Influence of an Oscillating Bed on Cutaneous Temperature and Oxygen Tension of Ischemic Toes

By Carlos Forno, M.D., Hugh Montgomery, M.D., and Orville Horwitz, M.D.

Measurements of temperature and oxygen tension of the skin demonstrated that treatment with an oscillating bed increases the circulation to ischemic toes. When the angle and duration of the dependent position of the foot of the bed were increased, further increments in circulation resulted.

The effect of the dependent position upon blood flow to the extremities has long been a matter of controversy. Even when the limbs remain in the plane of the body, and the whole is tilted foot-downward, there is little agreement concerning the changes in blood flow that take place in the limbs. Youmans, Akeroyd, and Frank in 1935 found a rapid decrease in the temperature of the skin of the toes and of the lower legs when subjects were changed from the horizontal to the erect posture. The opposite result was obtained in 1938 by Roth, Williams, and Sheard, who reported an increase in the temperature of the toes in 15 of 23 observations when the standing position was adopted. Studies utilizing a tilt table have given varying results, apparently depending upon the degree of downward inclination of the table. With 15 and 20 degrees of downward tilt, Roth and co-workers found an increase in the skin temperature of the toes. Nielsen et al. observed a rise in the skin temperature of the toes with 45 degrees downward inclination, although the skin temperature at other parts of the body was lowered. When the angle was 70 degrees the skin temperature of the toes decreased. Mayerson and Toth observed a decrease in both the cutaneous and subcutaneous temperatures with a 75-degree foot-downward position. They thought that the difference in angles of inclination explained the divergence of their results from those of Roth. Bridgen, Howarth, and Sharpey-Schafer, studied blood flow by venous occlusion plethysmography in subjects tilted from the horizontal to the vertical position, and found that flow decreased in a normal forearm but not in a sympathectomized limb. Similar results in the hand have been observed by Beaconsfield and Ginsburg. Williams, Montgomery, and Horwitz, by the polarographic method, found an increase in oxygen tension of the skin of the toes in normal, and especially in ischemic, limbs when the foot of a horizontal tilting table was lowered 7 inches (5 degrees), but no change in skin temperature was detected either in normal or ischemic toes.

Disagreement also exists about the measurements of blood flow in dependent limbs while the rest of the body is unchanged in position. Differences in method may in part account for this. Thus, Wilkins, Halperin, and Litter, by means of venous oxygen measurements, observed that blood flow to a dependent resting arm or leg of a subject in a recumbent position was greater than to the horizontal limb. Rosensweig also found an increase in flow, by the same method, in the dependent arm of the seated subject. Opposite results have been obtained by the method of venous occlusion plethysmography, in which the inherent difficulties, particularly "after drop," have long been recognized. Gaskell and Burton reported a decrease in blood flow to the toes of a normal limb made dependent at the knee. Beaconsfield and Ginsburg reported a decrease in flow in both normal and sympathectomized limbs. In recent studies.
of some of the problems connected with the use of the venous occlusion plethysmograph, Allwood\textsuperscript{15} avoided making comparisons of blood flow in the dependent and horizontal positions measured by this method. Roddie\textsuperscript{16} used a calorimetric method, and his measurements suggest that the rate of blood flow through the fingertips is slightly greater and the peripheral resistance slightly less when the arm is dependent than when it is horizontal.

An oscillating bed allows a person to recline while the limbs remain in a constant position with respect to the body. It is in essence a mechanically driven tilting table supported at the center. It was designed in 1936\textsuperscript{17} and has been widely used in the treatment of ischemic limbs. Favorable clinical results after use of this bed have been reported, but very few measurements of its effect upon blood flow have been made. The cyclic changes create a complicated circulatory situation. The only studies we know of its effect on blood flow have been made by measurements of skin temperature. Barker and Roth in 1939\textsuperscript{18} were the first to evaluate the effect of this apparatus on ischemic limbs. They made a few measurements of the temperature of the toes of patients who had reduced blood flow to the lower limbs, usually, but not always, finding a slight increase after lowering the feet. Horton, Krusen, and Sheard\textsuperscript{19} found no change in the temperature of the toes of normal subjects directly attributable to the oscillating bed, and thought that the results of Barker and Roth were probably due to uncontrolled factors.

The purpose of the present study was to determine the effect of the oscillating bed on both the temperature and the oxygen tension of the skin of ischemic toes, and the part played by the degree and duration of downward inclination of the foot of the bed.

**METHOD**

An oscillating bed\textsuperscript{5} permitting a wide range of adjustment of angles and timing was used. The patients studied had arteriosclerosis obliterans of the lower limbs. In each patient the more ischemic foot was used, and the skin temperature and oxygen tension of the toes were measured on different days. Skin temperature studies were made in a constant temperature room with air 23 ± 1 C. Temperatures were recorded by a Brown potentiometer, 4 copper constantan thermocouples being placed at the base and 3 at the tips of the toes, and held in place by a single layer of adhesive tape. By means of the polarographic technic described by Montgomery and Horwitz\textsuperscript{20} changes in cutaneous oxygen tension were measured in a room with a temperature of 24.5 to 30.0 C.; that during any one experiment varied by no more than 1 C. Four electrodes were inserted intracutaneously at the base of the toes. Percentage changes in oxygen tension were calculated from the changes in electric current. Skin temperature was recorded every 2 minutes and oxygen tension every 5 minutes except in the experiments in series IIb (table 1).

**Series I.** The first series of experiments was designed to establish the optimal oscillating pattern of the bed. Four patients, 2 male and 2 female, with arteriosclerosis obliterans were studied. Their ages ranged from 47 to 70 years. One was diabetic. None had ulcers or gangrene at the time the studies were made. A mean temperature of 27.2 C. (25.0 to 28.9 C.) was obtained in the skin of the tips of the toes after the patients' bodies were warmed in a constant temperature room at 20 C.

Eight skin temperature studies and 8 oxygen tension studies were made on each of the 4 patients (table 1). The patients were kept comfortably warm. The period of oscillation was always preceded and followed by a period in which the bed was immobile at the horizontal (fig. 1). The foot-up position was held at 5 degrees for 12 seconds. The foot-down positions were maintained 12 and 20 degrees for 12 seconds and for 1, 2, and 5 minutes. In any single experiment only 1 downward angle for 1 of the above periods of time was used. It took 27 seconds for the foot of the bed to move between the 5-degree foot-up angle and the 12-degree foot-down angle, and 40 seconds to

\[\text{FIG. 1. Schema of oscillating bed, angles used, and sequence of the first series of experiments.}\]
INFLUENCE ON OXYGEN TENSION OF ISCHEMIC TOES

Table 1.—Changes in Temperature and Oxygen Tension of Skin of Toes of Patients on the Oscillating Bed

<table>
<thead>
<tr>
<th>Series</th>
<th>Foot-down angles and timing</th>
<th>Temp. change tips of toes (°C)</th>
<th>Temp. change bases of toes (°C)</th>
<th>Oxygen tension change, bases of toes (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>mean t</td>
<td>p</td>
<td>N</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 12°, 0.2 min.</td>
<td>12</td>
<td>+0.48 3.0 0.02</td>
<td>16</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 12°, 1.0 min.</td>
<td>12</td>
<td>+0.55 2.9 0.02</td>
<td>15</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 12°, 2.0 min.</td>
<td>10</td>
<td>+0.79 2.9 0.02</td>
<td>15</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 12°, 5.0 min.</td>
<td>12</td>
<td>+1.10 6.6 0.001</td>
<td>15</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 20°, 0.2 min.</td>
<td>11</td>
<td>+1.19 4.5 0.001</td>
<td>16</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 20°, 1.0 min.</td>
<td>12</td>
<td>+0.22 2.3 0.05</td>
<td>16</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 20°, 2.0 min.</td>
<td>12</td>
<td>+1.24 3.3 0.01</td>
<td>16</td>
</tr>
<tr>
<td>I</td>
<td>Oscillating: 20°, 5.0 min.</td>
<td>12</td>
<td>+2.08 8.9 0.001</td>
<td>16</td>
</tr>
<tr>
<td>IIa</td>
<td>Not oscillating: horizontal</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IIb</td>
<td>Oscillating: Average of 5 readings taken after 5.0 min., 20° foot-down position, compared with average of 5 readings taken after intervening 2 min. foot-up position</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IIc</td>
<td>Not oscillating: 20°</td>
<td>5</td>
<td>+1.24 5.6 0.01</td>
<td>6</td>
</tr>
<tr>
<td>IID</td>
<td>Not oscillating: horizontal intermittent 33 mm. Hg venous occlusion in 5.0 min. cycles</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

N = number of data; t = mean response/standard error, and p = probability that the mean change differs from zero due to random sampling variation only. The oxygen tension changes, expressed as the ratio of the experimental period observation to the average control period observation, were subjected to a logarithmic transformation before statistical analysis. The mean responses have been converted back to per cent change in the table.

move between the 5-degree foot-up angle and the 20-degree foot-down angle.

When temperature of the skin was being measured, oscillation of the bed was started as soon as the skin temperature of the toes had stabilized. The first control period averaged 78 minutes, the experimental period 47 minutes, and the second control period 18 minutes. For the oxygen tension experiments 40 minutes were allowed for each of the 3 periods. The changes induced during any experiment were calculated by comparing the reading recorded at the end of the period of oscillation with the average of the readings obtained at the end of the 2 control periods. All results are reported as average changes.

Series II. The second series of experiments planned to clarify the details of the results of the first series, were of 4 types: (a) measurements with the bed horizontal, omitting the oscillating period, (b) measurements of the changes in skin temperature and oxygen tension during each cycle of the oscillating bed, (c) measurements of the effect of the constant foot-down position without oscillation, and (d) learning the effect of venous pressure pressure on the readings of the oxygen electrode. Cutaneous oxygen tension was recorded throughout all these experiments; some cutaneous temperatures were also recorded. In (a) the same patients were studied as in the first series of experiments; in (b), (c), and (d) some substitutions of patients were made, but all had previously been shown by vasodilatation test to have capacities for blood flow strictly comparable with those previously studied. Their range of skin temperature at full vasodilatation in a 20 C. constant temperature room was between 25.4 and 28.8 C.

RESULTS

General

All results are summarized in table 1. Since there was no significant relationship between
responses of toes of 1 foot and of all feet, when angles and timing were unchanged, responses of all toes are considered samples of a single population. The 3 types of response listed are the change in temperature of the skin of the tips of the toes, the change in temperature of the skin of the bases of the toes, and the per cent change in oxygen tension of the skin of the base of the toes.

Series I

The responses to the 20-degree dependent position are consistently and significantly more marked than to the 12-degree dependent position. For example, the greatest response in temperature of the tip of the toe to the 20-degree foot-down angle was significantly greater than the greatest response to the 12-degree angle ($p < 0.001$).

For a given angle, the temperature responses tend to increase as the time of dependency is increased, whereas the oxygen tension responses are about the same for all 3 cycle times greater than 12 seconds.

Of the combinations in series I, 20-degree dependency for 5 minutes produced the greatest response by all 3 types of measurement in which case the average increase in skin temperature of the tips of the toes represents an increase in blood flow to approximately 13 ml. per 100 ml. of tissue per minute from a control flow of 6 ml. per 100 ml. of tissue per minute.\(^{21}\)

Series II

a. With the bed horizontal for 120 minutes, oxygen tension of the skin was measured throughout experiments on the 4 original patients. It decreased 9 per cent. Although this is not statistically significant ($p = 0.06$), it suggests a slightly lessened flow during prolonged horizontal immobility.

b. The separate effect upon oxygen tension of the foot-down and the foot-up part of each cycle was measured throughout experiments performed on 2 patients (1 a substitute). The 20-degree foot-down position was used for 5 minutes. The foot-up period was extended to 1 minute to provide time for all 4 electrodes to be read. Each total cycle lasted 7 minutes; 5 cycles were studied in each experiment. In order to avoid variations in times of polarization of the electrodes, 3½ minutes were allowed to elapse between readings taken in the foot-up and in the foot-down positions. In all but 1 of the 10 cycles the oxygen tension was greater in the foot-down position than in the foot-up position. However, the degree of the effect differed widely in the 2 patients: in the first the mean oxygen tension in the foot-down position was 57 per cent greater than in the foot-up position, whereas in the second it was 2.8 per cent. The average of all the data is an increase of 20.3 per cent, which is not statistically significant.

c. The effects of a constant foot-down angle of 20 degrees without oscillation on 4 patients (1 a substitute) were measured in 11 experiments on skin temperature and 4 on oxygen tension. The duration of the experimental periods and of the preceding and succeeding control periods were the same as in the 20-degree angle experiments in series I. The skin temperature of the tips of the toes increased significantly ($p = 0.01$) as did the skin temperature at the base of the toes ($p = 0.001$); oxygen tension increased very significantly ($p = 0.001$). The results are in general similar to those from oscillations at 20-degree dependency for 5 minutes. However, the change in tip skin temperature was significantly smaller ($p = 0.01$), the change in base skin temperature was significantly greater ($p = 0.02$), and the oxygen tension change was about the same.

d. Whether dilatation of capillaries caused by increased venous pressure in the dependent foot might of itself affect oxygen electrode readings was studied in 3 patients (2 substitutes). Even though oxygen tension remained constant, we considered the possibility that an error might arise from a shortened diffusion distance from distended capillaries to electrode. In order to check this possibility the following experiment was performed. Each patient was kept in the horizontal position for 40 minutes. The increment of pressure that would result from a 20-degree tilt,
33 mm. Hg, was applied for 5 minutes by a
cuff placed at the ankle, followed by a 5-
minute period of release of pressure. Pressure
was applied for a total of 12 times. Readings
of oxygen tension were taken every 3 minutes
throughout and no significant changes were
observed during the application of pressure.

Discussion

The factors involved are probably mainly
those of hydrostatic pressures and vasomotor
tone. When the body is tilted downward at
the foot, there must be increments in arterial
pressure at all points below the heart, and
equal increments in the veins, unless venous
valves close. As the veins fill, the valves open
if they were closed, and the increment in
hydrostatic pressure becomes equal in veins
and arteries at any particular distance below
the heart. If vasomotor tone is unchanged,
a resulting dilatation of vessels decreases res-
ristance, and flow increases even with an un-
changed arteriovenous pressure difference.
The increased flow continues until the foot is
elevated, unless vasoconstriction should abol-
ish the hydrostatic dilatation, and in our ex-
periments it did not. If the valves do close
during early dependence, there will be an
increase in arteriovenous pressure difference
until they again open, and this will contribute
temporarily to an increase in flow. Such a
rise in arteriovenous pressure difference would
account for only a part of the measured in-
crease in flow, because it would not explain
the augmented flow as duration of dependency
increases. More information about this might
be gained from measurements of venous pres-
sure, or by noting the flow of radiopaque sub-
stances in the veins.

When patients with severely ischemic limbs
are treated on an oscillating bed, more than
1 minute of dependency at a 20-degree angle
is required for the pink color of the foot to
return. It is not surprising that the more
prolonged foot-down positions resulted in the
greater increments in temperature and oxygen
tension.

Although the responses during 40 minutes
of continuous dependency at a 20-degree angle
are marked, and comparable to those obtained
during 40 minutes of oscillation to this angle
with 5-minute foot-down, we have not studied
this further. The oscillating bed has, when
such a steep angle is used, the great clinical
advantages over the constant foot-down posi-
tion of avoiding hydrostasis, edema formation,
and possible venous thrombosis. Previously,
moderate increases in oxygen tension were
demonstrated by using as small a constant
foot-down angle as 5 degrees (7-inch elevation
of the head of the bed), a constant foot-down
angle that has less risk.\(^7\)

The oscillating bed may have another ad-
vantage over the constant foot-down position;
it may lessen the sludging of blood in ischemic
limbs. If an ischemic limb is raised and then
lowered, the time for return of color is greater
than that in a normal limb that has the same
vasomotor tone. If the procedure is then re-
peated, the time for return of color is less.
This suggests that cyclic elevation and de-
pendence has flushing action, combating a
tendency to sludging.

Neither the interrupted closure method for
measuring changes in oxygen tension nor the
estimation of flow in skin by the temperature
method lend themselves to repeated measure-
ments during a single cycle of less than 2
minutes, and we did not attempt to analyze
changes during such a short single cycle.

In our experiments changes in oxygen ten-
sion probably resulted for the most part from
changes in blood flow, because changes in
blood flow were usually demonstrable, the
limbs were at rest and oxygen utilization is
presumed to have been constant, and venous
pressure per se of this order of magnitude
seemed not to affect the readings of oxygen
tension. In the venous pressure experiments,
skin temperature was not measured, and it is
possible that blood flow decreased and capil-
lar permeability increased concomitantly. So,
it may be that some of the oxygen tension of
the tissue resulted from changes in capillary
permeability, or from shortening of the oxy-
gen gradient from capillaries to the electrode
tip.
Summary
Experiments were performed upon the ischemic feet of patients with occlusive arterial disease in order to learn whether an adjustable oscillating bed will increase blood flow as measured by an increase of the temperature of the skin of the toes and of cutaneous oxygen tension as estimated by the polarographic technic.

The effect of 2 angles of downward inclination, 12 and 20 degrees, and of various timings was studied. The greatest increase in the temperature of the skin of the toes and of cutaneous oxygen tension resulted after the greater angle and the most prolonged foot-down position of 5 minutes. These increases were significant at a probability of 0.05 or less. Intermittent venous occlusion had no significant effect on the oxygen tension.

It is concluded that the oscillating bed increases the flow of blood and the supply of oxygen to the ischemic foot if a considerable foot-down angle of the bed is maintained for a prolonged period during each cycle of the oscillation.

The clinical advantages of the oscillating bed over the constant foot-down position, in particular the avoidance of hydrostasis, edema formation, and possible venous thrombosis, are mentioned.

Summary in Interlingua
Esseva effectuate experimentos con le pedes ischemic de patientes con occlusive morbo arterial, con le objectivo de determinar si le uso de un regulable lecto oscillante resulta in un augmento del fluxo de sanguine, me- surate como un altiamento del temperatura cutanea in le digitos del pede e como un elevation del cutanea tension oxygenic (super le base de estimationes obtenite per medio del technica polarographic).

Le effecto de 2 differente angulos de inclination in basso—12 grados e 20 grados—e etiam le effecto de varie durationes esseva studiate. Le augmento maxime del temperatura cutanea del digitos del pede e del cutanea tension oxygenic resultava quando le plus grande del duo angulos e le plus grande prolongation del abassation del pede—i.e. 5 minutas—esseva usate. Le effectos esseva significative con un probabilitate de 0,05 o minus. Intermittente occlusion venose habeva nulle effecto significative super le tension oxygenic.

Es formulate le conclusion que le lecto oscillante augmenta le fluxo de sanguine e le provision de oxygeno in un pede ischemic, providite que le angulo de abassamento del pede es considerabile e es mantenite durante un intervallo prolongate in le curso de omne cyclo de oscillation.

Es mentionate le avantage clinic del lecto oscillante in comparation con le abassation constante del pede. Istos include specialmente le evititation de hydrostasis, de formation de edema, e possibilemente de thrombosis venose.

References


Because of the variability in oxygen saturation of venous blood within the normal heart, a method of withdrawing repeated blood samples in rapid succession through a cuvette oximeter, an instrument of high relative accuracy, has been developed for use during cardiac catheterization in an attempt to reduce the effects of incomplete mixing and changing cardiac output to a minimum. This presentation is an analysis of the data on oxygen saturation of blood obtained in this manner in an adequate series of unanesthetized, ambulatory, healthy, adult subjects. In addition to defining the mean and ranges of oxygen saturation within the right chambers of the heart and great vessels and the differences in the oxygen saturation of blood from these various sites, it has been possible to make some inference as to the relative importance of changes in cardiac output and laminar flow (incomplete mixing) on the variability of the values obtained at these various sites.

MAXWELL
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