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PLETHYSMOGRAPHIC RECORDINGS OF SKIN PULSES

V. *Piezoelectric and Photoelectric Measurements in Venous Leg Ulcers*

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Abstract. Piezoelectric and photoplethysmographic pulse curve recordings from toes and ankle regions in patients with venous leg ulcers are reported. A spastic toe pulse was more frequently observed in post-thrombotic than in non-thrombotic states. A sclerotic toe pulse, indicating arteriosclerotic changes of the larger vessels, was only observed in the older patients. Sclerotic pulses were recorded from the border of the ulcer in 31/46 legs. In particular, showed lesions as atrophie blanche and dermatosclerosis alterations in the pulse shape. Pressure pulses could be obtained from superficial veins in both post-thrombotic and non-thrombotic cases. The findings are related to organic and pathophysiological changes occurring in chronic venous insufficiency. The results indicate that except for some particular skin areas, the cutaneous, arterial blood supply is not significantly reduced in venous leg insufficiency.

The present work concerns skin pulses recorded in venous leg insufficiency. The significance of such measurements and various characteristics of the pulse curve were described in a preliminary report (27). It has been reported that the piezoelectric method is more convenient for measurements on the toes and that the photoelectric device is well suited for studies in other areas. As shown by several investigations (5, 12, 20, 28), photoelectric plethysmography with reflected light may be of special value when the cutaneous circulation of a restricted area has to be examined. Such examinations performed at the ulcer area, in addition to toe plethysmography, have been suggested by Wengi (31), but as far as is known they have not previously been reported.

In general, pulse plethysmography permits a qualitative estimation of the circulation and both functional and organic changes are recorded (5, 11, 12, 17, 29). Consequently vasoconstriction, venous stasis and changes of the vessels of the surrounding tissue may alter the configuration of the curve (11, 20, 24). These are factors of fundamental importance for the development of a venous leg ulcer and it was proposed that measurement of skin pulse might contribute to the understanding of this common circulatory disease. In the present investigation, particular emphasis was laid on measurement of the cutaneous circulation in the vicinity of the ulcer besides recordings of toe plethysmograms which were taken in order to examine the condition of the larger vessels (31).

MATERIAL AND METHODS

Toe and ankle pulses were recorded on 20 healthy subjects in the age groups 22 to 36 years and 54 to 80 years (Table I). The mean age of the latter group was 65 years. The subjects were selected from the staff of the hospital and their relatives. Subjects suffering from symptoms of vascular or cardiac disease were excluded from the examination.

Ankle pulses were recorded from the border of the ulcer area on 46 legs in 35 patients aged 40 to 80 years (mean age 64 years). Toe plethysmograms were recorded from 150 legs with venous ulcerations in 139 patients (Table II). Sixty-five cases were anamnestically diagnosed as post-thrombotic and 85 as non-thrombotic venous insufficiency.

The amplitude of the ankle pulses was measured before and 15 min after stimulation with a rubefacient, 3% pyridine-β-carbolic acid-benzyl-ester (Rubriment Tinktur®; Nordmark-Werke GMBH, Hamburg), on 22 legs in 11 healthy subjects aged 52 to 80 years (mean age 63 years). The amplitude of pulses recorded from the border of venous leg ulcers was measured on 23 legs in 18 patients aged 40 to 76 years (mean age 65 years). In order to obtain comparable data for the amplitude of the ankle pulses in healthy persons and patients, index *I* was calculated according to the equation

Table I. *Results of ankle pulse plethysmography in 40 healthy legs (20 subjects) and in 46 legs with venous ulcers (35 patients)*

	Number of individuals		
	Control subjects		Patients
Age in years ...	22–36	54–80	40–80
Normal in both ankles	10	6	4
Normal in one ankle	0	0	7
Sclerotic in one ankle	0	0	17
Sclerotic in both ankles	0	4	7
Total number	10	10	35

$$I = \frac{\text{Pulse height (unit of measurement: 5 mm)}}{\text{Sensitivity (mm/1 mV)}}$$

A high index value *I* indicates a large amplitude. Two or three recordings were taken from each ankle area. The smallest value of pulse amplitude obtained was used for calculation of the index. Recordings were also taken from lesions as atrophie blanche (10 cases), dermatosclerosis (14 cases) and from varicose veins (10 cases).

The pulse recordings on the toes or varicose veins were performed by the piezoelectric method. The other recordings were performed by photoelectric plethysmography with reflected light. The plethysmographs were connected to an electrocardiograph for recording of the pulse curves. The paper speed was 50 mm/sec. The photoelectric pulse meter was constructed following the principles originally described by de Pater et al. (20) with the exception that only one lamp was used. This was placed behind the cadmium sulphide (Philips) which served as photoconductive material. It has the highest spectral sensitivity at 550 nm to 680 nm which means that both reduced and oxygenated hemoglobin is recorded. The influence of oxygen saturation may, however, be disregarded during investigations of short duration (5). In the present material the hemoglobin content was found to be normal in all the patients examined. Previous studies with photoelectric plethysmography and reflected light have shown that only the dermal circulation is recorded (28). The sensing area of the present pulse meter is 8 × 8 mm. The photoelectrically recorded or opacity pulse represents pulsatile variations in optic density caused by the pulsatile blood flow. By means of the Philip's lens lamp operating at 0.5 W, light is directed into the skin. Varying amounts are absorbed or dissipated but some are reflected back to the apparatus. The intensity of the light returning to the photocell varies with the pulsatile blood flow of the skin and will cause inversely proportional variations in the resistance of the photoconductive material which can be recorded as pulse curves.

Table II. *Age distribution and results of toe plethysmography in 150 legs with venous ulcers (139 patients)*

Age (y.)	Pulse form: Normal p.-t.[a]	Normal n.-t.[b]	Sclerotic p.-t.	Sclerotic n.-t.	Spastic p.-t.	Spastic n.-t.	Total
20–39	2	—	—	—	3	—	5
40–49	2	3	—	—	7	1	13
50–59	3	5	—	4	5	3	20
60–69	3	8	12	10	7	5	46
70–79	1	4	10	40	10	2	66
Sum	11	20	22	54	32	11	150
	31		76		43		

[a] p.-t. = post-thrombotic. [b] n.-t. = non-thrombotic.

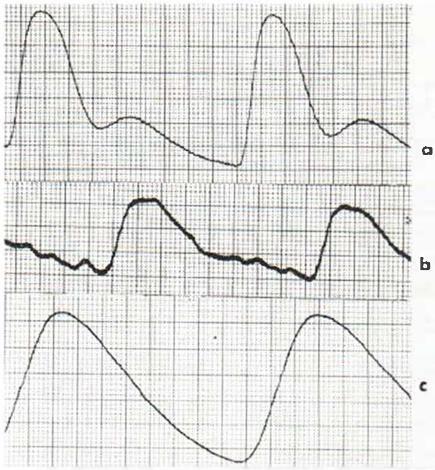

Fig. 1. Piezoelectric pulse recordings from the toes. (*a*) Normal, (*b*) spastic, (*c*) sclerotic pulses.

The principles of the piezoelectric pulse meter have been outlined previously (27). The curves recorded by this method are induced by the pressure caused by the volume variations of the pulsating tissue. They are thus true pressure curves recorded from the pulsating skin surface. For measurements of the toes the pulpa was enclosed in the capsule of the transducer and for measurements on the superficial veins the capsule was changed for a wing-formed plate which rested freely on the skin.

Although in normal persons a direct relationship between the amplitude and the cutaneous circulation has been suggested, it must be stressed that the measurements performed are not at all quantitative only qualitative (5). The pulse volume is thus not synonymous with the rate of blood flow. The form of the wave depends upon the stroke volume of the heart, the arteriolar tonus, the peripheral resistance, the elasticity of the vessel walls, the consistency of the surrounding tissue and the momentary vasomotoric activity (3, 17, 29). It is for the most part influenced by the arteriolo-capillary system (17). The pulse may be classified according to its shape as shown by Völker (29), Wengi (31) and Olivier (19), or it may be evaluated by means of various pulse times. The latter has in particular been performed by Mune (18) and is of special value in arterio-sclerotic cases. The present investigation was primarily directed towards the venous circulatory disturbances in which the shape of the curve is of greater importance.

According to Völker (29) and others (12, 31) the following pulse curves may be distinguished: 1) The normal pulse (Fig. 1 *a*) has a rapid ascent and a dicrotic, slower descent producing a rather pointed crest. 2) The spastic pulse (Fig. 1 *b*) is observed in vasoconstrictive conditions. It has a broader crest, a slow ascent and often an upward convex descending branch without dicrotism. The amplitude is often small and many small oscillations due to alterations in the vasomotor tone may occur on the descending branch. 3) The sclerotic pulse (Fig. 1 *c*) is particularly observed in arteriosclerotic conditions and is due to organic changes of the vessel walls. It has a normal ascent whereas the descending branch is concave without dicrotism or oscillations, creating a stiff appearance. 4) The stenotic or collateral pulse is observed in partial or total arterial occlusion. It has a delayed and very slow ascent, the crest is rounded and the descending branch is convex without any dicrotism. The curve is altered in the direction of a sinus wave. This type is not concerned in the present study.

The precautions taken during registration and the technique of application of the pulse meters have been described in previous communications (27, 28). The blood pressure which may have some influence on the pulse amplitude (18), was determined in all patients and was found to be within normal limits. The room temperature was kept constant at 25°C (±1°). The digital pulse curves were recorded during reactive hyperemia which was achieved by applying a blood pressure cuff inflated to 200 mm Hg for 5 min, to the ankle (18). The examinations were performed on recumbent subjects after they had rested for 20 min prior to the investigation. The toe plethysmogram was recorded from the first or second toe.

RESULTS

Representative toe and ankle pulses are shown in Figs. 1 and 2, respectively. Generally, the ankle pulses recorded in younger healthy subjects showed a more variable descending branch whereas a stiffer appearance was seen in the

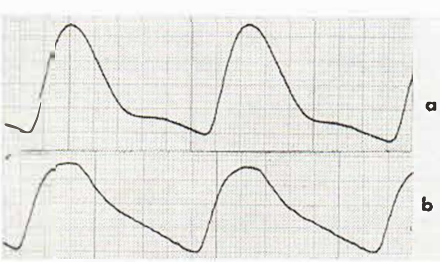

Fig. 2. Photoelectric pulse recordings from the ankle area. (*a*) In a normal person. (*b*) At the border of a leg ulcer showing sclerotic pulses.

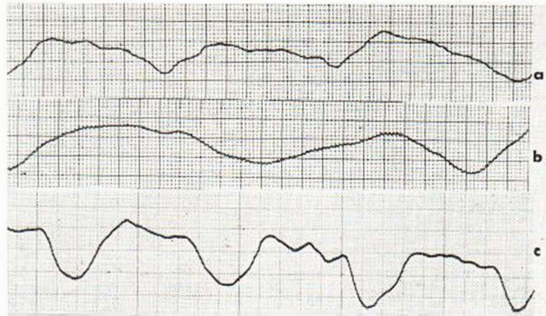

Fig. 3. Photoelectric recordings beyond 3 cm from the border of an ulcer, showing spastic pulses.

older subjects. Spastic pulses were not recorded. Sclerotic ankle and toe pulses were observed in 8/20 and 7/20 legs, respectively, in the older age group. Only normal skin pulses were observed in the younger age group.

In patients with venous ulcerations 31/46 legs showed sclerotic pulses at the ulcer border. Normal ankle pulses were obtained in 15/46 legs. No spastic pulses could be recorded from the vicinity of the ulcer within a zone of about 3 cm from the border. Pyridine-β-carbolic acid benzyl ester had no effect on the pulse amplitude in this area. However, individual and interindividual variations were observed and both sclerotic and normal pulse curves could be obtained from areas around the same ulcer. Variations in pulse amplitude were also observed. Generally, the pulse curves were more sclerotic and showed a smaller amplitude in long-standing cases. Such changes could be observed even in cases where the toe pulses were normal.

The results obtained by toe plethysmography on 150 legs are illustrated in Table II. A normal pulse was observed in 31 legs while a spastic pulse was obtained in 43 legs and was significantly more frequent in post-thrombotic than in non-thrombotic states, 32/65 and 11/85, respectively. The spastic pulse curves were similar to those described by Olivier et al. (19). They could be obtained not only in post-thrombotic states but also in non-thrombotic. In 76 legs a sclerotic pulse was observed. This pulse form was particularly frequent in the age group above 60 years. Spastic pulses and small deformed pulse waves could be obtained beyond a distance of about 3 cm from the ulcer area (Fig. 3) both in post-thrombotic and non-thrombotic cases. The curves obtained

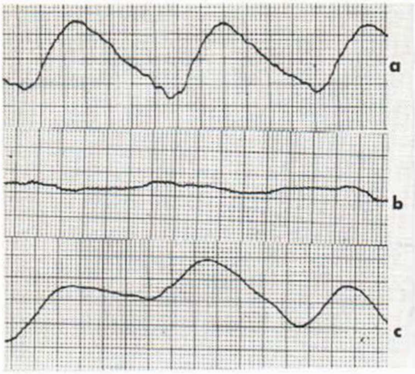

Fig. 4. Photoelectric recordings in atrophie blanche showing sclerotic (*a*) and almost absent skin pulses (*b, c*).

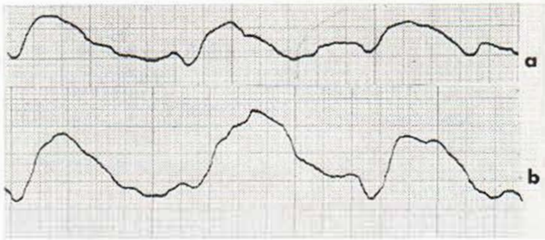

Fig. 6. Pressure pulses from varicose veins. Before (*a*) and after (*b*) proximal stasis. 50 mmHg.

in areas with atrophie blanche (Fig. 4) and dermatosclerosis (Fig. 5) were small and sclerotic. In one area with atrophie blanche no pulsations could be recorded.

The pressure pulses obtained from the superficial veins showed marked variations (Fig. 6). They were particularly pronounced at the blow-out perforating veins, but could also be recorded elsewhere. In one case the waves had a rather large amplitude and a distinct rebound. As a rule, however, they were quite small without dicrotism. They could be obtained in both post-thrombotic and non-thrombotic cases. The amplitude increased when venous stasis (50 mmHg) was applied proximally. It decreased when the leg was elevated above heart level.

Fig. 7 shows the index *I* of the ankle pulses in 22 normal legs and at the border of the ulcer in 23 legs from persons of the same age group. The average value for the index in normal legs was 1.4 before and 6.0 after stimulation with Rubriment Tinktur®. For the patient material the average index value was 3 before and after stimulation indicating a decreased reactivity.

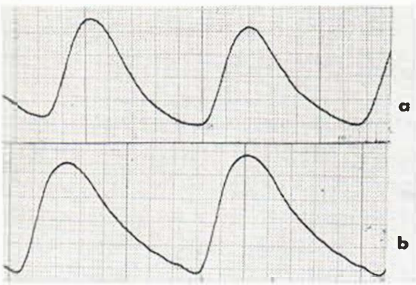

Fig. 5. Photoelectric recordings in dermatosclerosis showing sclerotic skin pulses.

DISCUSSION

The increased venous pressure and the state of the small dermal vessels are factors of paramount importance in venous leg ulcers. Recently, important haemodynamic studies of venous dysfunction have been performed by Bjordal (1) who applied simultaneous pressure and flow recordings in varicose veins. His observations indicate that "the venous hypertension during ambulation is caused by the retrograde flow through the saphenous main channel and is not transmitted through the dilated perforators".

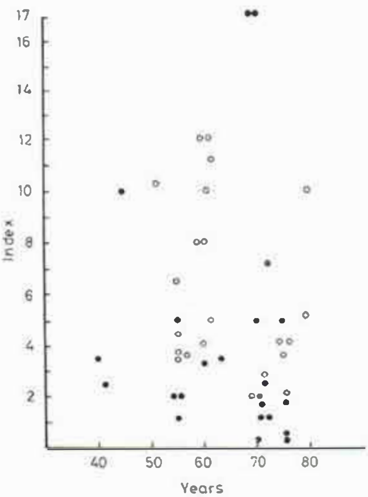

Fig. 7. Results of measurements of the ankle pulse index in 22 normal legs obtained after stimulation with Rubriment Tinktur® (○) and at the ulcer border in 23 legs (●).

$$\text{Index} = \frac{\text{Pulse amplitude (measuring unit: 5 mm)}}{\text{Sensitivity (mm/1 mV)}}$$

The part played by the arteries in chronic venous insufficiency has been studied by Wiedmann (32) in particular and a pathogenetic significance of arterial disease was considered probable in all cases with venous ulcers. The interaction between arteries and veins has also been mentioned by other authors (10, 21, 33, 34) and according to Gerson (7) are the sequelae of phlebitis nearly always accompanied by arterial incompetence. Wittels & Zuchristian (33) observed arterial circulatory disturbances in 50% of post-thrombotic cases. They explained this by the fact that the deep arteries and veins are running together in a common sheath. The phlebitic inflammatory changes might thus be transferred to the arteries.

In the present study a normal toe pulse curve was obtained in 20.6%. Presumably this excludes any significant disease of the larger arteries (29, 31). A sclerotic toe pulse was obtained in 50.6% and was only observed in the age group beyond 50 years. The results indicate that the organic changes of the larger arteries are related to the process of ageing. However, since venous leg ulcers most frequently occur in older people the influence of arterio-sclerotic processes of the larger arteries cannot be entirely disregarded. The ankle region is particularly poorly supplied by arteries (25) and an arterial disease in addition to venous insufficiency may accordingly have serious consequences. A factor of importance in this context is the involvement of the terminal dermal vessels in the arteriosclerotic processes. These are added to the post-thrombotic sequelae in which the cutaneous arterioles and venules are particularly affected (2, 4).

By definition the pulsations recorded by reflex photoplethysmography are due to variations in the amount of blood in the skin, i.e. indirectly to the blood supply (5, 20, 30). The pulse curves obtained around the ulcer area varied from one site to another and even at the border of the same ulcer normal and sclerotic pulses could be recorded. The sclerotic pulses were observed at the ulcer border irrespective of normal or abnormal toe pulses. These findings indicate that the changes in the curves are a result of the tissue changes in the areas examined and not of changes of the larger vessels. This interpretation is supported by the fact that sclerotic ankle pulses were more frequent in legs with ulceration.

The variations in shape and amplitude of the pulsations suggest that areas with poor skin circulation alternate with areas more abundantly supplied. In the former the skin pulses are smaller and more sclerotic, indicating organic tissular changes. These observations are compatible with the histological findings as in some areas oedema and fibrosis may replace the vessels, causing rather poor vascularization, whereas in other areas a rich vascularization may be found with new vessel formation and thickened capillaries and arterioles (6, 13).

Normal skin pulses were recorded from the ulcer border in 15/46 legs. This suggests that ulceration may occur without obvious organic vascular changes. The results obtained by measurement of the ankle pulse index indicate that the cutaneous blood supply of the ulcer area is not seriously interfered with since the average values were higher than those obtained in non-stimulated ankle areas of normal subjects. However, one must bear in mind that for all pulsations obtained in diseased areas, the pulse amplitude may not be proportional to the blood flow (5).

As evidenced by the photoelectric pulse recordings there is a zone of vasodilatation and decreased vascular reactivity around the ulcer. This is probably due to organic changes and metabolities produced by the ulcerative process. The observation accords with the data given by Gilje (8) who found a refractory reaction to histamine in this area. The altered pulse curves recorded at some distance from the ulcer (Fig. 3) may have several explanations. In chronic venous insufficiency the cutaneous veins are engorged. This will influence the angiologic or venous part of the pulse curve, i.e. the descending branch, and induce a slow descent and less marked rebound (20, 24). Short circuiting of blood through arteriovenous anastomoses as observed in venous insufficiency (14, 19, 21, 22), may reduce the pulsations (5, 11, 24).

Arterial and venous spasm both occur in post-thrombotic states (16, 21) and according to Malméjac (15) constriction of the veins may increase the venous pressure up to 40 mmHg. According to Reinharez (21) the arterial constriction develops secondary to venous stasis as an attempt from the organism to reduce the latter.

In this investigation spastic and sclerotic toe pulses were observed in 119/150 legs, i.e. 79.3%. These values are somewhat higher than those obtained by Konzelmann & Storck (12). This may be due to different methods applied as the latter authors do not mention any particular vasodilatory test. The spastic pulses observed accord with the findings of Olivier et al. (19). There is reason to believe that the vasoconstrictive tendency affects the whole leg (19). This explains the pulse waves illustrated in Fig. 3 *c* which are similar to those observed during vasoconstriction of the dermal vessels (28).

The small and sclerotic pulse curves obtained in areas with atrophic blanche and dermatosclerosis indicate that the microcirculation is markedly affected. In one case the pulsations were entirely lacking suggesting a reduced vascularization. This may be explained by the histologic findings, since the dermal vessels in these lesions may more or less be replaced by sclerotic tissue (9, 13, 23).

Direct measurements of venous pulsations by means of puncture of the veins in post-thrombotic states have recently been described by Schoop (26). There seems to be no reason to doubt that the pulses are actually caused by changes of the venous blood flow induced by the rhythmic action of the heart. In the present study, the pulse configuration was frequently very similar to that of the arterial pulse wave with a distinct rebound and a rapid ascending and slowly descending branch. This indicates that the pulses are not retrograde in origin but probably intravascularily transmitted from the arteries. This is further supported by the fact that they increased when venous stasis was applied.

From the present investigations it may be concluded that piezoelectric and photoelectric pulse plethysmography provide a better understanding of the pathophysiology underlying the clinical symptoms in chronic venous insufficiency. Although the measurements are only qualitative the data obtained indicate that except for some particular skin areas, the cutaneous, arterial blood supply is not significantly reduced in venous leg ulcers.

REFERENCES

1. Bjordal, R.: Simultaneous pressure and flow recordings in varicose veins of the lower extremity. Acta Chir Scand (Stockholm) *136:* 309, 1970.
2. Bossi, P. G., Cartia, A. & Peirone, F.: In tema di malattia varicosa degli arti inferiori. Minerva Derm *41:* 445, 1966.
3. Bystryn, J. C.: Comments. *In* Yearbook of Dermatology (ed. A. W. Kopf & R. Andrade), p. 293. Year Book Med. Publ., Chicago, 1970.
4. Chomette, G., Monsaingeon, A., Yaker, A., Pineaudeau, Y., Auriol, M. & Brocherion, C.: Importance des lésions veineuses dans la décompensation des artérites séniles des membres inférieurs. Étude anatomique et angéiographique de 23 pièces d'amputation. Presse Méd *76:* 2267, 1968.
5. Elings, H. S.: Plethysmografie met behulp van gereflekteerd licht. Dissert. Groningen, 1959.
6. Gans, O. & Steigleder, G. K.: Histologie der Hautkrankheiten II, p. 163. Springer-Verlag, Göttingen, 1957.
7. Gerson, L.: The treatment of varicose veins. Angiology *13:* 260, 1962.
8. Gilje, O.: Ulcus cruris in venous circulatory disturbances. Acta Dermatovener (Stockholm) *29,* Suppl. 22: 94, 1949.
9. Gray, H. R., Graham, J. H., Johnsen, W. & Burgoon, C. F.: Atrophie blanche, periodic painful ulcers of lower extremities. Arch Derm (Chicago) *93:* 187, 1966.
10. Hæger, K.: Venous and Lymphatic Disorders of the Leg, p. 89. Bokförlaget Universitet och Skola, Lund, 1966.
11. Kappert, A.: Klinische Plethysmographie. Cardiologica *24:* 353, 1954.
12. Konzelmann, M. & Storck, H.: Photoplethysmographie und Oscillographie bei Hautveränderungen der Extremitäten. Hautarzt *16:* 109, 1965.
13. Leu, H. J. & Schnyder, U. W.: Epitheliale und kutanvaskuläre Veränderungen beim postthrombotischen Ulkus, ihre prognostische Aussage und ihre Bedeutung für die Therapie. Med Welt *18:* 1024, 1967.
14. Lofferer, O., Mostbeck, A. und Partsch, H.: Arteriovenöse Kurzschlüsse der Extremitäten. Nuclear-medizinische Untersuchungen des postthrombotischen Unterschenkelgeschwürs. Zbl Phlebol *8:* 2, 1969.
15. Malméjac, J.: Régulations vasomotrices locales. Phlebologie *18:* 327, 1965.
16. Merlen, J.-F.: Physiopathologie du syndrome postphlebitique. Phlebologie *15:* 2, 1962.
17. Merlen, J.-F., Chevat, H. & Cachera, J. P.: Acrocyanose et capillaro-plethysmogramme. Phlebologie *7:* 9, 1954.
18. Mune, O.: Clinical Plethysmography of the Forefoot in Arteriosclerosis Obliterans. Munksgaard, Copenhagen, 1967.
19. Olivier, Cl., Ducros, R. & Scheublé, Cl.: Étude du retentissement capillaire dans les séquelles phlebitiques par la pléthysmographie électronique. Ann Chir (Par) *20:* 1136, 1966.
20. de Pater, L., van den Berg, J. & Bruno, A.: A very sensitive photoplethysmograph using scattered light and a photoconductive resistance. Acta Physiol Pharmacol Neerl *10:* 378, 1962.
21. Reinharez, D.: Incidences des maladies veineuses sur la dynamique artérielle. Phlebologie *18:* 319, 1965.

22. Ryan, T. J.: The epidermis and its blood supply in venous disorders of the leg. Trans St John's Hosp Derm Soc *55:* 51, 1969.
23. Santler, R.: Atrophie blanche. XIII Congr. Internat. Derm., p. 469, München, 1967.
24. Scheublé, Cl.: Étude de la circulation capillaire par la pléthysmographie électronique. Presse Méd *74:* 2265, 1966.
25. Schneider, W. & Fischer, H.: Die chronisch-venöse Insufficiens, pp. 28, 31, 104. Ferdinand Enke Verlag, Stuttgart, 1969.
26. Schoop, W.: Variations pulsatiles de la pression dans les veines des extrémités. Angéiologie *21:* 239, 1969.
27. Thune, P.: Plethysmographic recordings of skin pulses with particular reference to the piezoelectric method. I. Preliminary report. Acta Dermatovener (Stockholm) *50:* 27, 1970.
28. — Plethysmographic recordings of skin pulses. IV. The vasoconstrictive effect of steroids in normal and stripped skin. Acta Dermatovener (Stockholm) *51:* 261, 1971.
29. Völker, R.: Herz- und Gefässerkrankungen, p. 4. Dr. Dietrich Steinkopf Verlag, Darmstadt, 1957.
30. Weinman, J. *In* Manual of Psychophysiological Methods (ed. P. H. Venables & I. Martin), p. 191. North-Holland Publ. Co. Amsterdam, 1967.
31. Wengi, G.: Photoplethysmographische Untersuchungen an Patienten mit Ulcus cruris. Inaug. Diss. Zürich, 1963.
32. Wiedmann, A.: Die arterielle Genese des Ulcus cruris "Varicosum". Hautarzt *5:* 85, 1954.
33. Wittels, W. & Zuchristian, G.: Verlauf und Prognose des postthrombotische Syndroms. Med Welt *18:* 648, 1967.
34. Zannini, G., Conti, A. & Negro, G.: Rapports entre phlebopathies et artériopathies. Angéiologie *15:* 23, 1963.

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