Measurement of Blood Flow in the Femoral Artery in Man at Rest and during Exercise by Local Thermodilution

By V. GANZ, M.D., A. Hлавá, M.D., A. Froněk, M.D., J. Linhart, M.D., and I. Přerovský, M.D.

In 1960 we reported a method of measuring blood flow in individual vessels based on the principle of local thermodilution. The present communication presents application of the same principle to measurement of blood flow in the femoral artery in man at rest and during exercise.

Methods

An upstream catheter was used, modified to allow for percutaneous insertion by the Seldinger technic (fig. 1). The catheter had an asymmetrical lumen, the narrower lumen being occupied by the leads from the thermistor to an external resistance bridge, the large lumen (1.2 mm.) being used to introduce the catheter over a spiral guide and for injection of indicator. The external diameter was 2.5 mm. The tip of the catheter was slightly conically narrowed and slightly curved. The thermistor was located on the concave surface of the curve (to prevent contact with the vessel wall) about 5 to 10 mm. from the tip. The thermistor was slightly raised from the surface of the catheter, resting on its own lead wires, in order to limit a thermal influence on it by the intraluminal contents of the catheter. The insulation layer on the thermistor was as thin as possible in order to have a small time constant, 0.3 second or less, measured in cool water.

The indicator was 5 ml. of physiologic saline kept at room temperature. The duration of the injection varied from 0.3 to 0.5 second. Just before each injection we fill the catheter with blood by opening the stopcock slightly. This allows us to subtract a precise dead space of the catheter from the known total injectate.

Flow is calculated by the arterial formula:

\[ F = \frac{m \times 60 \times r / t_B - t_I / 1.08}{A \times f} \]

where \( F \) = flow in ml./min., \( m \) = amount of injectate, corrected for dead space, \( r \) = registra-

tion paper speed in mm./sec., \( t_B \) = blood temperature in degrees C., and \( t_I \) = indicator temperature in degrees C., \( A \) = area under the thermodilution curve in \( \text{mm}^2 \), and \( f \) = degree of temperature change corresponding to 1 mm. of deflection on the registration paper. Other details have already been described.

The terminal part of the dilution curve may be distorted by cooling of the thermistor from the intraluminal contents, and this is manifest as a delayed return to baseline (fig. 2). This source of error can be removed by extrapolating the exponential decay of the curve from two points (O and P) previous to the distortion, and the integral area (\( A \)) integrated from 0 to infinity:

\[ A_2 = \frac{y_1 \cdot t_2 - t_1 \cdot 0.4343}{\log y_1 - \log y_2} \]

where \( A_2 \) = area under extrapolated curve from 0 to infinity in \( \text{mm}^2 \), \( y_1 \) = distance in mm. of 0 to baseline, \( y_2 \) = distance in mm. of P to the baseline, \( t_2-t_1 \) time difference between O and P in mm., and 0.4343 = \( \log e \). Area \( A_1 \), cross-hatched, is determined planimetrically.

The accuracy of the results was tested by model experiments where total flow was known from a rotameter, with use of 8-mm. tubing, which approximates the lumen of the femoral artery in the inguinal region. Figure 3 shows the degree of agreement between the two methods over the range 240 to 3,820 ml.

Femoral Artery Blood Flow at Rest

The catheter was introduced about 3 to 4

![Diagram of local thermodilution catheter for femoral blood flow measurements. T, thermistor.](image)

Figure 1
cm. into the femoral artery by the Seldinger technic with local anesthesia. The only complication in the entire group of healthy controls and patients with obliterative arterial disease was an occasional hematoma at the insertion site. Measurements were carried out in a reclining position 30 or more minutes after introduction of the catheter. Eight healthy volunteers were tested. Table 1 shows values of femoral artery flow per 100 ml. of limb volume, the latter figure being obtained by water displacement in special containers. Average values were taken from 4 to 8 measurements. The variability seen in 48 measurements was ±13.7 per cent, probably mainly due to phasic alterations in flow during the cardiac cycle.

Femoral artery flow in seven of eight subjects varied from 383.7 to 766.0 ml./min., average 567.5 ± 130.7. In patient E. M. we measured 1,114.4 ml./min., probably due to a high room temperature of 26 to 27 C. during the investigation. The average from all eight subjects was 635.9 ± 223.1 ml./min.

Flow calculated per 100 ml. of limb volume in the first seven subjects varied from 3.8 to 6.5 ml./100 ml./min., average 5.2 ± 1.1. In patient E. M. the value was 11.0 ml./100 ml./min. The average from all eight was 6.0 ± 2.3 ml./100 ml./min.

**Figure 2**

Record of thermodilution curve from femoral artery (bottom). The upper record, electrocardiogram; middle, time in seconds.

**Figure 3**

Comparison of flow values obtained by local thermodilution with values recorded by rotameter in model experiment.

**Femoral Artery Flow during and after Exercise**

After the measurement of values at rest, the subjects carried out work on a bicycle ergometer for 15 minutes, only with that extremity measured. The work rate was 150 Kg./min. for the first 5 minutes, 200 for the next 5 minutes, and 250 for the last 5 minutes. During exercise and for 10 minutes after exercise, values were taken 3 to 4 times per minute. Further values were read off at 15, 20, and 30 minutes after exercise.

Figure 4 shows changes in femoral artery flow during and after exercise, calculated per 100 ml. of limb volume, with individual and average (thick line) values given. During and 10 minutes after exercise the values given rep-
Figure 4
Flow changes in the femoral artery calculated for 100 ml. of leg volume per minute during and after exercise.

Figure 5
Flow changes in the femoral artery during and after exercise, expressed as percentage of control values.
resent 2.5-minute periods. Later values are single measurements at 15, 20, and 30 minutes.

During the first half of the exercise period there was a sharper rise in flow than during the second half.

Average flows per 100 ml. increased from 6.0 to 31.9 ml./100 ml./min. at the height of the exercise response. The return of these values following exercise was rapid with a decreasing rate of change. Thirty minutes after exercise baseline had not yet been achieved.

Figure 5 shows the same data expressed as per cent change from resting values.

Discussion

The average values for resting femoral artery blood flow per 100 ml. limb volume are higher when measured by local thermodilution than reported in the literature from occlusion plethysmographic studies. The latter data present values from the upper or lower leg from 1.1 to 4.8 ml./100 ml./min.²-⁶ Only Snell et al.⁷ have reported resting values in the calf of 5.5 to 6.6 ml./100 ml./min. The higher values in the present data may be related to the fact that our flows include the thigh where the ratio of highly perfused muscle to poorly perfused nonmuscular tissue is higher than in the lower leg. Our results are in agreement with those of Agrifoglia et al.,⁸ who used a dilution method with labeled albumin as the indicator to achieve values of 6.3 to 7.78 ml./100 ml./min. for the entire lower extremity.

On the basis of these results it is suggested that local thermodilution is suitable for measurement of femoral artery flow in man. The advantage is that flow can be measured with the same technic both at rest and during muscular work. The measurements can be repeated three to four times per minute without limitation, since the indicator leaves the vascular compartment. The procedure is simple, and does not even require blood sampling.

Summary

A new method is described for measuring blood flow in the femoral artery in man, based on local thermodilution. The method makes it possible to take 3 or 4 measurements per minute at rest and during muscular exercise of the investigated limb. The average blood flow in eight subjects at rest was 635.9 ± 223.1 ml./min., or 6.0 ± 2.3 ml./100 ml. limb volume/min.

Changes during graded and increased work loads were also measured in 5-minute periods (150, 200, and 250 Kg./min.). The rate of flow rise was faster at the start of a given period than in the latter half of the same period. After the end of the work load, the rate of return of blood flow to the baseline fell off rapidly with time, but by 30 minutes later baseline values had still not been attained.

References

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