Temperature of the Great Toe as an Indication of the Severity of Shock

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SUMMARY
To establish whether changes in skin temperature would provide objective indication of the presence and severity of shock, hemodynamic and temperature measurements were obtained with the aid of a digital computer. Values obtained 3 hours after admission and 3 hours prior to discharge or death in 100 patients who presented with clinical signs of circulatory shock were analyzed. Temperature was measured with standard thermistor probes at five sites: the digital pad of the third finger, the large toe, the deltoid region of the arm, the lateral portion of the thigh, and the rectum.

A significant correlation was demonstrated between the cardiac output and temperature of the toe \( r = 0.71 \). Correlations were increased to 0.73 when corrections were made for changes in ambient temperature. A stepwise regression analysis provided no significant improvement in the predictability of cardiac index when the values for temperatures of other skin sites were included. Discriminant function analysis showed that an early measurement of toe temperature correctly predicts patient outcome 67% of the time.

Additional Indexing Words:
Skin temperatures Hemodynamic data Rectal temperatures
Serum lactate Burton's index

AFTER TRAUMA, or during the course of a severe systemic illness, a critical curtailment of effective blood flow and a consequent curtailment of the function of vital organs is clinically recognized as circulatory shock. Reduction in arterial blood pressure, decline in urinary output, lessened mental alertness, and inadequacy of blood flow in the extremities with reduced or absent peripheral pulsation, constriction of superficial vessels, and loss of warmth in the hands and feet are physical signs on which the clinician bases the diagnosis of shock.

The present study was undertaken to establish whether quantitative changes in skin temperature might provide a more competent indication of the presence and severity of circulatory shock. Such measurements would be objective and yet available without trauma or discomfort to the patient. They would require only a minor investment in instrumentation and technical support, and therefore their potential value for routine monitoring was especially attractive.

The possibility that an index based on multiple measurements of skin temperature and rectal temperature would serve as a competent indication of peripheral blood flow, and hence would quantitate a circulatory defect characteristic of shock, was suggested by the previous work of Burton. Preliminary studies in our unit on patients who had shock in consequence of pancreatitis indicated that increases in the skin temperature, measured in

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the ventrum of the great toe, were closely related to increases in systemic blood flow and clinical improvement.\textsuperscript{2}

Data were then gathered on a larger group of patients to document the potential value of changes in skin temperature as an objective measure of the severity of shock. Skin temperature was measured at various sites on the body and changes in temperature were compared to simultaneous changes in other hemodynamic and metabolic parameters.

\textbf{Methods}

\textbf{Patients}

Observations were made on patients admitted to the Shock Research Unit by referral from the medical and surgical service of the Los Angeles County-USC Medical Center. To facilitate statistical analysis, we examined data on 100 patients. A group of 153 patients representing sequential admissions to the Shock Research Unit (SRU no. 654 to SRU no. 807) were reviewed and of these 53 were excluded from the study. Cases were excluded (1) if the period of observation, or of survival, was less than 6 hours and (2) if a complete inventory of measurements was unavailable because of technical or clinical limitations as was the case with patients who had extensive body burns in whom application of thermistors was medically contraindicated. Left for analysis were observations on 54 men and 46 women. Each patient was critically ill and had an acute life-threatening respiratory, circulatory, or metabolic defect. The primary causes of life-threatening illness were myocardial infarction in 17 patients, overwhelming infection in 20, massive loss of blood or fluid in 12, drug overdose in 15, and other causes including pulmonary embolism, central nervous system injury, and mesenteric infarction in 36 patients. The series of measurements were made over periods ranging from 6 to 144 (mean 31, SEM ± 3) hours. Of the 100 patients under observation, 44 died during the period of observation and treatment.

\textbf{Procedure}

Temperatures were measured with the use of standard Yellow Springs Instruments thermistors (Model 401 interchangeable thermistor probes). The thermistors were positioned on the lateral arm at a site corresponding to the central mass of the deltoid muscle, the center of the digital pad of the third finger, the lateral mid-thigh, and the digital pad on the ventrum of the first toe. All thermistors were positioned opposite to the side of the body used for arterial and venous catheterization. General purpose thermistor probes were used in preference to the discs specifically provided for measurement of the skin temperature. The general purpose probes, which are ordinarily used for measurements of esophageal and rectal temperature, proved less fragile than the usual surface probes and were of adequate sensitivity. Their use obviated the high breakage rate of the vinyl-covered wire lead at the junction with the disc of the surface probe.

The application of the thermistors to the skin is illustrated in figure 1. The probes were covered with a three-quarter inch rectangle of polyethylene sheet, which was sealed to the skin with waterproof tape to preclude local loss of heat and to maintain the thermistors in a saturated environment.

In addition to skin temperature, rectal temperature was measured with a probe which was inserted into the rectum for a distance of approximately 8 cm. Ambient (amb) temperature was monitored by means of an additional general purpose probe which was mounted on the bedside console at a position corresponding to the height of the patient's hip, but approximately 25 cm distant from the skin surface.

The thermistor probes were connected to an 8-channel data-acquisition device which was developed in our unit to replace the YSI telethermistor. From the device, the information was transmitted to an analog-to-digital converter and an IBM 1620 digital computer (fig. 2) for automated measurements according to techniques previously described.\textsuperscript{3} Each thermistor was separately calibrated with a thermometer having a precision of 0.2 C in a water bath. A computer

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{image.png}
\caption{Application of thermistor to toe.}
\end{figure}

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program was adapted for purposes of automated calibration over the range of interest. The computer calibration was based on a least squares fit of three points establishing intercept and slope for each thermistor. A systematic error, not exceeding 0.5 C, over the range of 25 to 45 C, is introduced by this method because the output of the thermistors is logarithmic whereas the calibration procedure assumes linearity over this range.

In addition to measurements of temperature, a series of hemodynamic and metabolic measurements were made according to methods previously described. Cardiac output, appearance time, mean circulation time, and central blood volume were measured by the indicator-dilution technique. Arterial pressure was measured with an indwelling catheter in the femoral or brachial artery; central venous pressure was measured in the superior vena cava or right atrium; heart rate was measured by means of standard electrocardiographic techniques. Urinary flow was monitored by use of a urinometer as previously described. Concentrations of lactate were measured by an enzymatic technique. The arterial resistance was computed from the intra-arterial pressure and cardiac output. The sensors were incorporated into a system which included the analog-to-digital converter and the IBM 1620 computer (IBM 1710 system) which provided both numerical and graphic outputs of data.

**Analysis**

For each of the 100 patients, two sets of 22 parameters were measured. The temperature values obtained at two stages of the patient's stay were compared with the 16 other reference measurements which served to indicate the hemodynamic and metabolic status of patients. A set of "early" values was obtained approximately 3 hours after admission, and a set of "late" values was obtained from measurements recorded 3 hours prior to the patient's discharge or death. The statistical methods for analysis of temperature relationships included a stepwise regression analysis, a two-sample t test on two groups of patients (patients who survived, patients who died), and a discriminant function analysis.

Burton's index (B.I.) was computed according to the following formula:

\[ B.I. = \frac{T_{\text{toe}} - T_{\text{amb}}}{T_{\text{rec}} - T_{\text{toe}}} \]

**Results**

**Clinical Observations**

Observations on two cases illustrate the relationship of changes in toe and rectal temperature to objective hemodynamic and metabolic measurements during circulatory shock. The first case graphically summarized in figure 3 is that of a 65-year-old woman who was observed after an acute myocardial infarction. Cardiac output and toe temperature were increased from a markedly reduced level in response to administration of isoproterenol. The subsequent course was characterized by a progressive decline in cardiac index, and both clinical and physiological signs of progressive perfusion failure. Hypotension, anuria, lactic acidosis, and a decline in toe
temperature were observed during the terminal course.

Improvement in effective circulation was demonstrated by the case of a 20-year-old woman who had attempted suicide by ingestion of a barbiturate drug and sodium cyanide. Hemodynamic and metabolic changes indicating progressive improvement in clinical status during infusion of 11 L of fluid over a period of 26 hours are graphically summarized in figure 4. Clinical improvement was closely related to gradual increases in cardiac index and arterial pressure to normal levels. The mean transit time of dye from the right atrium to the femoral artery was reduced to normal levels, and reduction in the lactate concentration in blood confirmed that perfusion was restored to levels which were adequate to sustain aerobic metabolism. A progressive increase in toe temperature was therefore closely related to improvement in the hemodynamic (and metabolic) status of the patient. These cases suggested that there was a predictable relationship between changes in toe temperature and changes in cardiac output.

**Relationship to Cardiac Output**

Data on 100 cases were then accumulated to define the statistical relationship between toe temperature and cardiac index. In 56 of the cases, cardiac index exceeded 2 L/min/m², and in 43 (76%) of this group, toe temperature exceeded 27 C. A critical reduction in cardiac index to levels of less than 2 L/min/m² was associated with a decline in toe temperature to less than 27 C in 42 of 44 cases (95%). When toe temperature exceeded 29.2 C, the cardiac index exceeded 2 L/min/m² in each case (fig. 5). We confirmed a highly significant correlation between cardiac index

**Table 1**

<table>
<thead>
<tr>
<th>Mean arterial pressure</th>
<th>Cardiac index</th>
<th>Appearance time</th>
<th>Mean circulation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe</td>
<td>0.28</td>
<td>0.71</td>
<td>-0.52</td>
</tr>
<tr>
<td>Toe — ambient</td>
<td>0.27</td>
<td>0.73</td>
<td>-0.54</td>
</tr>
<tr>
<td>Finger</td>
<td>0.15</td>
<td>0.56</td>
<td>-0.37</td>
</tr>
<tr>
<td>Rectal</td>
<td>0.25</td>
<td>0.11</td>
<td>-0.03</td>
</tr>
<tr>
<td>Burton’s index</td>
<td>0.03</td>
<td>0.62</td>
<td>-0.34</td>
</tr>
</tbody>
</table>
and toe temperature: \( r = 0.71 \) (\( P < 0.01 \)). The correlation coefficient was slightly improved when correction was made for differences in ambient temperature: \( r = 0.73 \) (\( P < 0.01 \)).

When the effects of rectal temperature were also taken into account by computation of Burton's ratio, no further improvement in correlation was achieved. To the contrary, \( r \) was reduced to 0.62. The implication that the internal body temperature did not independently affect the predictability was surprising and was contradictory to concepts inherent in the use of Burton's ratio. For this reason a separate partial correlation analysis was undertaken. The partial correlation between Burton's index, after the effects of skin and ambient temperatures were excluded, was \( r = 0.12 \), a value which was not statistically significant. This computation confirmed that after changes in toe and ambient temperature had been taken into account, changes in rectal temperature did not independently affect the cardiac index (table 1).

Concerning other hemodynamic parameters, significant correlations were found between toe temperature and mean circulation and appearance times which are measures of the velocity of blood flow. The low correlation with arterial pressure is not surprising since major workers in the field of shock have reaffirmed that flow and pressure are poorly related (table 1).

### Other Sites of Measurements

Of the four sites at which skin temperature was measured, the toe provided the best indication of changes in blood flow. We have investigated the extent to which predictability of blood flow could be improved by including measurements of skin temperatures at additional sites. The results of a stepwise regression analysis reveal no significant improvement in predictability when measurements obtained from the three other sites are included (table 2). Hence, the information of temperature changes in the toe provides the full source of information contained in the

### Table 2

*Stepwise Regression Analysis*

<table>
<thead>
<tr>
<th>Site</th>
<th>( r )</th>
<th>Increase in ( r^2 )</th>
<th>( F )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe — ambient</td>
<td>0.7115</td>
<td></td>
<td>99.42</td>
<td>( P &lt; 0.01 )</td>
</tr>
<tr>
<td>Deltoid — ambient</td>
<td>0.7169</td>
<td>0.0078</td>
<td>1.54</td>
<td>NS</td>
</tr>
<tr>
<td>Finger — ambient</td>
<td>0.7277</td>
<td>0.0024</td>
<td>0.48</td>
<td>NS</td>
</tr>
<tr>
<td>Rectal — ambient</td>
<td>0.7280</td>
<td>0.0132</td>
<td>2.64</td>
<td>NS</td>
</tr>
<tr>
<td>Thigh — ambient</td>
<td>0.7280</td>
<td>0.0004</td>
<td>0.07</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Cardiac index is the dependent variable. The temperatures at other sites, corrected from ambient temperature, are independent variables. NS = not significant.

### Table 3

*Temperature (°C) Differences and Significance of Differences Between Means for Survivors and Patients Who Died after Circulatory Shock*

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Mean of survivors</th>
<th>Mean of fatal cases</th>
<th>( F )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe — ambient</td>
<td>3.40</td>
<td>0.95</td>
<td>19.00</td>
<td>(&lt;0.001 )</td>
</tr>
<tr>
<td>Deltoid — ambient</td>
<td>6.62</td>
<td>5.26</td>
<td>9.44</td>
<td>(&lt;0.01 )</td>
</tr>
<tr>
<td>Finger — ambient</td>
<td>4.22</td>
<td>2.56</td>
<td>4.76</td>
<td>(&lt;0.05 )</td>
</tr>
<tr>
<td>Rectal — ambient</td>
<td>12.68</td>
<td>11.52</td>
<td>5.79</td>
<td>(&lt;0.025 )</td>
</tr>
<tr>
<td>Thigh — ambient</td>
<td>7.04</td>
<td>5.05</td>
<td>13.00</td>
<td>(&lt;0.001 )</td>
</tr>
<tr>
<td>Burton's index</td>
<td>0.69</td>
<td>0.20</td>
<td>6.42</td>
<td>(&lt;0.025 )</td>
</tr>
</tbody>
</table>
skin temperature measurements. A relatively high correlation between toe and finger temperature was observed \((r = 0.56)\). This indicates that much, but not all, of the pertinent information is also contained in the finger temperature.

**Temperature and Prognosis**

A study of the clinical course of this group of patients confirmed that increases in skin temperature, and especially in toe temperature, indicated improvement in the patient’s status. For purposes of assessing the value of measurement of temperature in establishing prognosis, the extent to which an “early” measurement served to indicate the likelihood that the patient would survive was examined. Our population of 100 patients was therefore classified on the basis of survival. Skin temperature measurements were compared in the two groups using a two-sample \(t\) test. Toe temperature and toe temperature minus ambient temperature gave the best discrimination between survival and death (table 3). The computation of Burton’s ratio did not give as good a discrimination. The highly significant difference between the mean toe temperature in the two groups (fig. 6) allows to a certain extent a prediction of the prognosis since the temperatures taken into account are the result of the “early” measurement. The prediction was correct in 67% of the cases.

When a “late” measurement is considered, the difference between toe temperature in the two groups is of course even greater (fig. 6). A good prognosis was correctly predicted in 40 patients out of 45 on the basis of toe temperature alone. When other temperatures were included in the computation, 44 out of 47 were correctly classified although this is not a statistically significant improvement in predictability.

We also related prognosis to observed changes in temperatures during the course of
observation. A rising toe temperature in the interval between admission and discharge was a reliable indication of good prognosis and vice versa (fig. 7). A two-sample t test showed a highly significant difference in the changes of toe temperature minus ambient temperature for the two groups (fig. 8).

Discussion

In assessing the severity of shock, the physician recognizes the importance of taking into account a combination of parameters. For instance, changes in blood pressure are interpreted in relation to changes in flow of urine, mental alertness, and both the color and warmth of the extremities. Increasingly recognized is the importance of assessing those changes which indicate alterations in blood flow. Demands of clinical management, the restlessness of patients, and congestion at the bedside preclude use of refined techniques, such as plethysmography. The patient cannot cooperate and the essential rigor of medical and nursing activities at the bedside usually preclude mechanical stability and a steady state.

More recently, measurement of cardiac output has become an established routine in some clinical research centers. However, this method for routine use involves major technical commitment.

On the other hand, measurement of skin temperature may be achieved with relatively little commitment of staff, without costly equipment and supplies, and without significant mechanical impediment at the bedside. Since measurements of toe temperature are not significantly affected by patient movement, it may be used without reference to the patient's mental status. Finger temperature does not provide the same level of reliability since significant increases are sometimes observed after the patient moves his upper extremity and especially when he rubs his finger against the bedding.

Ibsen evaluated changes in the skin temperature of the thumb and the toe when patients in shock were treated with chlorpromazine in a temperature controlled environment. In his description of observations on 150 patients, the author stated that clinical improvement was closely related to increases in skin temperature. As in the present study, the toe served as a more reliable indicator than the finger for assessment of severity of the shock state.

There is no simple relationship between skin temperature and blood flow. When this relationship is quantified by the use of plethysmographic techniques, an equation which corresponds well to experimental data provided by several workers is as follows:

\[
\text{Flow} = K \frac{T_s - T_r}{T_b - T_x}
\]

where \( K = 6.3 \),

\( T_s = \text{temperature (skin)} \),

\( T_r = \text{temperature (room)} \) (20.5 C),

\( T_b = \text{temperature (blood)} \) (foot) (33.0 C).

However, such data are based on studies performed on normal subjects during steady states. No adequate data are currently available which would confirm the validity of temperature measurements for estimates of quantitative changes in peripheral blood flow during clinical shock states. On the other hand, the present data do indicate that toe temperature is a reliable indicator of cardiac output and indirectly an indicator of systemic blood flow. It provides particularly competent directional information with regard to effective blood flow in terms of tissue perfusion.

Conclusions

In addition to aiding in the assessment of blood flow, toe temperature permits a helpful indication of prognosis. If toe temperature, 3 hours after admission, is less than 27 C, or if the difference between toe and ambient temperatures is less than 2 C, the likelihood of death is high (67%). Increases in skin temperature are likely to improve cardiac output and survival. Since toe temperature provides objective information on the severity of shock, with minor investment in instrumentation, the authors regard it as a valuable addi-
tion for clinical monitoring of patients with shock.

References


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