat loss when volunteers were covered with warmed blankets was similar to that with the other covers. Cutaneous vascular tone is determined by a complex interaction between central and locally mediated thermoregulatory responses (and other autonomic factors); less vasodilation is likely in hypothermic patients.[18]

Cutaneous heat loss from minimally dressed humans is approximately 125 W during the first 30 min of exposure to a typical operating room environment.[4,8] However, we have demonstrated previously that heat flux in volunteers decreases to ≈100 W over the course of 2 h.[19] (Central temperature remains constant during this time; decreased flux results from decreased temperature of the peripheral compartment.) Heat losses during the control periods in the current study were lower than those in some of our previous studies because the initial control period was 1–2 h, and enough time elapsed between the study of each cover to allow flux to return to baseline values.

We studied volunteers to evaluate thermal flux with each insulator type in each individual, independent of the confounding factors of surgical and clinical differences among study participants. We found ten thermal flux transducers and cutaneous thermocouples to be the maximum number practical for data collection in our subjects. Although regional variations in skin-surface temperature and heat loss or errors in estimating the area of various skin surfaces may have introduced errors in our measurements, such errors would be comparable with each type of cover; comparisons between the covers thus remain valid.

Thermal flux transducers do not detect evaporative loss. Sweating would not be expected in a 20.6° C environment, and none was observed. Thermoregulatory sweating does not occur during anesthesia until central temperatures reach ≈38° C.[20] Although evaporative heat loss can be enormous under conditions of heat stress,[21] basal evaporative loss from skin accounts in humans for only about 15% of the total heat loss.[22] Although impermeable covers minimize evaporative loss, water loss is unlikely to contribute significantly in most clinical situations.

In summary, we evaluated cutaneous heat loss in five volunteers covered with each of six passive insulators. Heat loss decreased significantly from 100 ± 3 W during the control periods to 69 ± 6 W (average of the loss with each of the covers) after 60 min in a 20.6° C environment. The Thermadrape™, Bair Hugger® cover, and paper surgical drape were more effective than were a cloth surgical drape, cotton blanket, or plastic hamper bags. However, there was little clinically important difference among the thermal barriers. Insulating covers therefore may be chosen on the basis of cost and convenience. It is likely that the amount of skin surface covered is more important than the choice of skin region covered or the choice of insulating material.

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