Valvular function of peripheral veins after hyperemic dilation

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Purpose: **We wanted to answer the question of whether physiological dilation of normal extremity veins can induce temporary valvular leakage and reflux.**
Methods: **Directional flow was recorded in 22 forearm and popliteal veins by Doppler duplex scanning after distal compression. Reflux was assessed by valve closure time and calculation of a "reflux index," the ratio of backward to forward flow areas.**
Results: **Hyperemia and enhanced flow did not increase but lowered reflux. During control conditions the mean reflux ratio (backward/forward flow area) of 21 veins was 0.058 and decreased to 0.028 ($p < 0.05$). Reflux was slightly longer in patients in the erect position in the popliteal vein, compared to forearm veins (with the patients in the sitting position). Significantly increased reflux occurred during hyperemia in only one deep forearm vein (valve closure time 0.92 seconds).**
Conclusions: **Most veins of the upper (forearm) and lower extremity (popliteal vein) were competent even after a maneuver that induced venodilation and an increase in blood flow (exercise hyperemia or postocclusion reactive hyperemia). Veins with an inherent valvular weakness can be identified by a hyperemia test with duplex flow analysis. (J VASC SURG 1996;23:611-5.)**

Because of the presence of valves, blood flow in veins normally is unidirectional from the periphery toward the heart. Competence of a venous valve mainly depends on the integrity of the valve leaflets and the appropriate supporting wall structures and diameter of the vein supporting it. Our previous in vitro studies performed on isolated normal human saphenous veins have shown their remarkable resistance to distension by introducing a retrograde perfusion pressure of up to 300 mm Hg.[1]

However, one question remains to be answered: under normal conditions can valvular function of peripheral veins be affected by venous dilation as a result of changes in venomotor tone or as the result of active or reactive hyperemia and subsequent physiological distension? Such dilation should by virtue of separating the cusps lead to a degree of enhanced "physiological reflux." Some studies actually have implied that the function of venous valves is subject to variation with time of the day so that valvular competence deteriorates enough to change noninvasive test results to abnormal.[2] It has been speculated that a short refilling time as evaluated by air plethysmography and a rise in peripheral venous pressure after exercise could be related to a short reflux as the result of intense venodilation. This problem is not only of physiological significance but also has practical consequences during examination of patients with venous insufficiency because methods for evaluation of venous function largely depend on parameters such as refilling flow or refilling time after standardized exercise.[3]

The objective of this study was to determine valvular function by measurement of directional flow with the Doppler duplex technique in veins of control subjects before and during hyperemia.

MATERIAL AND METHODS

Subjects. The study was performed in six male control subjects, aged 18 to 63 years. Six popliteal, 10 superficial, and six deep proximal antecubital veins were examined. Measurements on the popliteal veins were performed with subjects standing and on forearm veins with subjects in the sitting position with the forearm slightly flexed.

Flow measurements. Directional flow and vessel

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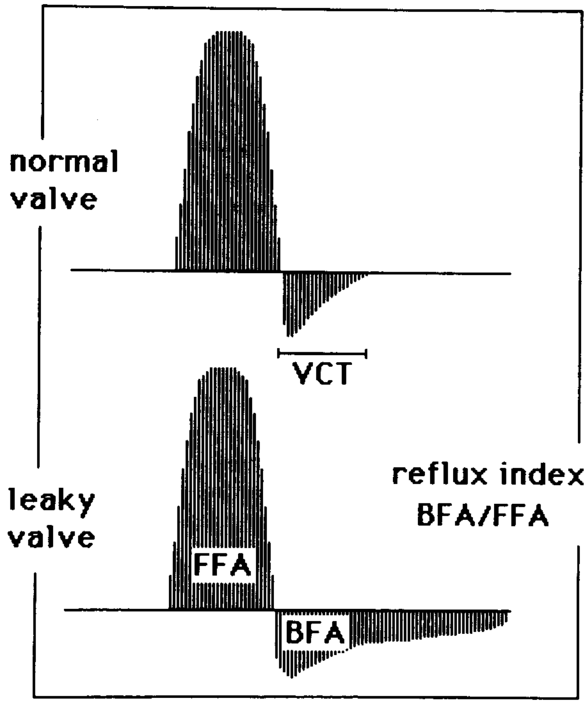

Fig. 1. Schematic illustration of forward and backward flow pattern in veins with normal and leaky valves. Principles of calculation of reflux index (BFA/FFA) and backflow time = VCT.

diameter were assessed by use of a 128 XP/ 10 Acuson color duplex unit (Acuson, Inc., Mountain View, Calif.) with a 5 MHz probe. We investigated the popliteal vein before and during active hyperemia after muscular exercise consisting of a 10-minute exercise performed on a treadmill with an elevation of 10 degrees and a speed of 10 km/hr. Superficial and deep antecubital veins were insonated before and during reactive hyperemia after a 2-minute period of arterial occlusion. To induce directional flow we used manual limb compression distal to the flow probe by applying a quick pressure on the leg or forearm, followed by fast release. The results of insonation before and during hyperemia were stored on videotape, and data for calculations were obtained from hard copies of duplex flow records. Flow measurements during hyperemia were obtained as soon as possible: within 3 to 5 seconds in arm veins and within 6 to 8 seconds in popliteal veins when subjects came off the treadmill and repositioned themselves near the duplex scanner.

Parameters. The following measurements and calculations were made: forward and backward flow velocity (in meters per second), and forward and backward flow duration = valve closure time (VCT) (in seconds). Diameter of popliteal veins was assessed with subjects at rest and during hyperemia. Furthermore, we calculated a reflux index, which is the ratio of forward and backward time integral of flow velocity (forward flow area/backward flow area [FFA/BFA]) (Fig. 1).

Statistics. Statistical analysis included data from six popliteal and 15 forearm veins, with calculation of mean values, standard deviation, and 95% confidence levels. Detection of differences between mean was performed with paired *t* testing, where $p < 0.05$ was considered significant.

RESULTS

In the resting control recordings from the popliteal and forearm veins, we noted a normal flow pattern on distal compression, that is a marked forward flow signal followed by a small retrograde flow (Fig. 2). During hyperemia forward flow increased but retrograde flow declined, except in one deep forearm vein, which exhibited a long "tail" of reflux and a VCT of 0.92 seconds (Fig. 3). Data from this vein were excluded from further analysis because the VCT was markedly different from the rest (in excess of 2 standard deviation [SD]).

The numeric data of 21 experiments are summarized in Table I. During control condition mean reflux ratio (FBA/FFA) of all veins was 0.058 and decreased to 0.028 ($p < 0.05$) during hyperemia (Fig. 4). The mean backward flow duration (VCT) in 21 veins at rest was 0.093 second, and after hyperemia it declined to 0.067 second (NS). In the 21 experiments backflow time never exceed 0.5 seconds, which would indicate venous insufficiency, according to a previous investigation.[4]

The popliteal veins, compared with arm veins, showed a tendency toward higher mean backward flow time (VCT), flow velocity, and reflux ratio both before and after dilation.

Probably because of the small sample, these differences were, however, not statistically significant. The mean inner diameter of the popliteal vein was 8.12 ± 1.36 mm at rest and 8.63 ± 1.81 mm after exercise. This means that hyperemic dilation increased the diameter by only 6%. The resting mean diameter of the forearm veins was 3.4 mm.

It can be concluded that in normal arm and leg veins, active and reactive hyperemia is not associated with an increase in physiological reflux. Therefore physiologic venous dilation caused by muscular exercise and reactive hyperemia after arterial occlusion does not induce incompetence in normal veins. Reflux ratio and backward flow time increased remark-

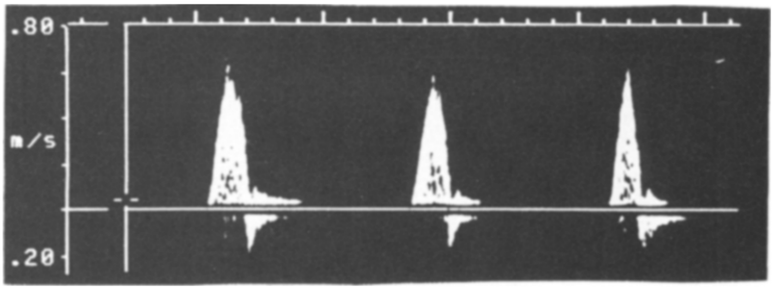

Fig. 2. Apparently normal valve function in deep forearm vein with control subject at rest.

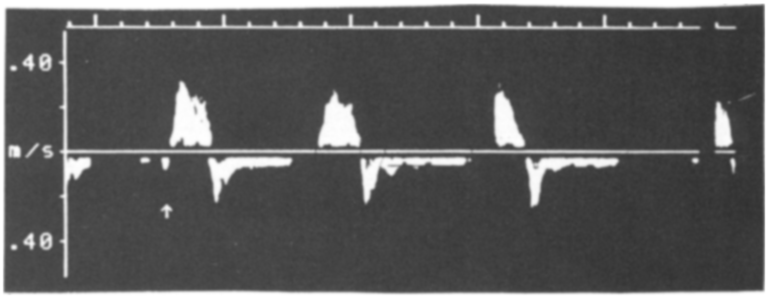

Fig. 3. Record of blood flow velocity in same deep forearm vein as in Fig. 2 after reactive hyperemia. Note marked reflux, VCT = 0.92 seconds.

Table I. Hemodynamic data from 21 veins of the lower (popliteal, n = 6) and upper extremity veins (superficial and deep forearm veins, n = 15) before and after active (popliteal vein) and reactive hyperemia (forearm)

	FFb (m/sec)	*FFa (m/sec)*	*BFb (m/sec)*	*BFa (m/sec)*	*BFA/FFAb*	*BFA/FFAa*	*VCTb (sec)*	*VCTa (sec)*
Popliteal (mean)	0.64	1.10	0.14	0.13	0.10	0.03	0.15	0.11
SD	0.18	0.30	0.06	0.04	0.06	0.02	0.06	0.03
Arm (mean)	0.89	0.94	0.10	0.08	0.04	0.02	0.07	0.05
SD	0.51	0.37	0.09	0.08	0.05	0.03	0.05	0.06
Total (mean)	0.82	0.99	0.12	0.09	0.06	0.03	0.09	0.07
SD	0.45	0.36	0.08	0.08	0.06	0.03	0.06	0.06

FF, Forward flow; *b*, before; *a*, after; *BF*, backward flow; *BFA/FFA*, backward/forward flow area; *VCT*, valve closure time; *SD*, standard deviation.

ably in only one deep antecubital vein, probably because of a local valve anomaly.

DISCUSSION

This investigation clearly shows that, on distal compression, blood flow in human peripheral veins of the upper and lower extremities shows all the characteristics of a predominant centripetal pattern both at rest and after active or reactive hyperemia. In terms of valvular function, this must mean competent closure under these conditions.

In only one vein of the upper extremity, a clearly enhanced retrograde flow appeared after release of arterial occlusion with a VCT of 0.92 second as compared to the average 0.07 second. This observation is relevant from a practical point of view, and therefore analysis of hyperemic flow could be used for functional testing of potential homograft veins, to be transferred from the upper to the lower extremity. Clinical experience has already shown that in a number of cases the valves of the upper extremity veins are potentially incompetent.[5]

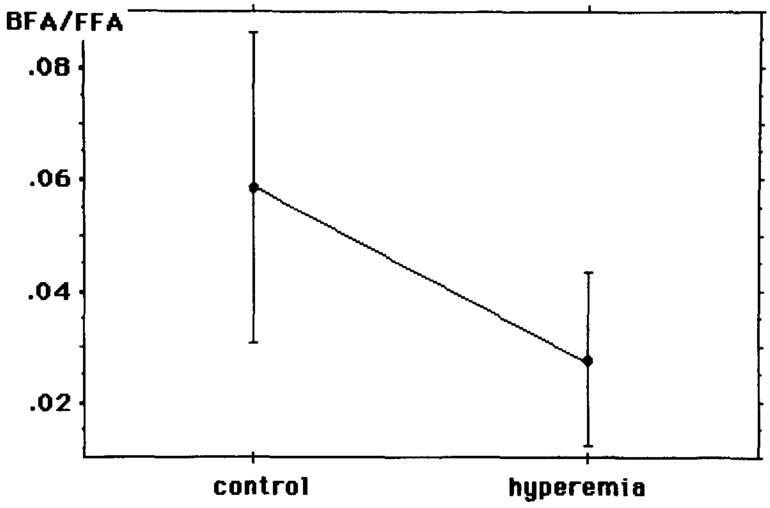

Fig. 4. BFA/FFA ratio with 95% error bars in all popliteal and forearm veins tested (n = 21) shows decline after active and reactive hyperemia ($p < 0.05$).

An important factor when testing valve competence is the frequency with which the vein is compressed to induce forward flow. Forward flow varies with compression pressure and frequency, that is, high distal pressure enhances and high frequency of compression, which empties the veins reduces forward flow. Therefore testing of valve function can vary depending on how well manual compression is performed. To standardize the procedure we also tested distal compression using a blood pressure cuff (popliteal vein), quickly filled to 100 mm Hg for 2 seconds followed by fast release. With this technique the BFA/FFA ratio was very similar to the manual compression protocol used in our experiments and conforms with a previous study by Araki et al.[6]

When evaluating valve function we chose to calculate a BFA/FFA ratio instead of backward flow velocity in comparing veins of different diameters. A method similar to the one used in this investigation has previously been validated in model experiments.[7] In that study the augmented wave area (forward flow) and reflux wave (backward flow) were calculated as a "valvular efficiency index," on the basis of area integration of antegrade and retrograde flows, and correlated with directly determined directional volume flow.

In a study like ours, when monitoring flow in a vein with Doppler ultrasonography, it will be noticed that distal limb compression gives rise to a gush of forward (centripetal) flow, which is followed by a brief period of backflow. We have interpreted the short backflow as indicative of physiological reflux before valve closure. In a system with a low flow and with valves far apart (long vessel distance between valves), it may, however, also be due to redistribution of blood within a venous segment. With forward flow increasing, such as after exercise, backflow as a result of redistribution will become less significant and therefore will reduce the reflux index as a result of this phenomenon. Therefore it has to be realized, that a reduction of BFA/FFA values as found here does not necessarily mean "better" valve function.

An interesting finding in our study was the tendency toward higher retrograde flow and reflux ratio of popliteal veins. This can be interpreted as being indicative of a greater physiological reflux in these vessels. The most reasonable explanation obviously is a higher venous back pressure in leg veins, which is present in subjects in the standing position. Admittedly our study includes only a limited number of individuals, and an extension of the material would probably have clarified the question if there is a significant difference between physiological reflux in arm and leg veins.

This study shows that, in normal veins, valvular function does not deteriorate during active or reactive hyperemia. We observed a significant increase in reflux only in one forearm vein, and such a change probably only occurs in "weak" veins of the upper extremity, a finding that corroborates previous observations.[5] Therefore flow testing as performed in our study with subjects both at rest and during hyperemia can be recommended as a possible "stress test" before vein transplantation or to increase the sensitivity of venous diagnosis. Further investigations with our technique in patients with chronic venous insufficiency should be performed.

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