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Cutaneous Heat Loss with Three Surgical Drapes, One Impervious to Moisture

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Abstract

A new surgical drape, which is impervious to moisture, presumably reduces evaporative heat loss. We compared cutaneous heat loss and skin temperature in volunteers covered with this drape to two conventional surgical drapes (Large Surgical Drape and Medline Proxima). With IRB approval and informed consent, we calculated cutaneous heat loss and skin-surface temperatures from 15 area-weighted thermal flux transducers in 8 volunteers. In random order, each of the drapes was evaluated with dry transducers and moistened transducers (simulating wet skin). After a 20-minute uncovered control period, volunteers were covered from the neck down for 40 minutes. Data were recorded continuously and averaged over 10-minutes. Results were similar for all three drapes for dry or moist conditions. Under dry conditions, baseline heat loss was 82 ± 14 watts (W) and decreased 30% with a surgical drape ($P < 0.001$). Under moist conditions, baseline heat loss was 231 ± 45 W and decreased 29% with a drape covering ($P < 0.001$). Moist skin increased heat loss 282% ($P < 0.001$). There were no clinically important differences in skin temperature among the covers with dry or moist skin. Moist skin increased heat loss nearly three-fold, but there were no differences among the drapes. We conclude that loss is comparable with impervious and conventional drapes with either moist or dry skin.

Keywords

Evaporation; Heat flux; Insulation; Surgical drapes; Sweat; Temperature; Thermoregulation

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Implications: Our results indicate that heat loss from dry or wet skin is comparable when subjects are covered with a new surgical drape impervious to fluid (Tiburon) to when they are covered with conventional surgical drapes. Hypothermia or hyperthermia is thus no more likely to occur when using the Tiburon than conventional drapes.

Introduction

Anesthetic-induced inhibition of normal thermoregulatory control (1), combined with cold exposure (2), makes most surgical patients hypothermic (3). There is considerable evidence that even mild hypothermia causes severe complications that adversely influence patient outcome (4). It is thus routine to maintain perioperative core normothermia unless hypothermia is specifically indicated (5). Any method is suitable, but passive insulation such as surgical draping material is among the most commonly used approaches.

Ordinary surgical drapes reduce cutaneous heat loss by 30% (6), which is a clinically important amount. This measurement, though, included only radiative, conductive, and convective loss; evaporative loss was not measured. Normally, accuracy is sacrificed slightly by ignoring evaporation since insensible evaporative heat loss is only about 10% of the metabolic rate in adults (7). However, evaporative heat loss can be substantial in infants (8) or when skin is moistened by sweat (9) or other fluids (10).

Recently, a novel surgical drape (Tiburon Surgical Drape, Cardinal Health, Inc., McGaw Park, IL) has been developed that is impervious to moisture and viruses. Its primary purpose is to prevent contamination of operating room personnel or the surgical site due to “striethrough” (fluid passing through the drape). However, an additional benefit of an impermeable drape may be reduced evaporative heat loss. We thus tested the hypotheses that non-evaporative heat loss (radiative, conductive, convective) is similar among ordinary drapes (Kimberly Clark and Medline) and the Tiburon drape, but that the Tiburon Drape reduces total heat loss (including evaporative) more than the other drapes.

Methods

With approval of the University of Louisville Human Studies Committee and written informed consent, we studied 5 women and 3 men. 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 near 21°C.

Protocol

The volunteers refrained from ingesting coffee or alcohol for 8 hr before and during the study, but snacked lightly during the day. We evaluated the time-dependent insulating efficiency of the following coverings: 1) a Tiburon surgical drape (Cardinal Health, Inc., McGaw Park, IL), 2) a Medline Proxima surgical drape (Medline Industries, Inc., Mundelein, IL), and 3) a Large Surgical Drape (Kimberly-Clark, Corp., Rosell, GA). In addition, one of two conditions was randomly selected: a “dry” condition in which the drape was placed directly over dry skin or a “wet” condition in which a thin strip of moistened felt was placed on top of each thermal flux transducer (see below) to simulate wet skin. A small metal coil was taped to the skin surrounding the flux transducers that slightly elevated the drape, allowing the drape to remain dry ≈ 1.5 cm above each transducer. Each covering and each condition was tested on all volunteers. The order in which the drapes were applied was determined from computer-generated codes that were kept in sealed, opaque envelopes until just before the start of the first equilibration period.

After an initial 40-minute equilibration period with no covering, the volunteer was covered from the neck down with the selected drape. It remained in place for forty minutes. The skin was then left uncovered for twenty minutes to allow mean skin temperature and total cutaneous heat loss to return to baseline values before the next cover was tested. The 20-minute period preceding each drape application was considered the control period for that test. If a moist

condition was the next random application, then moistened felt was applied during the preceding control period. The total time required for all measurements was approximately eight hours.

Measurements

Heat flux from 15 skin-surface sites was measured in W/m² using thermal flux transducers (Concept Engineering, Old Saybrook, CT) (10). The transducers were attached to the skin with small amounts of tape around the periphery of each. Approximately 20 cm of lead wire for each was taped to the skin to prevent artifactual cooling of the flux monitors by conduction to the environment. Flux values for each subject were converted into W/site by multiplying by the calculated body surface area [area (m²) = weight (kg). height (cm). 0.007184] of each volunteer and assigning the same regional percentages as used for calculating mean skin temperature (see below) (6). 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.

Thermal flux transducers measure heat lost *via* radiation, conduction, and convection. Transcutaneous (11) and respiratory (12) evaporative heat loss in non-sweating adults represents only a small fraction of normal heat loss (13). 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 $\approx 0.83 \text{ kcal.kg}^{-1}\text{C}^{-1}$ (14). As in previous studies (15), flux from moistened transducers was assumed to estimate loss from wet skin.

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% (6). 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.

Core temperature was recorded from a tympanic temperature probe connected to a second Iso-Thermex thermometer. The aural probes were inserted by the volunteers until they felt the thermocouple touch the tympanic membrane; appropriate placement was confirmed when volunteers easily detected a gentle rubbing of the attached wire. The aural canal was occluded with cotton and the thermocouple taped in place. Additionally, ambient temperature was recorded at a site well away from the volunteer and heat-generating equipment.

Data analysis

Temperatures and thermal flux were recorded at 10-min intervals using a previously described computerized data acquisition system (16). These data were averaged into 10-min acquisition epochs, with -20 to 0 elapsed minutes representing control measurements and 0-40 minutes representing the treatment period.

Time-dependent changes in cutaneous heat flux and mean skin temperature from time zero (control values) were evaluated using repeated-measures ANOVA and Dunnett's test. This analysis allowed us to simultaneously assess differences among the covers, differences over time, and differences between moist and dry conditions. Data are expressed as means $\pm$ SDs; differences were considered statistically significant when $P < 0.05$.

Results

The mean age of volunteers was 26 ± 3 yr; weight was 69 ± 16 kg; height, 173 ± 10 cm; and body mass index, 23 ± 3 kg/m². Ambient temperature was $21.0 \pm 1.5^{\circ}\text{C}$, and relative humidity was $49 \pm 2\%$. Initial core temperatures were $\approx 36.7 \pm 0.4^{\circ}\text{C}$ and were similar for each cover test. There were no statistically significant changes in core temperature during any of the treatments ($P = 0.63$).

Mean skin temperatures were significantly greater during each treatment than during the control periods preceding each drape application for both moist and dry conditions. During the 20-min control measurements before drape applications, the average total cutaneous heat loss during dry conditions was 82 ± 14 W and did not vary significantly between treatments. During the control periods preceding wet conditions, the average total cutaneous heat loss was 231 ± 45 W and also did not vary significantly between treatments. Heat loss with moist transducers was 282% greater than under dry conditions ($P < 0.001$).

After the volunteers were covered for 40 minutes with the Tiburon drape under dry conditions, cutaneous heat loss decreased to 49 ± 7 W (a $33 \pm 11\%$ reduction from control values). Cutaneous heat loss decreased to 54 ± 15 W (a $29 \pm 17\%$ decrease) with the Medline Proxima. The Kimberly-Clark surgical drape caused a decrease to 60 ± 18 W (a $31 \pm 14\%$ decrease). Consequently for heat flux, there were no significant differences among the three drapes ($P = 0.730$). Using Dunnett's post-test, all heat flux values during the treatment (10, 20, 30, and 40 min) were significantly less ($P < 0.001$) than the initial heat flux value at time 0 (Fig. 1).

When the volunteers were covered for 40 minutes with the Tiburon drape under moist conditions, cutaneous heat loss was 156 ± 38 W (a $28 \pm 8\%$ reduction). While covered with the Medline Proxima drape, cutaneous heat loss was 148 ± 43 W (a $29 \pm 17\%$ reduction). While covered with the Kimberly-Clark surgical drape, cutaneous heat loss was 159 ± 27 W (a $26 \pm 8\%$ reduction). Again, there were no statistically significant differences among the three drapes under moist conditions ($P = 0.730$) (Fig. 1).

For skin temperatures, both time and skin moisture were highly statistically significant factors ($P < 0.001$). Skin temperatures during treatment (10, 20, 30, and 40 min) were significantly greater than the initial values at time 0 ($P < 0.001$). However, there were no statistically significant or clinically important differences in skin temperature among the covers, with either moist or dry skin (Fig. 2).

Discussion

Normal core-body temperature is maintained by behavioral and autonomic thermoregulatory defenses. Behavioral responses (such as increasing ambient temperature or seeking appropriate shelter) are the most powerful thermoregulatory defenses and are what allows humans to survive in extreme environments. However, general anesthesia obliterates behavioral responses, leaving only autonomic defenses (1). Among the autonomic response, the most important cold-defenses in humans are vasoconstriction and shivering. General anesthetics markedly and comparably reduce the thresholds (triggering core temperatures) for each. It is this impairment of cold defenses that makes patients hypothermic in a cold surgical environment (17).

We have previously demonstrated that a single layer of most passive insulators reduces non-evaporative cutaneous heat loss by approximately 30% (6). This is a clinically important reduction in heat loss and may be sufficient to keep patients normothermic depending on body morphology, fractional surface area covered, ambient temperature, and the size and duration of surgery (18).

A variety of surface coverings comparably reduce heat loss because most of the insulation results from air trapped below the material layer, rather than the material itself. It is thus unsurprising that the Kimberly Clark and Medline covers each reduced heat loss by almost exactly 30%. Evaporative heat loss from dry adult skin is trivial (11). It is thus similarly unsurprising that the Tiburon drape, although impermeable to moisture, would also reduce heat loss by 30%. Our results thus indicate that each of the tested covers comparably reduces heat loss and will therefore provide comparable protection against perioperative hypothermia.

Sweating is a remarkably effective thermoregulatory defense and is the body's only mechanism for dissipating heat when ambient temperature exceeds core temperature. In a dry convective environment, for example, sweating can dissipate many times the basal metabolic rate — even at extreme ambient temperatures (19). Interestingly, general anesthesia only slightly increases the core temperature triggering activation of the warm-defenses, sweating and active vasodilation (1). Sweating thus remains available to defend against excessive heating, even in anesthetized patients.

Our simulation of moist skin reduced mean skin temperature $\approx 1.5^{\circ}\text{C}$ which is similar to previous observations (10). Reduced skin temperature decreases radiative, conductive, and convective heat loss. Over small temperature ranges, the reduction is roughly a linear function of the difference between skin and environmental temperature. The difference with dry skin was initially $\approx 10^{\circ}\text{C}$. The observed $\approx 1.5^{\circ}\text{C}$ reduction with moisture would thus be expected to reduce *non-evaporative* heat loss by about 12 W from 82 W to 70 W. Instead, simulated moist skin tripled *total* cutaneous heat loss, to 231 W — again a value that is similar to previous observations (10). The entire 171-W increase from 70 to 231 W can thus be attributed to evaporation. This impressive increase demonstrates the remarkable efficacy of sweating and the ability of this thermoregulatory defense to protect against inadvertent overheating.

Sweating is hardly the only cause of moist skin during surgery. Far more commonly, moist skin results from surgical skin preparation (10), irrigation liquids, or from fluids that leak from within surgical incisions. Almost any aqueous fluid will increase evaporative and total heat loss by roughly the same amount as vigorous sweating. (Alcohol-based fluids increase loss even more (10).) Wet skin thus has the potential to triple cutaneous heat loss in moistened areas and may thus contribute to inadvertent perioperative hypothermia.

Each of the covers reduced total heat loss by about 30% during the moist skin simulation. But again, there were no statistically significant or clinically important differences among the covers. Each cover thus provides comparable protection against inadvertent hypothermia resulting from wet skin. And each comparably reduces the ability of sweating to prevent inadvertent hyperthermia. The critical difference, though, is that hypothermia is a passive process so a 30% reduction in cutaneous heat loss will have a predictable and linear effect on the core-cooling rate. Sweating, in contrast, is a regulated process with a distinct gain (intensity increase as a function of further hyperthermia) (20). Sweating intensity will thus increase, at least within limits, as necessary to overcome the reduction in heat loss that results from passive insulation.

A limitation of our study is that we assumed that moistened transducers reasonably estimate total cutaneous heat flux, including evaporative heat loss. This method was adopted from previous studies (15). However, surface characteristics of felt obviously differ somewhat from those of skin, and the amount of water that evaporates from each may similarly differ. Nonetheless, it is unlikely that the differences are substantial, and *relative* changes with each cover are surely correct. We did not record airflow in our laboratory, a converted operating room. However, flow was probably typical for operating rooms, with an air speed of ≈ 20 cm/

second and roughly ten air exchanges per hour. It is thus likely that our results can be extrapolated to the typical clinical situation.

In conclusion, an impervious surgical drape prevents strike-through and may thus limit infection risk to both patients and operating room personnel. However, cutaneous heat loss and skin temperatures were similar with each tested drape. Moist skin significantly increased heat loss by nearly a factor of three, but there was no difference among the tested drapes. Our results therefore indicate that moist skin markedly increases heat loss, but that loss is comparable with impervious and conventional drapes with either moist or dry skin. Hypothermia or hyperthermia is thus no more likely with the Tiburon than with conventional surgical drapes.

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Fig. 1.

Area-weighted heat loss in watts (W) over time. Heat flux from 15 skin-surface sites was measured in W/m^2 using thermal flux transducers. Flux values for each subject were converted into W/site by multiplying by estimated body surface area and assigning the same regional percentages as used for calculating mean skin temperature (see text). Using Dunnett's post-test, all heat flux values during the treatment (10, 20, 30, and 40 min) were significantly less ($P < 0.001$) than the initial heat flux value at time 0. However, heat loss was similar for all three drapes during both dry (open symbols) and moist (filled symbols) conditions. Data presented as means $\pm$ SDs from all 8 volunteers.

Fig. 2.

Skin temperature ($^{\circ}\text{C}$) of the volunteers over time. 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%. Skin temperatures at 10, 20, 30, and 40 min were significantly greater than at time 0 ($P < 0.001$); however, mean skin temperature was similar for all three drapes for both dry (open symbols) and moist (filled symbols) conditions. Data presented as means $\pm$ SDs from all 8 volunteers.