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Ultrasonographically Monitored Postocclusive Reactive Hyperemia in the Diagnosis of Peripheral Arterial Occlusive Disease

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SUMMARY

The femoral artery postocclusive reactive hyperemia response was monitored by transcutaneous Doppler ultrasonography. Normal values which were established from a group of 25 volunteers included a mean percentage increase

$$\left(\frac{\text{peak velocity} - \text{initial velocity}}{\text{initial velocity}} \times 100 \right)$$

of 225.8% and a mean recovery half time of 25.2 secs. In a group of 22 patients with angiographically documented arterial occlusive disease, the respective mean values were 55.9% and 47.1 secs ($P < .001$). There was no statistically significant difference in the percentage velocity increases in repeat examinations. On the other hand, the recovery half time of the second postocclusive reactive hyperemia response was significantly shorter than the preceding one. The described technique proved to be very useful as a simple and objective procedure to screen and follow-up the development of arterial occlusive disease before and after reconstructive vascular surgery.

Additional Indexing Words:

Transcutaneous Doppler ultrasonography
Arterial occlusive disease

Postocclusive reactive hyperemia

OBJECTIVE and quantitative assessment of peripheral arterial occlusive disease has become a desirable goal in recent years with the increasing capability of reconstructive vascular surgery. Although angiography still remains the major preoperative diagnostic procedure, it is primarily an anatomic, rather than a functional, assessment of disease, difficult to quantitate, and associated with a small but real risk and discomfort, which prohibit its routine use as a screening test or serial follow-up check.

On the other hand, determination of the resting flow rate of a compromised vascular bed has limited diagnostic value, because a significantly stenotic inflow system may still permit normal resting

flow.¹⁻⁸ This circumstance has been recognized by a number of authors who have concluded that the postocclusive reactive hyperemia (PORH) response is a more useful criterion than a determination of the resting flow rate.^{5, 6, 8, 9-15} The usual technique employed for such studies has been venous occlusion plethysmography, with water or air as the communicating medium,¹⁶ or the mercury-in-rubber gauge as the sensing device.¹⁷ However, these measurements have two drawbacks in common: (1) since venous occlusion must be performed intermittently, no continuous readout is available, and therefore the peak flow-rate may escape detection; and (2) the slopes of the volume increase have to be calculated separately and then plotted. These considerations led us to study the feasibility of applying the ultrasonic Doppler velocity metering system to transcutaneously monitor the PORH response.

Method

The Parks Model 805—Directional Ultrasonic Velocity Meter*—was used to study two groups of subjects. Group I: 25 normal volunteers (age 21-63 years), and Group II: 22 patients (age from 25-73 years) with

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Table 1

Postocclusive Reactive Hyperemia Response

Status	No. pts.	Max. increase in femoral arterial velocity (%; Mean ± SEM)	Recovery time (T½ ± SEM sec)
Normal controls	25	225.8 ± 16.2	25.2 ± 1.2
Angiographically documented arterial occlusive disease	22	55.0 ± 6.2	47.1 ± 1.5
Significance <i>t</i>		9.847; <i>P</i> < 0.001	11.40; <i>P</i> < 0.001

unilateral or bilateral arterial occlusive disease documented angiographically. An R-C passive filter with a time constant of 1 sec was added to the output stage of the original instrument in order to obtain the mean velocity value electrically. With the subjects in the supine position, a standard pressure cuff was placed below the knee. The ultrasonic probe was then placed at the level of the femoral artery with the tip aimed cephalad at an angle of approximately 45°, and held in position by a self-locking mechanical clamp. After obtaining the steady-state recording, the cuff was inflated to a suprasystolic pressure for 4 min. The cuff was then suddenly deflated and the PORH velocity response was continuously recorded until the velocity value returned to preocclusion levels. The response was evaluated in two ways (fig. 1): (a) the percentage increase: $(\frac{\text{peak velocity} - \text{initial velocity}}{\text{initial velocity}} \times 100)$, and (b) the recovery half time (T½), the time for the mean velocity to return to 50% of its peak response. In an additional series of observations on 10 control subjects, the reproducibility of the PORH response was studied by repeating the occlusion and measurements 20 min after the first determination.

Results

Control Subjects

The data is tabulated in tables 1-3. In 25 healthy control subjects, the mean percentage increase in 50 measurements was 225.8% with a standard error of the mean (SEM) ± 16.2%. The mean recovery half time was 5.2 secs (SEM ± 1.2). Figure 1 illustrates a

typical normal tracing with the respective indices. Comparing the PORH response in the right and left lower extremities, no statistical difference was observed (table 2).

Reproducibility

Table 3 summarizes the results of two consecutive measurements, 20 min apart, in ten control subjects. There was no statistically significant difference between the percentage velocity increases of the repeated measurements. On the other hand, the recovery half time was significantly shorter (Δ6.3 sec) in the second test.

Patients with Arterial Occlusive Disease

Table 1 also summarizes the results from 22 patients with angiographically documented arterial occlusive disease. The mean percentage increase was 55.0 (SEM ± 6.2), while the recovery half time was significantly prolonged (mean 47.1 sec, SEM ± 1.5). Figure 2 illustrates a pathological PORH response (bilateral iliac artery occlusion), (a) before operation, and (b) after reconstructive vascular surgery. Before the operation there is a smaller percentage increase in the left femoral artery flow velocity with a delayed recovery half time. After the operation a pronounced increase in the postocclusive reactive hyperemia response can be observed in both femoral arteries with a return of the recovery half time to the normal range.

*Parks Electronics, Beaverton, Oregon.

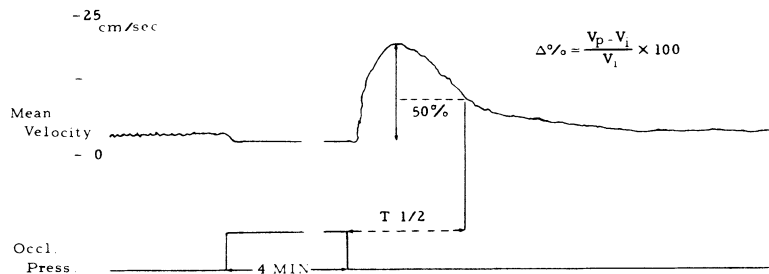


Figure 1

Typical normal femoral artery velocity response following four minutes of arterial occlusion, indicating the two indices calculated: peak velocity increase and recovery half time. Top curve: Mean blood flow velocity. Bottom curve: Occlusive cuff pressure.

Table 2

Comparison of Postocclusive Reactive Hyperemia Responses in the Left and Right Lower Extremities of Control Subjects

	Max. increase in velocity (%, Mean \pm SEM)	Recovery time (T $\frac{1}{2}$ \pm SEM, sec)
Right	219.1 \pm 22.2	25.6 \pm 1.6
Left	233.1 \pm 24.2	24.9 \pm 1.7
Significance	Not significant	Not significant

Discussion

Noninvasive physiologic tests for peripheral arterial occlusive disease would provide a means of screening, quantitating and sequentially following the progression or results of treatment of such processes. A variety of approaches to this problem have been advocated, including measurements of segmental blood pressure, limb volume, and arterial velocity, under circumstances of rest and activity. However, because of their inability to yield reproducible, quantitative data with simple, inexpensive equipment, none of these approaches has yet reached a stage of widespread clinical usefulness.

Perhaps the most generally useful physiologic approach to noninvasive peripheral vascular physiology is based on the development of transcutaneous Doppler ultrasonic velocity detecting systems. The Doppler effect, which refers to the alteration of frequency of backscattered ultrasound waves in proportion to the velocity of the moving objects they strike, was first utilized for this purpose by Franklin, Schlegel and Rushmer in 1961.¹⁸ This technique, which did not distinguish between forward and reverse velocity signals, was further developed by Rushmer, Baker and Stegal¹⁹ and by Strandness et al.,^{20, 21} and qualitatively applied to evaluate patients with both arterial and venous disease.²² The important contribution of McLeod²³ in developing circuitry to detect the direction of velocity changes permitted the subsequent usefulness of the directional Doppler as a quantitative

Table 3

Reproducibility of Two Consecutive Measurements of Postocclusive Reactive Hyperemia in 10 Control Subjects

	Max. increase in velocity (%, Mean \pm SEM)	Recovery time (T $\frac{1}{2}$ \pm SEM, sec)
Mean difference between studies	13.2 \pm 11.9	6.3 \pm 1.7
Significance <i>t</i>	Not significant	3.757; <i>P</i> < 0.05

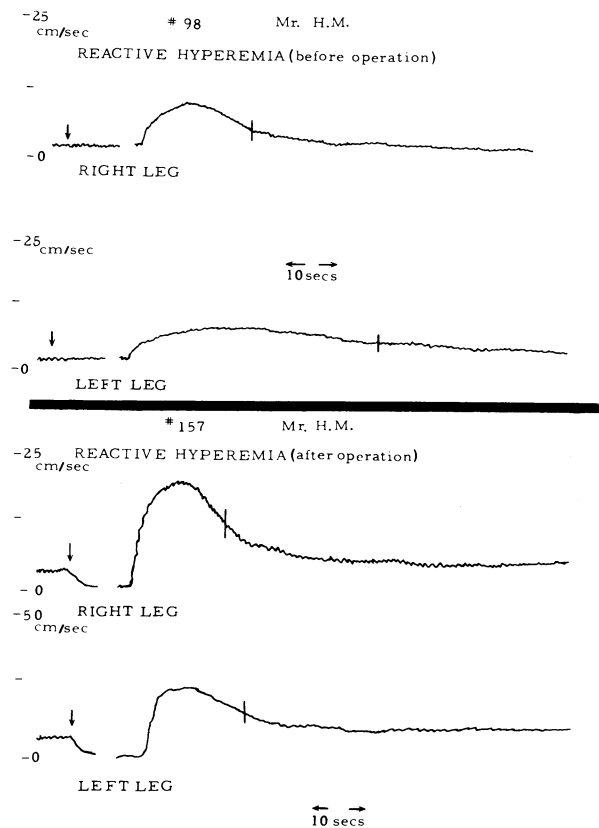


Figure 2

Femoral artery velocity response to occlusion in a patient with aorto-iliac occlusive disease. Upper panel: Patient H.M. before operation. Top curve: Mean blood flow velocity recorded from the right femoral artery. Bottom curve: Same from the left femoral artery. Arrow indicates occlusion below the knee, release of occlusion after 4 min. The short perpendicular line indicates the half time. Lower panel: Patient H.M. after aortofemoral bypass.

index. While the technique described in this report is based on relative changes in velocity, and does not require quantitative calibration, it does require a device which is directionally sensitive, since backflow of a significant degree is well documented in the normal human femoral artery during diastole, and must be accurately detected and subtracted from the forward flow signal. Since velocity is proportional to flow (when cross-sectional area is constant at the point of measurement), the data obtained are quite analogous to flow estimates obtained by more cumbersome techniques.

The use of the two parameters of postocclusive reactive hyperemia (% increase and recovery half-time) described in this report has permitted a clear separation of patients with symptomatic arterial occlusive disease from the normal controls. Both parameters do not always deviate in proportion,

however, and each would seem to be dependent upon different underlying physiologic mechanisms. The percent increase in flow appears to represent the available increase in functional cross-sectional area, or decrease in resistance, of collateral vessels in the ischemic portion of the limb. The recovery half-time, on the other hand, appears to relate to the development and subsequent relenting of some indicator of cellular ischemia, such as oxygen debt, the release of acid metabolites, or other autonomic control mechanisms. The former may, therefore, represent more of a capacity function, providing inflow is adequate, and the latter a tissue perfusion function. The relative diagnostic importance of each parameter remains to be explored, both in the laboratory and the clinic, and is of particular significance when only one of the parameters is abnormal.

In spite of these limitations, the described technique has proved to be very useful in the objective assessment of arterial occlusive disease, since it is simple and reproducible, and offers a continuous readout of the reactive hyperemia response.

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References

- EDHOLM OG, HOWARTH S, SHARPEY-SHAFER EP: Resting blood flow and blood pressure in limbs with arterial obstruction. *Clin Sci* 10: 361, 1951
- GASKELL P: The rate of blood flow in the foot and calf before and after reconstruction by arterial grafting of an occluded main artery to the lower limb. *Clin Sci* 15: 259, 1959
- SNELL ES, EASTCOTT HHG, HAMILTON M: Circulation in lower limb before and after reconstruction of obstructed main artery. *Lancet* 278: 242, 1960
- HILLESTAD LK: The peripheral blood flow in intermittent claudication. *Acta Med Scand* 174: 23, 1963
- STRANDELL T, WAHREN J: Circulation in the calf at rest, after arterial occlusion and after exercise in normal subjects and in patients with intermittent claudication. *Acta Med Scand* 173: 99, 1963
- DOHN K: On clinical use of venous occlusion plethysmography of calf. II. Results in patients with arterial disease. *Acta Med Scand* 130: 61, 1965
- TONNESEN KH: The blood flow through the calf muscle during rhythmic contraction and in rest in patients with occlusive vascular disease measured by ¹³³Xenon. *Scand J Clin Lab Invest* 17: 433, 1965
- BOLLINGER A: Durchblutungsmessungen in der klinischen Angiologie. Bern and Stuttgart, Hans Huber, 1969, p 63
- LEWIS T, GRANT R: Observations upon reactive hyperemia in man. *Heart* 12: 73, 1925
- ABRAMSON DJ, KATZENSTEIN KH, FERRIS EB JR: Observations on reactive hyperaemia in various portions of the extremities. *Am Heart J* 22: 329, 1941
- BENTLEY TH: Muscle blood flow in patients with arteriosclerosis obliterans. *Am J Surg* 96: 193, 1958
- HYMAN C, WINSOR T: Blood flow redistribution in the human extremity. *Am J Cardiol* 4: 566, 1959
- BOLLINGER A: Bedeutung der Venerverschlussplethysmographie in der angiologischen Diagnostik. *Schweiz Med Wschr* 95: 1357, 1965
- SIGGAARD-Andersen J: Obliterative vascular disease, classification by means of the Dohn plethysmograph. *Acta Chir Scand* 130: 190, 1965
- EHRINGER H: Die reaktive Hyperamie nach arterieller Sperre. In *Messmethoden bei arteriellen Durchblutungsstörungen*, ed by BOLLINGER A, BRUNNER U. Bern and Stuttgart, Hans Huber, 1971, p 20
- ABRAMSON DJ: *Circulation in the Extremities*. New York, Academic Press, 1967, p 78
- WHITNEY RJ: The measurement of volume changes in human limbs. *J Physiol (London)* 121: 1, 1953
- FRANKLIN DL, SCHLEGEL W, RUSHMER RF: Blood flow measured by Doppler frequency shift of back scattered ultrasound. *Science* 134: 564, 1961
- RUSHMER RF, BAKER DW, STEGAL HW: Transcutaneous Doppler flow detection as a nondestructive technique. *J Appl Physiol* 21: 554, 1966
- STRANDNESS DE JR, McCUTCHEON EP, RUSHMER RF: Application of a transcutaneous Doppler flowmeter in evaluation of occlusive arterial disease. *Surg Gynecol Obstet* 122: 1039, 1966
- STRANDNESS DE JR, SCHULTZ RD, SUMNER DS, RUSHMER RF: Ultrasonic flow detection, a useful technique in the evaluation of peripheral vascular disease. *Amer J Surg* 113: 311, 1967
- SIGEL B, POPKY GL, WAGNER DK, BOLAND JP, MAPP E MCD, FEIGL P: A Doppler ultrasound method for diagnosing lower extremity venous disease. *Surg Gynecol Obstet* 126: 339, 1968
- MCLEOD FD: Directional Doppler Demodulation. *Proc 20th Ann Conf on Eng Med Biol* 27: 1, 1967