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THE USE OF A MANNEQUIN TO ASSESS FORCED-AIR WARMING SYSTEMS BY TEMPERATURE MEASUREMENT

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INTRODUCTION

In order to promote normothermia during and after surgery, many patients receive forced-air warming in operating rooms and post-anesthesia care units. Typically, a 1-2 °C rewarming of the core temperature is needed. A forced-air warming system consists of a device that warms and propels ambient air and a diffuser in the form of a permeable coverlet. Forced-air warming systems can be compared, for a given duration of warming, by exhibiting normalized temperatures measured at selected locations on the surface of a mannequin for each of the candidate warming systems. Use of a mannequin is advantageous because it eliminates the biologic variation of patients (i.e., stage of anesthesia, thermogenesis, etc.). A separate but related study was performed to determine the relationship between coverlet-surface widthwise temperature variation and the manner in which heated air enters the coverlet.

METHODS

The fiberglass exterior of a mannequin is sectioned in order to minimize thermal communication among the eighteen surface zones which were selected for temperature monitoring. A thermocouple is installed at a representative surface location in each zone in a manner that minimizes measurement errors due to extraneous heat conduction [1]. In addition, the junctions are buried 0.16 cm below the surface of the mannequin to avoid measurement errors due to radiation. The leads from the thermocouples traverse the mannequin's interior, exiting through an aperture in its lower back. The leads pass through slits in the underlying mattress and frame and terminate at an automated data acquisition unit. The mannequin's interior is Emspray EM-220 foam (USA). This foam was selected because its low thermal conductivity accentuates the thermal isolation of surface zones and minimizes any depression in temperature at the thermocouple junctions resulting from extraneous heat conduction [1]. In addition, the foam provides prolonged thermal transients and structural support. Five different warming systems, designated here as A, B, C, D, and E, are compared. These warming systems are described in Table 1.

Table 1
Description of Forced-Air Warming Systems

Type	Therapy Name	Heater/Blower	Coverlet	Manufacturer
A	Bair Hugger®	Model 250/PACU Warming Unit	Model 300 Warming Blanket	Augustine Medical USA
B	WarmAir®	Hyperthermia System Model No. 130	FilteredFlo™ Adult Blanket Catalog No. 141	Cincinnati Sub-Zero Products USA
C	ThermaCare®	Patient Comfort System TC 1000	TC 1050 Comfort Quilt	Gaymar Industries USA
D	CareQuilt™	Warmtouch™ Unit Model 5000	CareQuilt™ Blanket Catalog No. 503-0810	Mallinckrodt Medical USA
E	Life-Air 1000®	Hypothermic Therapy System	Patient Warming Cover Recovery Room Model	Progressive Dynamics USA

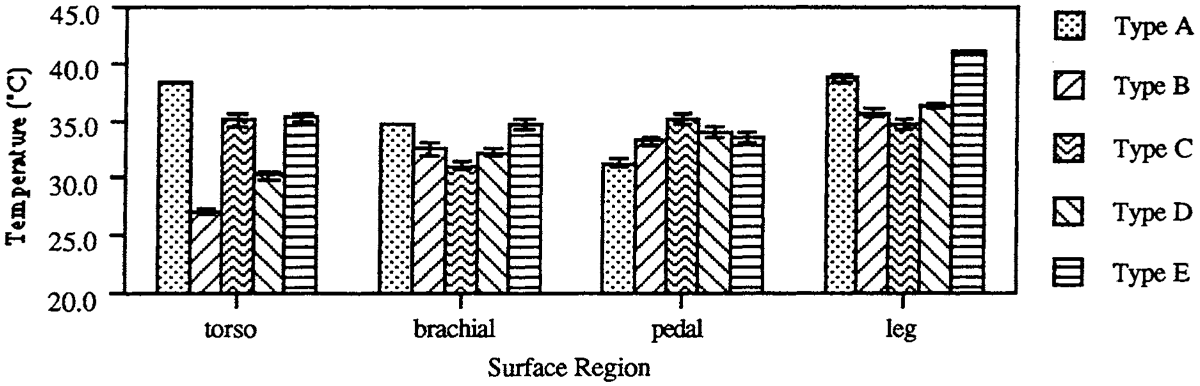
Each warming system was operated at its highest setting, and a cotton blanket was placed atop the coverlet and tucked around the mannequin and mattress. Temperature data were collected at the 18 surface measuring sites 20 minutes after initiation of warming because preliminary tests indicated that thermal saturation occurs after longer intervals. To achieve statistical significance, 6 repetitive trials were conducted for each warming system. Since the ambient temperature was not controlled during the trials, the measured data were normalized to an ambient temperature of 21.1 °C (nominal range: 21-24 °C). The normalized data were examined with respect to both temperature level and temperature symmetry across the medial plane.

A separate set of experiments was conducted in order to evaluate the relationship between coverlet-surface widthwise temperature variation and the manner in which the heated air enters the coverlet. For all the investigated coverlets except type D, the air enters the coverlet at an inferior, medial aperture. In contrast, the inlet of the type D coverlet is situated at an inferior corner. This difference in inlet position was investigated by comparing the type A system (representative of the medial inlet position) and the type D system. Since the coverlet temperatures were measured directly, a mannequin was not used. Instead, the air jets exiting the coverlet were directed either at a curved human-like form or at a planar surface. Ten thermocouples were uniformly spaced along the width of the coverlet, 36-41 cm below the top edge. Temperatures were recorded at one minute intervals after steady-state was achieved. Four replicate data runs were made. For both the medial and the corner aperture, the angular direction at which the air is admitted to the aperture was varied parametrically. The data were examined with respect to width-wise temperature variations.

RESULTS

Data from the mannequin that are related to temperature level are presented in Figure 1. The type A system provides the highest average torso temperature (average of the six torso zones is 38.4 °C). The Type E and C systems yield somewhat lower temperatures in this area (averages of the six torso zones are 35.4 °C and 35.1 °C, respectively). The type D and B systems produce the lowest temperatures in the torso region (averages of the six torso zones are 30.2 °C and 27.1 °C, respectively). The type A and E systems yield the highest average with respect to the four brachial temperatures. Furthermore, the Type A warming therapy provides the lowest average pedal temperatures, in contrast to the relatively high temperatures supplied by this system to the remainder of the mannequin. The type E system provides the highest average leg temperature.

Figure 1
Average Surface Temperature as a Function of the Surface
Region for Different Warming Systems



The mannequin-related data are also analyzed with respect to temperature symmetry across the medial plane. The average of the magnitudes of the side-to-side temperature differences from the mannequin-related data is lowest for the type A therapy (average = 0.6 °C). The remaining systems, listed in order of increasing temperature asymmetry, are: C, D, E, and B (averages are 1.0, 1.7, 1.7, and 1.8 °C, respectively).

The issue of temperature symmetry as well as of temperature uniformity also arises in connection with the effect of the air inlet position (medial versus corner position) on coverlet-surface widthwise temperature variations. Data indicate that, for a planar jet impingement surface, coverlet-surface widthwise temperature variations are more symmetric but less uniform for a medial air inlet than for a corner air inlet. For jet impingement upon a curved human-like form, data show the degree of coverlet-surface widthwise temperature symmetry to be independent of the air inlet position. However, for this impingement surface, the medial aperture data continue to be less uniform than the corner aperture data. The temperature distributions measured with the human-like form in place are insensitive to the angular direction at which the air is admitted to the aperture.

CONCLUSIONS

If it is postulated that torso warming will be most effective in raising core temperature and that pedal warming will be least effective, then the Type A warming system appears to be the best among those investigated. This finding is in accordance with that of [2], where both skin temperatures and skin heat fluxes of human subjects were monitored, in contrast to the temperature monitoring of an inanimate figure conducted here.

REFERENCES

1. Sparrow, E. M. 1993, Conduction Heat Transfer Notes, Chapter 3, University of Minnesota, Fall, 1993.

2. Giesbrecht G. G., et al.: Comparison of Forced-Air Patient Warming Systems for Perioperative Use. Anesth., in press.