Heat Loss in Humans Covered with Cotton Hospital Blankets

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We evaluated mean skin temperature, cutaneous heat loss, and perceived warmth in six volunteers covered with one or three cotton hospital blankets, warmed or unwarmed. Mean skin temperatures were significantly higher during each treatment than during the control periods preceding each blanket application. Total cutaneous heat loss during the control period was 81 ± 11 watts. Covering the volunteers with a single warmed or unwarmed blanket for 60 min reduced heat loss 33% ± 5%; when they were covered with three warmed or unwarmed blankets, heat loss was reduced an additional 18% ± 6%. Warmed blankets reduced heat loss 9–16 watts more than unwarmed ones, but the benefit dissipated in ≈10 min. The volunteers' perception of warmth was similar when they were covered with three warmed or unwarmed blankets; it also was similar when they were covered with a single warmed or unwarmed blanket. These data indicate that increasing the number of covering blankets from one to three decreases heat loss only slightly. Similarly, warming the blankets is relatively ineffective and the benefit short-lived. The reduction in heat loss, even by three warmed blankets replaced at 10-min intervals, was small compared to that provided by available active warming systems.

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Despite the documented complications of perioperative hypothermia (1–5) and available methods to prevent it (6), most patients have initial postoperative core temperatures well below normal. Hypothermic patients are often covered with several cotton blankets in postanesthesia care units. We previously demonstrated that a single layer of six different types of passive insulators reduced cutaneous heat loss ≈30%, and that the efficacy of all tested insulators was comparable (7). The added benefit, if any, of combining up to three insulating layers remains unknown.

Blankets used to cover postoperative patients frequently are heated to increase the perception of warmth and decrease cutaneous heat loss. Although patients prefer warmed blankets to unwarmed ones, the heat capacity of cotton is low, suggesting that warming may decrease heat loss only slightly. Furthermore, heat contained in warmed blankets is likely to dissipate rapidly to the environment. Therefore, nurses may replace the blankets as often as every 15 min with freshly warmed ones. The extent to which warming blankets decreases cutaneous heat loss, and the duration of the decrease, remains unknown. Accordingly, we evaluated mean skin-surface temperature, heat loss, and the perception of warmth in volunteers covered with one or three layers of warmed or unwarmed cotton hospital blankets.

Methods

After approval of the Committee on Human Research, University of California, San Francisco, we studied four women and two men. The mean age of volunteers was 28 ± 3 yr, weight was 58 ± 8 kg, and height was 169 ± 9 cm. None was obese, was taking medication, or had a history of thyroid disease, dysautonomia, or Raynaud's syndrome. During the study, minimally clothed volunteers reclined on a standard operating room table. Ambient temperature was maintained at 23.1°C ± 0.8°C and ambient relative humidity at 53% ± 3% during the study period (model HX93 humidity transmitter, Omega Engineering, Inc.). The percentage body fat in the volunteers was 23% ± 7%, as determined by infrared interactance (Futrex 1000, Futrex, Inc., Hagerstown, MD) (8).

Experimental Procedure

The volunteers refrained from ingesting coffee or alcohol before and during study periods, but snacked

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lightly during the day. We evaluated the time-dependent insulating efficiency of the following coverings: 1) a single unwarmed cotton hospital blanket; 2) a single warmed cotton blanket; 3) three unwarmed blankets; and 4) three warmed blankets. Warmed blankets were kept in an oven that was thermostatically controlled to 50°C until immediately before use. Each covering was tested on each volunteer in a randomly determined order. Typically, two study days were required for each volunteer.

Initial measurements on each study day were recorded during a 1- to 2-h period. One of the covers was then placed over the volunteer for 60 min. Adequate time (30–90 min) was allotted before the next cover was tested to allow mean skin temperature and total cutaneous heat loss to returned to baseline values. The 20 min preceding each blanket application was considered the control period for that test.

Measurements

Area-weighted, mean skin-surface temperature was computed from measurements at 15 sites by assigning the following regional percentages to each area: head, 6%; upper arms, 9%; forearms, 6%; hands, 2.5%; fingers, 2%; back, 19%; chest, 9.5%; abdomen, 9.5%; medial thigh, 6%; lateral thigh, 6%; posterior thigh, 7%; anterior calves, 7.5%; posterior calves, 4%; feet, 4%; and toes, 2% (9). Skin-surface temperatures were recorded from thermocouples incorporated into thermal flux transducers and connected to an Iso-Thermex (Columbus Instruments International Corp., Columbus, OH) 16-channel electronic thermometer with an accuracy of 0.1°C and a precision of 0.01°C.

We also measured the temperatures on the surface of the single blanket, and 1, 3, and 5 cm above the blanket surface on the thigh. When three blankets were tested, we measured temperatures between the first and second blanket, between the second and third blanket, on the surface of the third blanket, and 1, 3, and 5 cm above the blanket surface. Additionally, ambient temperature was recorded at a site well away from the volunteer and heat-generating equipment. We used bare-wire Mona-Therm® (St. Louis, MO) probes for these measurements, and the thermocouples were connected to a second Iso-Thermex thermometer.

Heat flux from 15 skin-surface sites was measured in watts (W)/m^2 by using thermal flux transducers (Concept Engineering, Old Saybrook, CT) (10). Flux values for each subject were converted into W/site by multiplying by the calculated body surface area [area (m^2) = weight$^{0.425}$ (kg)·height$^{0.725}$ (cm)·0.007184] of each volunteer and assigning the same regional percentages as used for calculating mean skin temperature (11). We defined flux as positive when heat traversed skin to the environment. All probes were exposed to room air during the control periods, except for the transducer on the back, which was placed under the volunteers to reflect the insulating properties of the foam mattress.

Contact between the flux transducers and skin was facilitated by application of a thin layer of Type 120 Thermal Joint Compound (EG & G Wakefield Engineering, Inc., Wakefield, MA) between the two surfaces. Approximately 20 cm of lead wire to each transducer were carefully taped to the skin to prevent artifactual cooling of the flux monitors by conduction to the environment.

Thermal flux transducers measure heat lost via radiation, conduction, and convection. Transcutaneous (12) and respiratory (13) evaporative heat loss in nonsweating adults represents only a small fraction of basal metabolic heat production (14). Consequently, cutaneous thermal flux well represents total heat loss under the circumstances of this study: 1 W = 1 joule/s = 0.86 kcal/h; the specific heat of humans is ≈0.83 kcal·kg^{-1}·°C^{-1} (15).

The volunteers' subjective perception of warmth was assessed at 10-min intervals, with a 100-mm-long visual analog scale; 0 mm was defined as the worst imaginable cold, 100 mm as unbearable heat, and 50 mm represented thermal comfort.

Temperatures and thermal flux were recorded at 5-min intervals by using a previously described computerized data acquisition system (16). These data were averaged into 10-min acquisition epochs, with −20 to 0 min representing control measurements and 1–60 min, the treatment period. Time-dependent changes in heat flux, mean skin temperature, and perception of warmth were evaluated by repeated measures of analysis of variance and Scheffé's F tests. Data are expressed as means ± SD; differences were considered statistically significant when $P < 0.05$.

Results

Results were similar in the male and female volunteers. As in our previous studies (16,17), regional heat loss was roughly proportional to skin-surface area during the control period.

Mean skin temperatures were significantly higher during each treatment than during the control periods preceding each blanket application. Temperatures were significantly higher when the volunteers were covered with three warmed or unwarmed blankets than when they were covered with a single warmed or unwarmed blanket (Figure 1).

During the 20 min of control measurements before blanket applications, total cutaneous heat loss was 81 ± 11 W and did not vary significantly among treatments. After the volunteers were covered for 60 min with a single warmed or unwarmed blanket, cutaneous

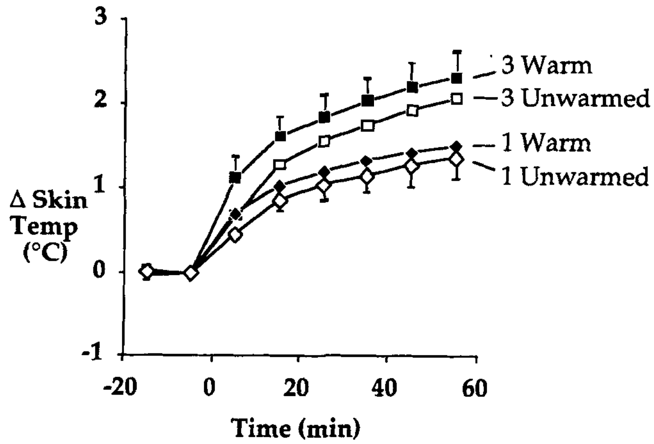

Figure 1. Change in mean skin-surface temperatures relative to values recorded at the end of the control period (−20 to 0 min); mean skin temperature at that time was 32.0°C ± 0.6°C. Temperatures were significantly higher at all times after the control period (− 20 to 0 elapsed minutes) when the volunteers were covered with a single warmed or unwarmed blanket ("1 Warm" or "1 Unwarmed") or three warmed or unwarmed blankets ("3 Warm" or "3 Unwarmed"). At all times after 20 elapsed minutes, temperature changes did not differ significantly between three warmed and unwarmed blankets or between one warmed and unwarmed blanket. However, temperatures were significantly higher when the volunteers were covered with three warmed or unwarmed blankets than when they were covered with a single warmed or unwarmed blanket.

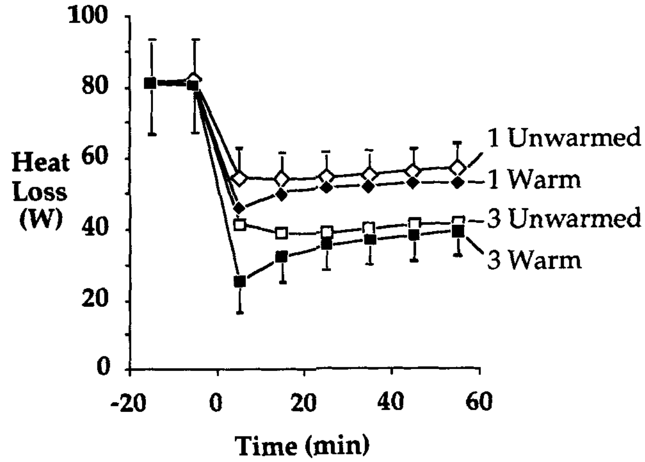

Figure 2. Mean cutaneous heat loss was significantly less at all times after the control period (−20 to 0 elapsed minutes) when the volunteers were covered with a single warmed or unwarmed blanket ("1 Warm" or "1 Unwarmed") or three warmed or unwarmed blankets ("3 Warm" or "3 Unwarmed"). From 0 to 10 elapsed minutes, loss during each treatment was significantly different, except between one warmed and three unwarmed blankets and between one warmed and one unwarmed blanket. At all times after 20 elapsed minutes, heat loss did not differ significantly between three warmed and unwarmed blankets or between one warmed and unwarmed blanket. However, when the volunteers were covered with three warmed or unwarmed blankets, loss was significantly less than when they were covered with a single warmed or unwarmed blanket.

heat loss decreased to 55 ± 8 W (a 33% ± 5% reduction from control values). After the volunteers were covered for 60 min with three warmed or unwarmed blankets, cutaneous heat loss was 41 ± 7 W (an additional 18% ± 6% reduction). When the volunteers were covered with three warmed or unwarmed blankets, loss was significantly less than when they were covered with a single warmed or unwarmed blanket (Figure 2).

The volunteers' perception of warmth was significantly increased by each treatment compared with values during the control periods preceding each blanket application. The volunteers' perception of warmth was similar when they were covered with three warmed or unwarmed blankets. Perception of warmth also was similar when the volunteers were covered with a single warmed or unwarmed blanket (Figure 3).

Thigh skin temperatures were ≈1°C higher when the volunteers were covered with three blankets than with just one. Temperature above the single blanket (0.5 cm above skin) was ≈5°C lower than skin temperature; interestingly, temperature of the air 1 cm above the blanket was only slightly lower than that just above the blanket. In contrast, air temperatures 3 and 5 cm above the blanket were comparable to ambient temperature measured at a remote site. Temperature decreased ≈2°C between each of the three blanket layers, with the top layer being ≈1°C warmer than the temperature just above a single blanket. Again, temperature of the air

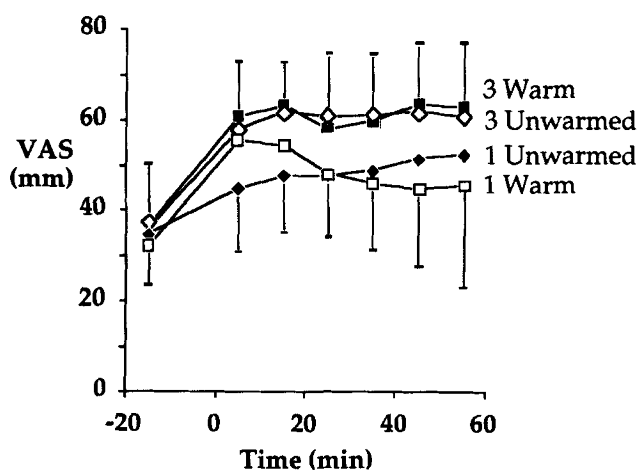

Figure 3. Thermal comfort (millimeters on a 100-mm visual analog scale) was significantly greater at all times after the control period (−20 to 0 elapsed minutes), when the volunteers were covered with a single warmed or unwarmed blanket ("1 Warm" or "1 Unwarmed") or three warmed or unwarmed blankets ("3 Warm" or "3 Unwarmed"). Between 0 and 20 elapsed minutes, comfort was significantly greater when the volunteers were covered with three warmed than one unwarmed blanket; similarly, between 20 and 40 elapsed minutes, comfort was significantly greater with three unwarmed than one warmed blanket.

1 cm above the top blanket was only slightly lower than that just above the blanket, but air temperatures 3 and 5 cm further were comparable to ambient temperature measured at a remote site (Figure 4).

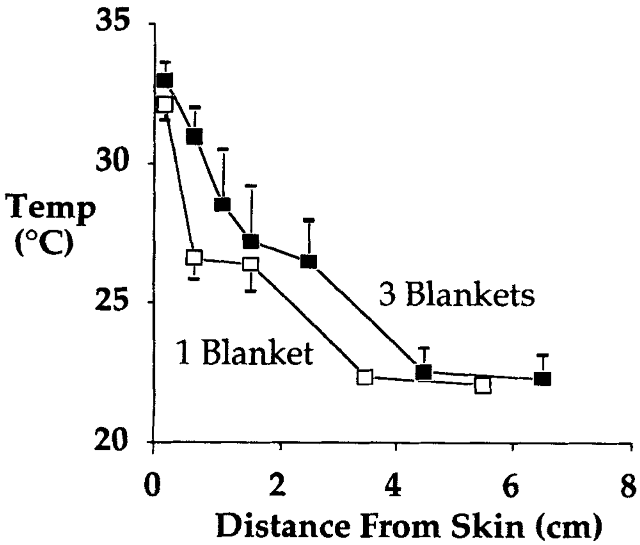

Figure 4. Thigh skin temperatures were ≈1°C higher when the volunteers were covered with three blankets than with just one. Temperature above the single blanket (0.5 cm above skin) was ≈5°C lower than skin temperature; interestingly, temperature of the air 1 cm above the blanket was only slightly lower. In contrast, air temperatures 3 and 5 cm above the blanket were comparable and equal to ambient temperature measured at a remote site. Temperature decreased ≈2°C between each of three blanket layers, with the top layer (1.5 cm above skin) being ≈1°C warmer than the temperature just above a single blanket. Again, temperature of the air 1 cm above the top blanket was only slightly lower. In contrast, air temperatures 3 and 5 cm above the blanket were comparable and equal to ambient temperature measured at a remote site.

Discussion

Typically sized, minimally clothed volunteers reclining on a padded operating room table usually lose 80–100 W via the skin (16,18). The exact values depend on the volunteer's body size, ambient temperature and air speed, duration of the volunteer's environmental exposure, and the thermoregulatory vasomotion (16). Since heat loss is similar in different skin regions (18), overall loss increases approximately linearly with exposed body surface area. Air speed in typical operating rooms is only ≈20 cm/s. Consequently, combined conductive and convective heat transfer from exposed skin is nearly proportional to the skin-ambient temperature difference (19). Initial heat loss was ≈20% lower than in our previous study of passive insulators (7), presumably because ambient temperatures were ≈3°C higher.

Cutaneous heat loss is reduced by insulators separating skin from the environment: insulation provided by the applied blankets reduced heat loss and consequently increased skin temperature. Because skin temperatures continued to increase during each treatment, heat loss also gradually increased throughout the study period. However, this increase was not clinically important.

We previously demonstrated that single layers of six different perioperative covers had comparable insulating efficacy (7), presumably because trapped air contributes more to total insulation than the covers *per se*. Since remote ambient temperature was comparable during each treatment, a small difference in skin temperature under one and three blankets indicates that adding two blankets only slightly increased total insulation. The relatively small, 18% ± 6% additional reduction in heat loss with three versus one blanket was consistent with this observation.

As expected from their similar compositions, temperature decreased comparably between each blanket layer. However, the total temperature gradient between the skin and the top surface was comparable with one or three blankets. These data, once again, are consistent with similar insulating capacities of each treatment. Interestingly, air temperature 1 cm above the blanket surface was only slightly lower than temperature at the blanket surface, indicating that the first centimeter of overlying air contributes significantly to the total insulation. In contrast, air temperatures 3 and 5 cm above the blanket surface did not differ from ambient temperature recorded from a remote portion of the room.

A circulating-water blanket (set at 40°C) positioned on the anterior surface of an individual virtually eliminates cutaneous heat loss (17), whereas the same device placed below an individual is relatively ineffective (6). Among available warmers, forced air transfers the most heat across the skin surface, typically ≈50 W. In distinct contrast to these active systems, our volunteers still lost 32 ± 7 W, even during the first 10 min after being covered with three warmed blankets.

Heat loss was reduced 5–15 W more by warmed than unwarmed blankets. However, the reduction was no longer statistically significant or clinically important 10 min after application. Rapid dissipation of the heat in the warm blankets is not surprising because the heat capacity of cotton is low. Thus, even when blankets are replaced with freshly warmed ones at 10-min intervals, cutaneous heat loss remains high compared with the best active warming systems (17). Because each fresh blanket must be washed and subsequently dried, the environmental cost of replacing several blankets at 10-min intervals is high.

We made no effort to measure respiratory heat loss because it is a tiny fraction of the total (13). Since most heat is lost via the skin, only cutaneous insulation (or warming) will prevent hypothermia in response to large intraoperative heat losses (20). Once hypothermic however, postoperative patients are difficult to rewarm, even with active cutaneous heating (21). Although some active warmers transfer considerable heat (17), that heat may contribute little to core warming because postoperative thermoregulatory vasoconstriction (2) isolates skin and peripheral tissues from the core (21). In contrast, it is relatively easy to prevent and treat intraoperative hypothermia (6,22). Maintaining normothermia during surgery has the additional advantage of minimizing the known complications of perioperative hypothermia (1–5).

Humans perceive phenomenally small changes in skin temperature, with increases as small as 0.003°C being detected (23). [The face is the most sensitive region, but overall area stimulated and rate of change are the major factors (24).] It thus is not surprising that blanket application, which increased mean skin temperature 1–2°C, markedly increased our volunteers' perception of warmth. Thermal comfort at first increased rapidly after all treatments, but then remained relatively constant when the volunteers were covered with three blankets. These data are consistent with studies showing that thermal perception is nonlinear and far more sensitive to temperature change and the rate of change than to absolute temperature (25).

We studied volunteers to evaluate skin temperature, thermal flux, and perceived warmth with each blanket/temperature combination in each individual, independent of the confounding factors of surgical and clinical differences among study participants. We found 15 thermal flux transducers and cutaneous thermocouples to be the maximum practical number in this study. Although regional variations in skin-surface temperature and heat loss, errors in estimating the area of various skin surfaces, or imperfect flux transducer calibration may have confounded our measurements, such errors would be comparable with each type of cover; comparisons among the covers thus remain valid.

In summary, we evaluated cutaneous heat loss in six volunteers covered with one or three, warmed or unwarmed, cotton hospital blankets. Covering the volunteers for 60 min with a single warmed or unwarmed blankets reduced heat loss 33% ± 5%; when they were covered with three warmed or unwarmed blankets, heat loss was reduced an additional 18% ± 6%. Warmed blankets reduced heat loss 9–16 W more than unwarmed ones, but the benefit dissipated in ≈10 min. These data indicate that increasing the number of covering blankets from one to three only slightly decreases heat loss; similarly, warming the blankets is relatively ineffective and the benefit short-lived. The reduction in heat loss, even by three warmed blankets, was small compared to that provided by available active warming systems.

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