IMPEDANCE PLETHYSMOGRAPHY IN RELATION TO THE UNILATERAL AMPUTEE [a]

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In any large amputee clinic, a considerable number of unilateral amputees are seen whose amputations resulted from generalized peripheral vascular disease. In evaluating the patient from a medical and prosthetic standpoint, it is advantageous to know the status of circulation in the remaining leg.

At the present time, there are several methods of obtaining some evaluation of this circulation status, namely, palpation of the dorsalis pedis and posterior tibial pulses in the foot, as well as the popliteal and the femoral pulses. The use of the pneumatic oscillometer cuff (Fig. 1) is occasionally of help (a blood pressure cuff about the leg is inflated to pressures just short of occluding the vessels, and the excursion of the oscillometer needle is recorded). It is has long been felt, however, that this method of recording blood flow is rather inaccurate. A more precise method of circulation evaluation can be obtained by performing an angiogram, inserting a needle into the femoral artery and obtaining X-rays of the arterial tree. This method, however, does not lend itself well to use in an out-patient clinic.

The search for a nondestructive method of quantitative measurement of blood flow in the remaining extremity of the unilateral amputee led to the electrical impedance plethysmograph (1,2,3,4,5). This technique endeavors to measure the resistance to the passage of a small electric current along a segment of human extremity when the arterial blood flow is the major variable factor. It has been recorded that the increased blood flow incident to the heart systole produces an increased ability of an extremity to carry an electrical current and, therefore, a decrease in the electrical resistance recorded at the distal end of a pair of electrodes. To graphically portray these changes requires two electronic devices: one, an electronic circuit that can deliver a small, constant flow of current; and two, an electronic recording device (Fig. 2).

[a] Based on work performed under VA Contract V1005M–1079.

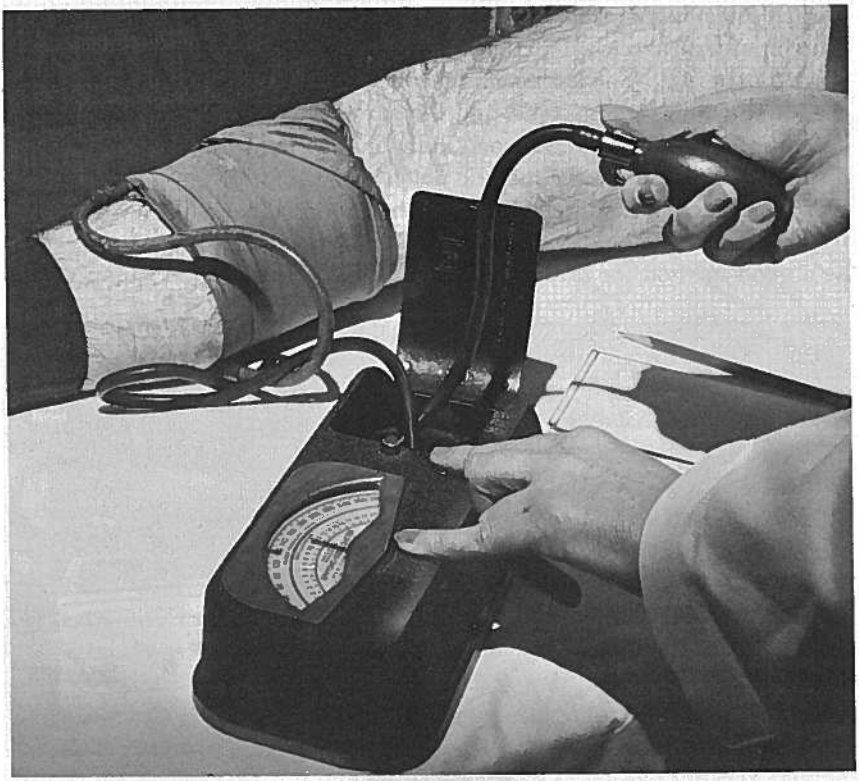

FIGURE 1

The first device, the Impedance Plethysmograph,[b] delivers through a transistorized circuit a current of two milliamperes with a voltage of less than one volt at a frequency of thirty kilocycles. This amount of electrical current is unnoticed by the patient and has no destructive effects. The electronic outflow from the electrodes on the patient is monitored on a Sanborn visiocardiograph utilizing the first lead connection. As the heart beats, each systolic contraction sends a flow of blood down the arterial tree, and if the blood flow is relatively normal, the resistance to the passage of the electric current is decreased and the electrocardiogram records this as a wave pattern (Fig. 3).

The wave pattern thus recorded in individuals with normal blood flow has certain characteristics: it has height or pulse amplitude (Segment A–B), which amplitude is higher the more blood is present in the arterial segment; and it also has a certain rate of ascendancy (crest time, Segment B–C), which time is shorter the more normal the arterial tree and the more

[b] Impedance Plethysmograph, Model 3#, Parks Electronics Laboratory, Aloha, Oregon.

normal the amount of blood flow. It has been further noticed that normal individuals reveal a wave pattern which is sharper at its crest than the abnormal patterns. The less normal the blood flow, the longer the crest time, the lower the wave amplitude, and the more rounded the wave curve (Fig. 4 and 5). Further, in the normal individual, as the wave pattern descends during diastolic filling, the dicrotic notch (Fig. 3) is seen in the descending limb; this notch is usually eliminated in the abnormal patient.

When this technique was first proposed, it was believed that this would be a good method for study of circulation in an amputation stump during

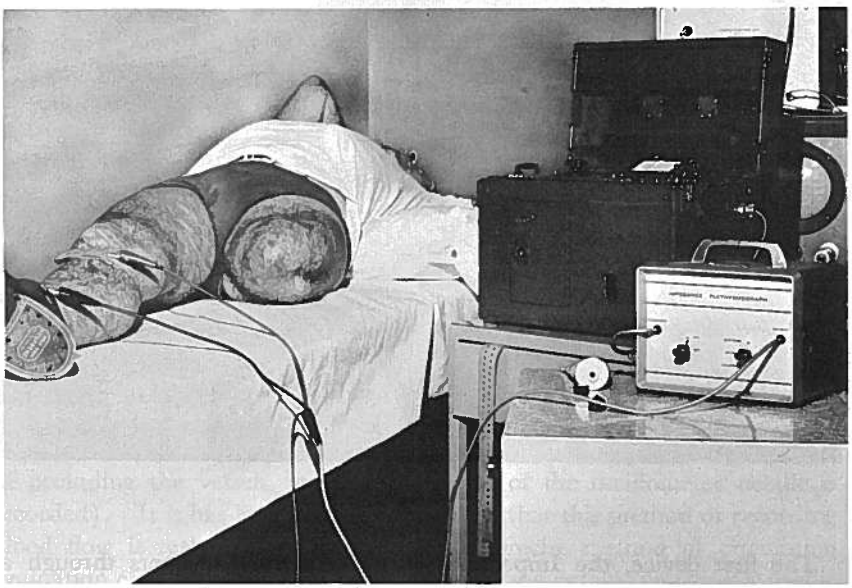

FIGURE 2

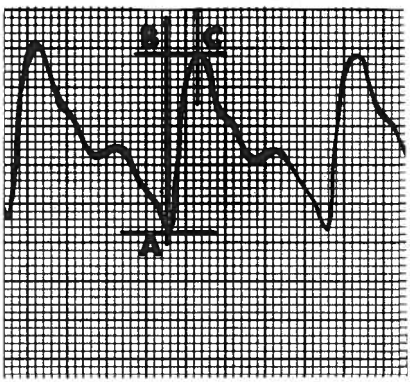

FIGURE 3. Normal individual, age 40, with normal wave pattern.

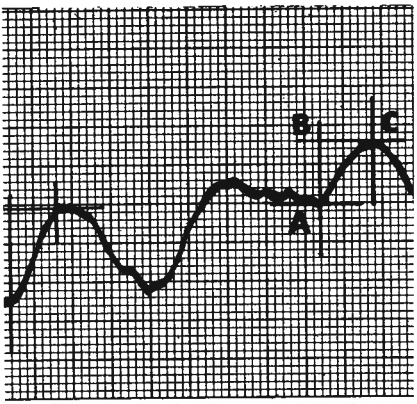

FIGURE 4. Unilateral amputee, age 74, with gangrene as cause of amputation. Chart shows typical arteriosclerotic wave pattern.

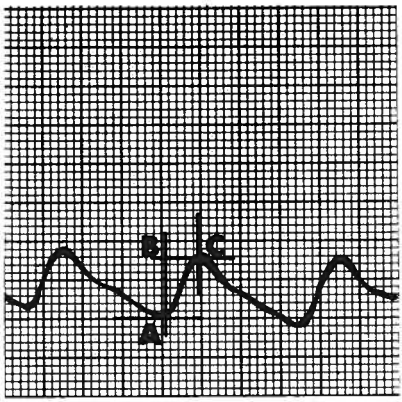

FIGURE 5. Unilateral amputee, age 36, with diabetic gangrene as cause of amputation. Chart shows abnormal wave pattern.

prosthetic wear. It was quickly noted, however, that any movement of the extremity caused severe disruption of wave patterns. Consequently, the method was then evaluated on completely quiescent limbs.

A series of normal individuals, as well as patients at the Rehabilitation Institute of Chicago, was studied, utilizing a standard technique as follows. Regular electrocardiograph electrodes with rubber cuff retainers were placed ten inches apart on the lower extremities of normal subjects, patients with various diseases, and on the remaining leg of unilateral amputees (Table 1).

TABLE 1

Normal subjects	10
Non-amputee patients with various diseases	10
Unilateral amputees examined two or more times	10

Table 2 reveals the range of values for the Impedance Plethysmograph for patients who were considered normal subjects.

Table 3 reveals the findings as regards wave amplitude, recorded in millivolts, measured in seconds, in a number of subjects who had retained both extremities, but who suffered from various listed diseases.

Table 4 reveals the findings in the remaining leg of unilateral amputees, some of whom were examined twice, and a few who had three examinations.

TABLE 2.—*Normal Non-Amputees: Wave Pattern Statistics*

Patient	Age	Amplitude (mv.)						Crest time (secs.)					
		Right leg			Left leg			Right leg			Left leg		
1	9	2.8	2.8	2.8	3.1	3.1	3.1	.20	.15	.20	.16	.20	.16
2	16	4.0	3.9	4.1	3.2	3.1	3.2	.16	.12	.12	.16	.12	.12
3	22	2.3	2.7	2.5	1.9	1.9	1.9	.16	.12	.16	.12	.12	.16
4	23	1.6	1.6	1.8	1.8	1.9	1.8	.12	.12	.12	.12	.16	.12
5	44	3.4	3.4	3.4	3.1	3.1	3.0	.12	.16	.16	.16	.12	.12
6	35	2.1	2.2	2.1	2.6	2.6	2.7	.12	.12	.16	.12	.12	.12
7	47	2.1	2.1	2.0	2.0	2.0	2.0	.12	.12	.16	.16	.16	.12
8	44	2.0	2.2	2.1	2.3	2.4	2.4	.12	.12	.12	.12	.12	.16
9	29	3.9	3.9	3.9	3.1	3.3	3.5	.16	.16	.16	.16	.16	.16
10	52	1.5	1.7	1.9	2.1	2.1	2.1	.16	.16	.20	.12	.12	.12

TABLE 3.—*Patients with Various Diseases: Wave Pattern Statistics*

Diagnosis	Age	Wave amplitude (mv.)						Crest time (secs.)					
		Right leg			Left leg			Right leg			Left leg		
Varicose veins	24	3.8	3.9	3.8	3.75	3.6	3.7	.16	.16	.16	.16	.16	.16
Polyomyelitis	32	3.6	3.5	3.5	3.0	3.2	3.2	.20	.20	.20	.12	.16	.12
Cerebral vascular accident	35	2.4	2.3	2.3	2.8	3.2	3.1	.16	.16	.16	.12	.12	.16
Rheumatoid arth.	41	1.4	1.2	1.2	1.6	1.8	1.7	.16	.16	.16	.12	.12	.16
Knee cartilage injury													
(Test 1)	42	1.9	1.9	1.9	3.8	3.9	3.9	.16	.1	.16	.12	.12	.12
(Test 2)	45	2.9	2.5	2.6	4.0	4.0	3.7	.12	.165	.125	.16	.16	.16
Hemiplegia (left)	53	4.35	3.9	4.2	3.3	3.5	3.4	.12	.16	.16	.12	.12	.12
Polycythemia	58				8.45	8.3	8.3				.12	.16	.16
Hemiplegia (left)	55	2.6	2.8	2.7	1.9	2.1	2.0	.16	.12	.12	.08	.12	.12
Hemiplegia (right)	63	1.2	.85	.9	.75	.95	.95	.12	.12	.12	.12	.12	.12
Hemiplegia (right)	67	1.1	1.1	1.1	2.3	2.3	2.1	.12	.12	.12	.12	.16	.12

TABLE 4.—*Amputees (Unilateral): Wave Pattern Statistics*

Patient	Age	Test	Time interval	Amplitude (mv.)			Crest time (secs.)		
1	68	1		1.9	1.8	1.9	1.0	.88	1.04
		2	2 months	.6	.6	.6	.36	.24	.32
2	68	1		1.35	1.3	1.45	.20	.20	.20
		2	7 months	.65	.7	.8	.20	.20	.24
3	42	1		.4	.4	.45	.12	.12	.08
		2	3 months	.4	.4	.4	.12	.16	.125
4	65	1		1.15	1.15	1.1	.16	.12	.125
		2	2 months	1.1	1.0	1.15	.12	.125	.12
5	52	1		1.6	1.65	1.8	.12	.125	.125
		2	1 month	1.5	2.15	1.75	.125	.16	.16
6	60	1		1.35	1.35	.95	.125	.16	.16
		2	3 months	1.1	1.15	1.1	.125	.16	.125
7	60	1		1.05	.95	1.0	.12	.125	.12
		2	13 months	1.9	2.0	1.8	.12	.12	.125
8	55	1		1.15	1.4	1.2	.20	.205	.16
		2	10 months	.8	.8	1.0	.16	.165	.20
9	60	1		1.3	1.1	1.1	.20	.20	.20
		2	4 months	2.5	2.3	2.3	.245	.245	.24
10	44	1		2.65	2.55	2.75	.16	.16	.16
		2	5 months	3.2	2.4	2.7	.16	.1	.16
		3	12 months	2.05	2.3	1.85	.16	.20	.16

In reviewing the statistics evolved from these various patient runs, utilizing the Impedance Plethysmograph with recording of wave patterns by the visiocardiograph, it appears as though the crest time evaluation has little significance in determining either efficiency or deficiency of circulation flow. The crest time was the same in many instances both in the normal and abnormal patients. Comparison of the wave amplitude as recorded in microvolts obtained from both legs of normal individuals reveals similar statistics indicating that, in general, the findings on one leg can be duplicated in the other. Certainly the wave forms are the same in both legs where the circulation to both legs was considered to be identical.

Since most of the quantitative studies of peripheral blood flow using the Impedance Plethysmography method are related to the above statistics, it

was felt that these statistics should be evaluated in the light of their consistency before too much credence is placed on the results obtained from utilizing these same statistics in evaluating by a mathematical formula the amount of blood flow. The wave patterns can be likened to those obtained by an electrocardiograph of the heart, with a slight difference, namely, that the recording of the wave patterns from the heart is due to production of electricity by the heart muscle in its own conduction system, whereas the wave pattern findings in the Impedance Plethysmography recordings are influenced by many factors which may either impede or speed up the flow of electric current along the length of a limb. Some of these factors would include the amount of blood flow, the percentages of the various ions of the blood, calcium, phosphorus, sodium potassium, the amount of salt in the perspiration on the skin, temperature of the tissues, and the presence or absence of microscopic dirt on the extremity. Thus, one has to be careful in interpreting the statistics from Impedance Plethysmography due to the many variables over which there is little control.

It has been our impression after studying a large number of the curves produced in both normal and abnormal individuals, that the shape of the wave pattern will yield a qualitative estimate of the blood flow ranging all the way from the normal appearance (Fig. 3) to the abnormal appearance (Fig. 4). Further, there appears to be a somewhat rough quantitative evaluation possible as witnessed in the findings of Table 3 in which the right and left legs of a patient who had had an injured knee cartilage were evaluated. The operated leg shows a marked diminution in wave amplitude in contrast to the normal side. However, retesting this same patient three years and three months later shows his amplitude to have increased to 2.9, 2.5, and 2.6, in contrast to previous readings of 1.9, 1.9, and 1.9. The patient's leg clinically seems to have been improved, and it appears to reflect an improved circulatory status. Further, a patient with hemiplegia exhibits on his hemiplegic side a slightly decreased amplitude in contrast to an increased amplitude on his normal side. A patient with polycythemia who was, unfortunately, examined only on one leg, reveals a tremendous amplitude in contrast to other more normal individuals.

It would thus appear as though there is a rough quantitative estimate of blood flow which can be obtained by the Impedance Plethysmography method. Table 4, which reveals findings in unilateral amputees, repeat evaluations being made at later intervals, reveals that in some patients the amplitude decreased, whereas in other individuals the amplitude increased (Figs. 6 and 7). This may indicate either a decrease of blood flow with the passage of time or an increased blood flow which may have been incident to the use of a prosthesis.

It is my opinion that this method of circulation study could be further investigated by interested parties to determine the relationship on a long

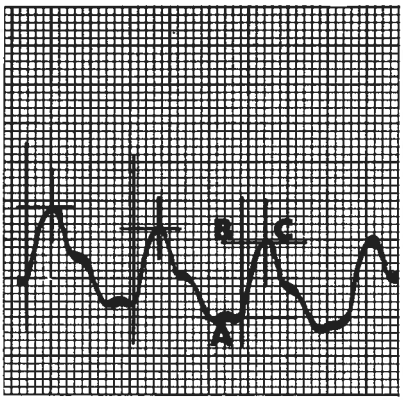

FIGURE 6. Unilateral amputee, age 60, with trauma as cause of amputation. Chart shows normal wave pattern (low amplitude) in February, 1962.

FIGURE 7. Same amputee as in Figure 6 in September, 1963. Note increased amplitude of wave pattern.

term basis of the changes in the plethysmography reading, and as to whether these would correctly forecast the necessity for further or future amputations.

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