TOTAL AND NUTRITIONAL BLOOD FLOW IN THE FINGER

J. D. COFFMAN

Boston University School of Medicine, and Robert Dawson Evans Memorial Department of Clinical Research, University Hospital, Boston, Mass.

(Received 14 July 1971)

SUMMARY

1. Total and nutritional flow in the fingertip were investigated during reflex sympathetic nerve stimulation (total body cooling) or adrenergic nerve transmitter administration. Nutritional flow was measured by the disappearance rate of a local depot of Na$^{131}$I, and total fingertip flow by venous occlusion plethysmography.

2. With body cooling the decrease in nutritional flow was not significant, but total and therefore arteriovenous shunt flow decreased significantly.

3. Norepinephrine infused into the brachial artery decreased total and nutritional flow significantly although total flow decreased more than nutritional.

4. It is concluded that sympathetic nervous system activity exerts a greater effect on finger arteriovenous shunt flow than on nutritional flow. Therefore nutritional flow is not adversely affected.

Key words: finger flow, nutritional finger flow, arteriovenous shunt flow, norepinephrine, reflex stimulation, plethysmography.

The fingertips are rich in arteriovenous (a–v) anastomoses. These communications between small arteries or arterioles and the corresponding venous channels allow blood to bypass the capillaries. Grant & Bland (1931) found 510 a–v shunts/cm² in the human nail bed and 236 in the fingertip. These shunts, if actively controlled, could greatly vary the amount of blood flow traversing the fingers. Although studies in animals suggest they play an important role in temperature regulation of the part and of the body by increasing or decreasing the radiation of heat (Sherman, 1963), their actual participation in such reflexes in man has not been shown. This mechanism to control temperature would be most effective if a–v shunt flow could be changed without significantly affecting nutritional flow.

In man the relationship of fingertip a–v shunt flow to nutritional flow has not been studied due to a lack of appropriate methods. In the present study nutritional blood flow was estimated by the disappearance rate of a radioactive isotope from the fingertip and total blood flow was measured simultaneously by plethysmography. From these two measurements changes in a–v...
shunt flow could be deduced. Sympathetic stimuli or agents could then be given to study their
effect on nutritional and total flows.

METHODS

Total fingertip blood flow was measured in one finger by venous occlusion air plethysmo-
graphy, while the disappearance rate of a radioactive isotope from a local injection in an adjacent
fingertip was used as a measure of cutaneous nutritional blood flow. The hand was held stable
on a sand bag slightly above heart level. The plethysmograph consisted of a finger-cup with a
tubular outlet. It was sealed to the fingertip beyond the distal interphalangeal joint with
caulking compound. A narrow pneumatic cuff was applied proximal to the finger-cup. The
lowest venous occlusion required to obtain the maximum rate of increase in fingertip volume
was determined at the beginning of each experiment and averaged 58 mmHg. Fluctuations of
fingertip volume were detected by a Sanborn pressure transducer (268A) connected by stiff
rubber tubing to the outlet of the finger-cup and recorded by using a Sanborn 150–1100 pre-
amplifier and direct writing recorder. The recording system was calibrated at the beginning
and end of each experiment by introducing known quantities of air into the system. In the
warm- and cool-room experiments the recording system was calibrated after equilibration for
1 h at each temperature. The volume of fingertip within the finger-cup was determined by
water displacement to express blood flow in ml min\(^{-1}\) 100 g of tissue\(^{-1}\).

For nutritional blood flow approx. 0.01 ml of Na\(^{131}\)I in saline (0.9\%) was injected with a
27-gauge needle into the skin of the pad of a fingertip. The disappearance rate was monitored
by a scintillation probe, ratemeter (time constant set at 1 s) and linear recorder. The scintilla-
tion probe contained a 1 in \(\times\) 1 in thick thallium activated sodium iodide crystal. The dose of
the radioactive isotope varied from 1 to 2 \(\mu\)Ci. Disappearance rates were plotted on semi-
logarithmic paper after subtraction of the background counts and expressed as half-times. The
disappearance rates were also converted into an estimated blood flow in ml min\(^{-1}\) 100 g\(^{-1}\) by
dividing the natural logarithm of 2 (0.693) by the half-time and multiplying by the tissue to
blood partition coefficient times 100. The partition coefficient was estimated to be 0.5 (Coff-
man, 1969). Since conversion into blood flow actually involves multiplication of the half-time by a
constant factor, a slightly different partition coefficient would alter results in a uniform manner.

The disappearance rate of Na\(^{131}\)I was used in this study as a measure of nutritive blood flow.
Lassen (1964) has shown that \(^{24}\)Na may be diffusion limited in skeletal muscle during reactive
hyperaemia and concluded that \(^{133}\)Xe would therefore be a better measure of blood flow. Howev-
er Gosselin & Audino (1971) found that the ratio of Na\(^{131}\)I/\(^{133}\)Xe disappearance rates varied with the stimulus that increased the blood flow and under certain conditions the ratio
was unity near a flow of 20 ml min\(^{-1}\) 100 g of muscle\(^{-1}\). Walder (1955) and Prentice, Stahl,
Dial & Ponterio (1955) found a linear increase in \(^{24}\)Na disappearance rates with changes in
blood flow within the physiological range. In studies on forehead skin blood flow we have
found that the disappearance rates of Na\(^{131}\)I, \(^{133}\)Xe and 4-iodoantipyrine were very rapid and
similar (Coffman, 1969). Leroy, Downey & Cannon (1971) report finger blood flow by using
\(^{133}\)Xe in the same range as our results but with a higher average flow which would depend on
the use of a larger partition coefficient value. Two other difficulties exist with the use of a
diffusible lipophilic gas to measure blood flow. In only half of the subjects that we tested with
\(^{133}\)Xe did the disappearance rate stop completely with arterial occlusion; therefore \(^{133}\)Xe
may escape through the needle tract. The complete diffusibility of \(^{133}\)Xe and the diffusion into
Finger total and nutritional flow

subcutaneous tissue may also mean that the ion may enter arteriovenous anastomoses. If nutritive blood flow is to be measured as opposed to non-nutritive (arteriovenous shunt or even capillary) flow, $^{24}$Na or $^{131}$I may therefore be the preferred tool (Hyman, 1971).

The volunteer subjects were instructed in the nature of the experiments and gave informed consent. They were lightly clothed and lay supine on a bed; subjects ranged in age from 21 to 37 years (average 27 years). In experiments involving body cooling, finger flow studies were first performed after 1 h in a room at 28-3°C and then repeated after 1 h at 20°C. In the experiment involving intra-arterial infusions an 18 gauge Cournand needle was inserted into the brachial artery after infiltration with Xylocaine. A 20 min rest period was then allowed in a 25-5°C room. Solutions were given by a constant infusion pump via the arterial needle. Total fingertip flows and a disappearance rate were determined while 5% (w/v) glucose and water was infused; after a rest period the test was repeated during norepinephrine infusion. Norepinephrine (levarterenol bitartrate, Winthrop) in 5% glucose and water was infused at a concentration of 0.125 µg of base/ml. The smallest dose which produced a decrease in total fingertip blood flow was used. Blood pressures were measured by the sphygmomanometric method and showed no significant changes during the norepinephrine infusions.

Statistical analyses were performed as described by Snedecor (1956) using the Student's t test method with each individual serving as his own control. A probability level of less than 0.05 was considered significant.

RESULTS

The rates of disappearance of Na$^{131}$I from the fingertips were usually biphasic with an early fast component ($t_1$) followed by a slower rate ($t_2$). Sometimes only one disappearance rate was apparent especially when the rate was slow (Table 1); in these instances, the same value was assigned to $t_1$ and $t_2$ for purposes of analysis. The fast component of the disappearance rate was distinguished from the slow component by the change in slope of the curve as determined by the intersection of visually fitted regression lines. The two components may represent flow through different tissues. Sejrsen (1969) has presented evidence that the slow component represents blood flow in subcutaneous tissue. Neither component was subtracted from the other since both may be contaminated by each other; instead both the fast ($t_1$) and slow ($t_2$) components of the disappearance rates were analysed although $t_1$ probably represents skin flow and is emphasized.

In ten subjects fingertip total blood flow after 1 h of body warming averaged 59.7 ml and after 1 h of body cooling, 32.7 ml min$^{-1}$ 100 g$^{-1}$ (Table 1), a highly significant decrease ($t = 4.81, P<0.001$). The disappearance rates of Na$^{131}$I from the fingertip ($t_1$) averaged 3.7 min in the warm room and 5.6 min in the cool room, a non-significant change ($t = 2.20, 0.05 < P < 0.1$) although seven of ten subjects showed a slower disappearance rate in the cool environment. Comparable values for $t_2$ were 6.6 min in the warm room and 12.1 min in the cool room ($t = 1.47, 0.1 < P < 0.2$).

If the fast components of the disappearance rates (nutritional flow) are converted into an estimated blood flow, flow is 10 ml in the warm room and 7.3 ml min$^{-1}$ 100 g$^{-1}$ in the cool room. By using these calculations of flow, total flow decreased by about 45.2% and nutritional flow only 27%.

In eight experiments during intra-arterial infusion of norepinephrine (Table 2) total fingertip flow averaged 34.8 ml compared with a control flow of 72.8 ml ($t = 3.44, 0.01 < P < 0.02$).
### TABLE 1. Total and nutritional fingertip blood flow during body warming and cooling

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>28.3° room</th>
<th></th>
<th></th>
<th>20° room</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total flow (ml min⁻¹ 100 ml of tissue⁻¹)</td>
<td>$t_1$</td>
<td>$t_2$</td>
<td>Total flow (ml min⁻¹ 100 ml of tissue⁻¹)</td>
<td>$t_1$</td>
<td>$t_2$</td>
</tr>
<tr>
<td>1</td>
<td>52.5</td>
<td>4.0</td>
<td>5.3</td>
<td>18.5</td>
<td>2.7</td>
<td>7.0</td>
</tr>
<tr>
<td>2</td>
<td>121.9</td>
<td>4.1</td>
<td>11.2</td>
<td>102.0</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>3</td>
<td>42.2</td>
<td>3.1</td>
<td>5.1</td>
<td>21.7</td>
<td>4.9</td>
<td>9.6</td>
</tr>
<tr>
<td>4</td>
<td>31.4</td>
<td>4.3</td>
<td>7.2</td>
<td>26.3</td>
<td>4.4</td>
<td>7.9</td>
</tr>
<tr>
<td>5</td>
<td>124.8</td>
<td>4.2</td>
<td>5.0</td>
<td>63.9</td>
<td>2.7</td>
<td>4.2</td>
</tr>
<tr>
<td>6</td>
<td>15.3</td>
<td>3.4</td>
<td>7.0</td>
<td>3.3</td>
<td>10.7</td>
<td>44.3</td>
</tr>
<tr>
<td>7</td>
<td>68.1</td>
<td>4.4</td>
<td>7.5</td>
<td>18.1</td>
<td>5.5</td>
<td>9.8</td>
</tr>
<tr>
<td>8</td>
<td>51.7</td>
<td>2.4</td>
<td>5.6</td>
<td>39.6</td>
<td>4.5</td>
<td>8.0</td>
</tr>
<tr>
<td>9</td>
<td>39.3</td>
<td>2.4</td>
<td>5.8</td>
<td>4.3</td>
<td>7.9</td>
<td>15.5</td>
</tr>
<tr>
<td>10</td>
<td>50.0</td>
<td>4.4</td>
<td>6.2</td>
<td>29.0</td>
<td>6.9</td>
<td>8.8</td>
</tr>
<tr>
<td>Mean</td>
<td>59.7</td>
<td>±3.6</td>
<td>±3.1</td>
<td>32.7</td>
<td>±3.0</td>
<td>±4.1</td>
</tr>
<tr>
<td>SD</td>
<td>±36.3</td>
<td>±0.8</td>
<td>±1.8</td>
<td>±30.0</td>
<td>±2.4</td>
<td>±11.7</td>
</tr>
</tbody>
</table>

* $t_1 =$ half times (min) of fast component of disappearance rates; † $t_2 =$ half times (min) of slow component of disappearance rates; if only one component of the disappearance rate was apparent, the same value was assigned to $t_1$ and $t_2$.

### TABLE 2. Total and nutritional fingertip blood flow before and during norepinephrine infusion

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Before norepinephrine</th>
<th></th>
<th></th>
<th>During norepinephrine</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total flow (ml min⁻¹ 100 ml of tissue⁻¹)</td>
<td>$t_1$</td>
<td>$t_2$</td>
<td>Total flow (ml min⁻¹ 100 ml of tissue⁻¹)</td>
<td>$t_1$</td>
<td>$t_2$</td>
</tr>
<tr>
<td>1</td>
<td>46.8</td>
<td>4.3</td>
<td>7.0</td>
<td>41.3</td>
<td>7.0</td>
<td>11.3</td>
</tr>
<tr>
<td>2</td>
<td>150.4</td>
<td>3.2</td>
<td>5.4</td>
<td>66.2</td>
<td>3.9</td>
<td>10.3</td>
</tr>
<tr>
<td>3</td>
<td>100.9</td>
<td>3.0</td>
<td>6.5</td>
<td>33.8</td>
<td>6.3</td>
<td>3.1</td>
</tr>
<tr>
<td>4</td>
<td>90.3</td>
<td>6.1</td>
<td>8.0</td>
<td>36.6</td>
<td>9.8</td>
<td>9.8</td>
</tr>
<tr>
<td>5</td>
<td>41.0</td>
<td>6.8</td>
<td>6.8</td>
<td>21.0</td>
<td>5.8</td>
<td>9.4</td>
</tr>
<tr>
<td>6</td>
<td>20.1</td>
<td>6.8</td>
<td>13.8</td>
<td>5.5</td>
<td>13.3</td>
<td>43.0</td>
</tr>
<tr>
<td>7</td>
<td>80.5</td>
<td>7.2</td>
<td>16.1</td>
<td>23.5</td>
<td>7.4</td>
<td>17.3</td>
</tr>
<tr>
<td>8</td>
<td>52.3</td>
<td>4.1</td>
<td>5.9</td>
<td>50.5</td>
<td>10.8</td>
<td>10.8</td>
</tr>
<tr>
<td>Mean</td>
<td>72.8</td>
<td>5.2</td>
<td>8.7</td>
<td>34.8</td>
<td>8.0</td>
<td>14.4</td>
</tr>
<tr>
<td>SD</td>
<td>±41.5</td>
<td>±1.7</td>
<td>±4.0</td>
<td>±18.7</td>
<td>±3.0</td>
<td>±12.2</td>
</tr>
</tbody>
</table>

* $t_1 =$ half times (min) of fast component of disappearance rates; † $t_2 =$ half times (min) of slow component of disappearance rates; if only one component of the disappearance rate was apparent, the same value was assigned to $t_1$ and $t_2$. 
Disappearance rates of Na$^{131}$I from the fingertip ($t_1$) averaged 8.0 min during norepinephrine infusion compared with 5.2 min in the control period ($t = 2.86$, $0.02 < P < 0.05$). Comparable values for $t_2$ were 14.4 and 8.7 min ($t = 1.63$, $0.05 < P < 0.1$). Six of the eight subjects had a slower disappearance rate during the norepinephrine infusion. After the end of the infusion, total flow increased to 69.4 ml and disappearance rates ($t_2$) increased from 1.4 to 9.8 min.

If the fast components of the disappearance rates are converted into an estimated blood flow, the control nutritional flow is 7.5 ml compared with a flow during norepinephrine infusion of 4.9 ml. Therefore during norepinephrine infusion total finger flow decreased by 48.6% and capillary flow by 34.7%. Fig. 1 demonstrates the total finger flow and disappearance rates before and during norepinephrine infusion for one experiment.
Grant (1930) found that a-v anastomoses in rabbit ears opened when the body was warm and closed when it was cold and that these reactions were effected through the sympathetic nerves. In the rabbit ear a-v anastomoses have been shown to react at a greater speed than arteries or arterioles and tend to act independently of neighbouring vessels (Clark & Clark, 1934). They reacted in the same manner as arterioles to the administration of epinephrine, norepinephrine, histamine or acetylcholine (Sherman, 1963). Grant & Bland (1931) suggested from their studies that early and rapid warming of the tip as compared with the base of the finger in man may be due to opening of a-v anastomoses in the fingertip. From studies with the rheoplethysmograph, Hale & Burch (1960) have gauged that the a-v shunts constrict during cold, psychogenic or neurogenic stimuli and dilate in a hot environment; however, a-v shunt flow could not be separated from nutritional flow in their studies.

In the present study the reflex sympathetic stimulus of body cooling did not significantly decrease fingertip nutritional blood flow as measured by the radioactive isotope disappearance rate although most subjects showed a decrease. However, total finger flow showed a definitely significant decrease. Therefore flow in a-v anastomoses must also have significantly decreased. These results would be expected if the sympathetic nerves controlled the flow through a-v anastomoses to regulate the temperature of the digits or body temperature without interfering with nutritional blood flow of the fingers. When the sympathetic neurotransmitter, norepinephrine, was given in physiological doses and produced a decrease in total finger flow comparable to body cooling, nutritional blood flow was decreased to a level of probable significance but not to the same extent as total or a-v shunt flow.

Folkow & Silvertsson (1964) found that cutaneous a-v shunts and nutritional resistance vessels in the cat paw were not different in their smooth-muscle sensitivity to norepinephrine or vasoconstrictor fibre stimulation. However, the greater wall/lumen ratio in a-v shunts exhibited an increased reactivity because the decreases of lumina were greater than those of nutritional vessels. This could explain the greater decrease in a-v shunt flow compared with nutritional flow during sympathetic stimulation.

The large and rapid fluctuations in total fingertip blood flow as illustrated in Fig. 1 are of note since the radioactive isotope disappearance rates (nutritional flow) were quite stable. Previous studies with epinephrine (Coffman, 1963; Alpert & Coffman, 1969), bradykinin (Coffman & Javett, 1963) and reactive hyperaemia (Hyman, Paladino & Zimmermann, 1963) have shown that Na\(^{131}\)I disappearance rates from both skin and muscle follow rapid fluctuations in blood flow quite closely when compared with simultaneous plethysmography studies. Burton (1939) using plethysmography first demonstrated the spontaneous fluctuation which occurs within a few seconds in finger flow. By using another method, Price (1966) found that variations in fingertip flow ranged between 50% and 87% of the peak flow rates in normal subjects. This large fluctuation in total fingertip flow in the face of a stable nutritional flow would indicate that the a-v shunts are actively opening and closing in the resting comfortable normal subject.

Studies with microspheres suggest that a-v shunts account for about 36% of the total blood flow in rabbit ears, but range from 5% to 70% (Rondell, Keitzer & Bohr, 1955). Quantification of a-v shunt and nutritional flow in the human fingertip has not been possible and the methods used in this study yield only an approximation. Total finger blood flow measured by venous
occlusion air plethysmography is sometimes inaccurate at high flow rates since the fingertip may fill quickly with blood, making flow curves difficult to analyse. The radioactive isotope method is also not exact. The fast component of the disappearance rate has been used to quantify flow, for it has been shown that this part of the curve agrees with simultaneous plethysmographic determinations in studies of skeletal muscle (Walder, 1955) and corresponds best to other methods of measuring flow in the forehead skin (Coffman, 1969). Tissue/blood partition coefficients for Na\textsuperscript{131}I or \textsuperscript{133}Xe have been measured only for muscle tissue and even these are undergoing constant revision (Gosselin & Audino, 1971). The partition coefficient for Na\textsuperscript{131}I would probably lie between 0.3 (Gosselin & Audino, 1971) and 0.7 because of the blood/tissue sodium concentration ratio and the similarity in disappearance rates from skin to \textsuperscript{133}Xe. If the partition coefficient for skin were 0.3 or 0.7 instead of 0.5 as used in this report, the nutritional blood flow would be about 4 ml smaller or larger and the percentage of total flow 6% or 7% different. It can therefore be estimated that nutritional blood flow in the fingertip is 10–20% of total blood flow, depending on the partition coefficient. With body cooling, nutritional blood flow constitutes a larger percentage of the total flow because of the more marked decrease in total and therefore a–v shunt flow. Arteriovenous anastomoses deserve further study since their large capacity for blood flow is capable of significantly affecting general circulatory dynamics.

ACKNOWLEDGMENT

This study was performed with the valuable technical assistance of Mrs Beverly Hull, R.N. This investigation was supported, in part, by a grant-in-aid from the American Heart Association and by grant HE07299 from the National Institutes of Health, Public Health Service.

REFERENCES


