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AN PLETHYSMOGRAPHIC STUDY

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HYPERAEMIA OF THE CALF AFTER ARTERIAL RECONSTRUCTION FOR ATHEROSCLEROTIC OCCLUSION

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AFTER successful arterial reconstruction of occluded major limb vessels, a marked increase in resting blood-flow occurs in the limb. Clinical evidence of this resting 'hyperaemia' appears within hours of operation in the form of increased skin temperature and fullness of veins on the dorsum of the foot. The increased flow is not dependent on the type of reconstruction performed and occurs after thrombo-endarterectomy or by-pass grafting.

Limb blood-flow can be measured within 24 hours of operation by venous occlusion plethysmography. As previous reports have dealt primarily with the increase which occurs in skin flow, this study was undertaken to determine whether a similar 'hyperaemia' developed in the muscles of the calf.

MATERIAL

Nineteen patients suffering from atherosclerotic stenosis or occlusion of major lower limb vessels were studied (*Table I*). Seventeen patients were males and 2 were females. The ages ranged from 38 to 78 years with a mean of 58. The duration of symptoms before operation was from 4 months to 14 years.

Patients were divided into 2 groups on the basis of severity of symptoms; 7 with severe ischaemia complained of rest pain with or without digital gangrene, and surgery in this group was considered to be a limb-saving procedure; 12 complained of disabling intermittent claudication which threatened loss of employment or seriously interfered with leisure activities.

Preoperative translumbar aortography was carried out on all patients and the type of operation performed (i.e., thrombo-endarterectomy or by-pass graft) was determined on the basis of the angiographic findings.

Of 15 patients with a superficial femoral block, 14 were treated by autogenous vein by-pass and 1 by femoral endarterectomy. Seven patients in this group had undergone previous surgery in the form of aorto-iliac reconstruction (4 patients) or lumbar sympathectomy (3 patients).

Four patients suffered from iliac stenosis or occlusion and all these were treated by thrombo-endarterectomy.

METHODS

Resting blood-flow was measured by venous occlusion plethysmography. Air displacement was

used in preference to water displacement since hydrostatic pressure interfered with the flow in patients with rest pain and rendered measurements unreliable.

Studies were made with the patient supine at a room temperature of 18 to 24°C. The calf was enclosed in an air-tight perspex plethysmograph. An arterial occlusion cuff was placed around the ankle and inflated to a level in excess of the arterial pressure. The venous occlusion cuff was placed above the plethysmograph about the knee. A series of collecting pressures were tried in each patient and the highest pressure which did not interfere with arterial inflow was selected. Tracings were obtained with a float recorder and rotating kymograph. Calf volume was measured by water displacement and blood-flow calculated in ml. per 100 ml. tissue per minute.

Ten normal patients in the same age range as those under investigation, but without evidence of arterial disease, served as controls.

Flow measurements in both limbs were obtained before operation and at regular intervals after operation in the 19 patients studied. Two additional patients who developed fever and evidence of wound sepsis after operation were excluded from the study.

RESULTS

Resting calf blood-flow in the 10 normal patients ranged from 1.2 to 3.4 ml. with a mean of 1.8 ml. (Table II).

In the 19 patients studied the preoperative calf flow ranged from 1.0 to 3.3 ml. with a mean of 2.1 ml. (Table III) and did not differ significantly from that of the control group (Table IV). This finding of normal or slightly increased resting blood-flow in

Table I.—MAIN CLINICAL DETAILS OF PATIENTS

CASE No.	AGE AND SEX	SYMPTOMS*	DURATION OF SYMPTOMS	PREVIOUS SURGERY	PREOPERATIVE DIAGNOSIS	OPERATION	CLINICAL RESULTS
1	54 M.	I.C., 100	6 mth.	—	Bilateral femoral block	Left femoropopliteal by-pass	Satisfactory
2	49 M.	I.C., 50	14 yr.	—	Right femoral block	Right femoropopliteal by-pass	Satisfactory
3	38 M.	I.C., 150	2 yr.	—	Left femoral block	Left femoropopliteal by-pass	Satisfactory
4	56 M.	I.C., 70	?	Bilateral lumbar sympathectomy	Bilateral femoral block	Right femoropopliteal by-pass	Satisfactory
5	63 M.	I.C., 25	1 yr.	—	Left femoral block	Left femoropopliteal by-pass	Satisfactory
6	61 M.	I.C., 50	3 yr.	—	Right femoral block	Right femoropopliteal by-pass	Satisfactory
7	62 M.	I.C., 100	3 yr.	—	Bilateral femoral block	Right femoropopliteal by-pass	Satisfactory
8	63 M.	I.C., 200	1 yr.	Right external iliac endarterectomy	Right femoral block	Right femoroposterior tibial by-pass	Satisfactory
9	66 M.	I.C., 100 R.P.	3 yr.	—	Left femoral block	Left femoropopliteal by-pass	Satisfactory
10	56 M.	I.C., 100 R.P.	3 yr.	Left lumbar sympathectomy	Left femoral block	Left femoropopliteal by-pass	Satisfactory
11	78 F.	I.C., 100 R.P.	7 mth.	Right external iliac endarterectomy	Right femoral block	Right femoropopliteal by-pass	Died eighth postoperative day
12	71 M.	I.C., 50 R.P. + digital gangrene	6 mth.	—	Bilateral femoral block	Left femoropopliteal by-pass	Graft blocked ninth postoperative day
13	60 M.	I.C., 25 R.P. + digital gangrene	8 yr.	Right common iliac endarterectomy	Right femoral block	Right femoropopliteal by-pass	Graft blocked first postoperative day
14	52 M.	R.P. + digital gangrene	12 yr.	Left lumbar sympathectomy	Left femoral block	Left femoropopliteal by-pass	Satisfactory
15	58 M.	I.C., 100	?	—	Right external iliac block	Right external iliac endarterectomy	Satisfactory
16	57 M.	I.C., 150	3 yr.	—	Left common iliac block	Left common iliac endarterectomy	Satisfactory
17	54 M.	I.C., 100	6 mth.	—	Left external iliac block	Left external iliac endarterectomy	Satisfactory
18	60 F.	R.P.	4 mth.	—	Right external iliac block Right femoral block	Right external iliac endarterectomy	Satisfactory
19	47 M.	I.C., 100	9 mth.	Aorto-iliac bifurcation graft	Left femoral block	Left femoral endarterectomy	Satisfactory

* I.C., Intermittent claudication, followed by claudication in yards.

† R.P., Rest pain.

limbs with major arterial obstruction has been recorded previously (Edholm, Howarth, and Sharpey-Schafer, 1951).

The resting flow on the non-operated side lay within the same range and in every case remained within this range after operation (Table III).

the form of increased skin temperature and fullness of veins on the dorsum of the foot. Associated oedema of the foot and ankle was usually observed.

In 15 of these 18 cases plethysmography on the first postoperative day showed an increase in resting calf flow which was well above the preoperative level

Table II.—RESTING BLOOD-FLOW IN CALF IN 10 CONTROLS (ml. of blood per 100 ml. of tissue per minute)

Sex	Age	Blood-flow
F.	61	1.5
M.	47	2.0
F.	60	1.7
M.	58	1.2
M.	60	1.8
M.	63	2.1
M.	66	1.2
M.	59	1.6
M.	44	3.4
M.	54	1.7
Mean	51	Mean 1.8
		(S.D. 0.63)

Table IV.—STATISTICAL ANALYSIS OF DATA IN Tables II AND III

GROUPS COMPARED	t	D. OF F.	P
Patients preoperative versus controls	1.29	27	0.3 > P > 0.2
Patients preoperative versus 1 day postoperative	6.40	34	< 0.001
Patients preoperative versus 12-14 days postoperative	6.25	26	< 0.001

Table III.—RESTING BLOOD-FLOW IN CALVES BEFORE OPERATION AND AT INTERVALS AFTER OPERATION (ml. of blood per 100 ml. of tissue per minute)

CASE No.	CONTROL LEG		OPERATED LEG						
	BEFORE OPERATION	DAY AFTER OPERATION	BEFORE OPERATION	After Operation					
				1 day	3-4 days	6-7 days	9-10 days	12-14 days	3-12 weeks
By-pass Graft									
1	2.4	2.7	2.7	4.3	5.3	4.3	4.5	4.5	—
2	2.1	2.7	2.4	4.9	4.5	4.3	4.2	—	—
3	2.1	3.1	1.7	4.2	4.4	4.5	4.1	3.3	—
4	1.7	1.5	1.3	5.2	5.2	7.2	3.2	3.8	—
5	2.0	2.2	1.8	3.8	6.5	6.0	2.2	—	—
6	2.4	2.3	1.9	5.4	4.9	6.1	6.0	—	—
7	3.1	2.9	1.4	9.2	4.4	5.0	5.3	—	—
8	2.3	3.0	2.3	6.7	8.3	8.4	—	5.2	1.7 (12 weeks)
9	1.9	1.7	1.4	12.7	6.0	4.7	5.5	—	—
10	1.9	1.3	2.2	9.1	8.3	7.3	7.3	—	—
11	2.9	2.9	3.3	3.2	3.2	(Died)	—	—	—
12	2.2	2.3	1.9	7.2	4.5	4.6	2.2*	2.0	2.0 (3 weeks)
13	1.7	2.0	1.9	1.5*	1.6	1.2	(Amputation)	—	—
14	2.6	2.1	2.4	4.6	7.8	5.7	3.8	3.5	3.5 (6 weeks)
Endarterectomy									
15	2.3	2.6	2.3	4.2	6.3	5.2	4.3	—	—
16	2.3	3.0	2.8	7.0	6.9	3.7	1.8	1.8	—
17	3.4	3.2	2.8	2.4	7.3	3.7	—	4.0	4.0 (3 weeks)
18	1.6	2.0	1.0	4.8	1.7	2.4	2.4	—	—
19	2.6	1.8	2.0	1.7	2.3	2.3	2.0	2.1	—
Mean	2.3	2.4	2.1	6.0	6.0	5.3	4.1	3.9	2.8
S.D.	0.48	0.58	0.57	2.59	1.98	1.54	1.56	1.17	1.12

* Graft occluded.

In 18 of the 19 patients there was clinical evidence of restoration of blood-flow on the first postoperative day. In most cases pedal pulses returned and in all 18 cases there was evidence of local hyperaemia in

(Table III). Flow ranged from 2.4 to 12.7 ml. with a mean of 6.0 ml. In one case (Case 17) flow did not increase appreciably until the third day, when it rose to 7.3 ml. Two patients (Cases 11, 19) failed to

develop any increase in calf flow in spite of the fact that pedal pulses returned after operation. *Case 11* died from pulmonary embolus on the eighth day after operation and at autopsy the by-pass graft contained only post-mortem thrombus.

In the majority of patients blood-flow remained at a high level until the third or fourth day after operation, and then declined slowly (*Table III, Fig. 1*).

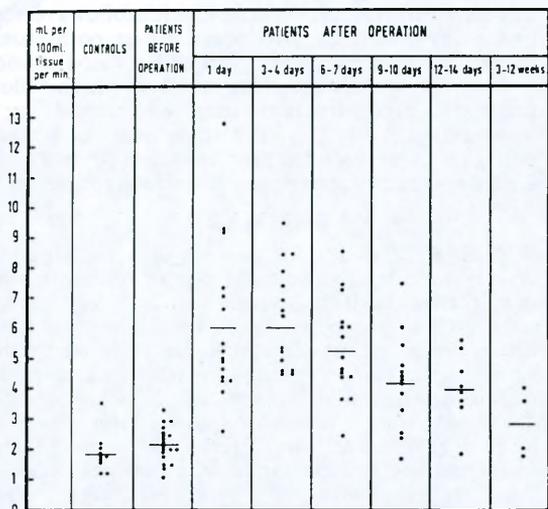


FIG. 1.—Resting blood-flow in calf. Graphic representation of data in *Tables II and III*. Each dot represents 1 patient and the horizontal lines indicate the means for the groups.

After 2 weeks the mean blood-flow was still 3.9 ml., which was significantly higher than that before operation. Subsequent recordings were made on 4 patients and in 2 the resting flow was still increased 3 and 6 weeks after operation respectively.

Table V.—INFLUENCE OF VARIOUS FACTORS ON PRE-OPERATIVE AND MAXIMAL POSTOPERATIVE RESTING BLOOD-FLOW IN THE CALF (STATISTICAL COMPARISONS)

SYMPTOM	NUMBER	MEAN BLOOD-FLOW	S.D.	t	D. OF F.	P
Rest pain versus claudication						
Preoperative Claudication	12	2.1	0.52	0.353	17	0.8 > P > 0.7
Rest pain	7	2.0	0.74			
Postoperative						
Claudication	11	6.6	1.30	2.855	13	0.02 > P > 0.01
Rest pain	4	9.2	2.19			
Bypass versus endarterectomy						
Postoperative By-pass	12	7.4	2.59	0.325	13	0.8 > P > 0.7
Endarterectomy	3	6.9	0.51			

One patient (*Case 13*), treated by femoropopliteal by-pass, failed to develop the usual signs of hyperaemia. The foot remained pulseless and the graft was obviously occluded. Resting blood-flow did not increase over the next week and the limb was

amputated on the ninth postoperative day. In another patient (*Case 12*) resting flow was 4.6 ml. on the seventh day after operation but fell to 2.2 ml. on the ninth day. This change coincided with disappearance of pedal pulses and clinical evidence of thrombosis of the graft.

When there was occlusive disease distal to the site of reconstruction the hyperaemia which followed operation was not typical. *Case 18* had both external iliac and superficial femoral blocks, and external iliac disobliteration was performed as the first stage in reconstruction. The increase in flow after operation was transient and blood-flow had returned to the preoperative level by the third day.

The magnitude of the hyperaemic response could not be correlated with the duration of the ischaemic symptoms, the level of the occlusion, or the type of reconstructive procedure performed (*Table V*). However, the postoperative resting blood-flow rose to a higher level in those patients with preoperative rest pain than in those whose only symptom was claudication (*Table V*). While the preoperative blood-flow was similar in both groups, the mean maximal flow after successful reconstruction reached 9.2 ml. in patients with rest pain, but increased to only 6.6 ml. in those with claudication only.

Previous arterial surgery had a variable influence on the hyperaemic response. Of 3 patients who had undergone preliminary aorto-iliac reconstruction and were now successfully treated for superficial femoral occlusion, only 1 developed the typical increase in calf blood-flow. However, all 3 patients who had had a previous lumbar sympathectomy demonstrated a marked increase in calf blood-flow after definitive reconstruction.

DISCUSSION

It is well recognized that hyperaemia develops in a limb after reconstructive arterial surgery. Both Eastcott (1953) and Rob (1953) have reported clinical evidence of hyperaemia of the foot and calf after reconstruction of an occluded major vessel. Eastcott measured the resting flow in the calf after operation and found it to be three times the preoperative level. Gaskell (1956) studied the calf blood-flow in 6 patients before and after arterial grafting and in 4 found postoperative hyperaemia which persisted for 4 weeks. As the increase in the flow in the calf was not as great as that in the foot, it was concluded that the flow through skin only was increased.

If one accepts that calf plethysmography is a measure of muscle blood-flow (Grant and Pearson, 1937), our findings indicate that the response is not confined to skin. The greater increase in calf flow in this series than in that of Gaskell (1956) may reflect the fact that we included a greater number of patients with severe ischaemia, for Gaskell found that the magnitude of the postoperative hyperaemia was related to the severity of preoperative ischaemia. Someone and Husni (1959), measuring digital flow, found likewise that the hyperaemia which developed was most marked in those with long blocks and poor collaterals and often failed to occur in those patients whose symptoms were minimal. However, in his patients the increase in resting flow after operation was greatest in those whose only symptom was claudication; this is not in agreement with our findings.

Several causes for the hyperaemia which follows arterial reconstruction have been suggested. Snell, Eastcott, and Hamilton (1960) have attributed the response to the effect of periarterial sympathectomy. One case is described in which simple mobilization of the common iliac artery on the non-operated side produced a marked hyperaemia in the ipsilateral foot. However, periarterial sympathetic fibres rarely exceed 6 cm. in length and are not confined to the adventitia (Mitchell, 1956), thus it seems unlikely that simple stripping of the common iliac artery could be responsible for an increased flow through the foot.

That previous lumbar sympathectomy did not affect the magnitude of the hyperaemia provides additional evidence against periarterial sympathectomy being responsible. No preoperative tests of sympathetic activity were performed in our patients and in 2 the time intervals between sympathectomy and reconstruction might have allowed some recurrence of vasomotor activity. In 1 patient, however, lumbar sympathectomy was performed only 6 months before reconstruction and it is unlikely that a sympathetic pathway became re-established in this short time (Barcroft and Swan, 1953).

Metabolic products of ischaemic muscle, having vasodilator properties, have also been cited as a possible cause (Simeone and Husni, 1959), but the long duration of the hyperaemia (over 14 days after operation) makes it unlikely that these play any important role. Moreover, as pointed out by Hilton (1962), the acid metabolites to which vasodilatation is usually attributed have very little vasodilator action.

Finally, the one constant factor necessary for the development of postoperative hyperaemia is successful restoration of blood-flow. Both periarterial sympathectomy and the accumulation of vasodilator metabolites during the operative period of arterial clamping should be common to all cases. However, if thrombosis of the graft or 're-bored' vessel occurs, blood-flow at once returns to normal (Cases 12, 13). Similarly, if there is arterial occlusion distal to the site of reconstruction, typical hyperaemia does not occur (Case 18).

Burton (1951) has defined the transmural pressure of a vessel as the difference between the intravascular pressure and the tissue pressure. Transmural pressure is opposed by the circumferential tension of the vessel wall, which is composed of passive elastic tension and active muscle tension, the latter being under vasomotor control. Ashton (1962, 1963), using the technique of pressure plethysmography in the calf, found that with progressive reduction in transmural pressure blood-flow decreased only gradually until a critical transmural pressure was reached. At this point all recordable flow ceased abruptly. This critical pressure was termed the flow-cessation pressure (F.C.P.). It was found that, in cases of obstructive arterial disease, the F.C.P. was actually higher than normal in spite of the fact that blood-pressure was reduced (Ashton, 1960). This could

indicate that in ischaemic limbs there is negligible flow through some areas of the vascular bed at any given time. It may be that, after surgical reconstruction of a blocked major vessel, the F.C.P. in the calf returns to normal and flow occurs through some vessels which were previously closed.

Another factor is the observation of Simeone and Husni (1959) and Husni (1961) that the low pressure in arterioles distal to obstructed large vessels may result in atrophy of the media. If this is so, the increased intravascular pressure which follows restoration of flow will be unopposed by smooth-muscle elements in the media and will cause vasodilatation.

Thus the increased resting calf flow which follows successful reconstruction may be caused by a combination of factors, including increased transmural pressure, reduced flow cessation pressure, and atrophy of the media in vessels distal to the obstruction.

SUMMARY

Resting blood-flow in the calf was measured by venous occlusion plethysmography in 10 controls and in 19 patients with large vessel obstruction before and after arterial reconstruction. In those patients in whom the operation was successful, all but 2 showed a marked increase in resting flow which was apparent within 24 hours of operation. The hyperaemia developed after either thrombo-endarterectomy or by-pass grafting and was greatest in those patients with most severe ischaemia. In 2 patients in whom the graft thrombosed, the hyperaemia disappeared. A possible explanation for this postoperative hyperaemia on the basis of increased transmural pressure and reduced flow cessation pressure is suggested.

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