VENOUS PATHOPHYSIOLOGY SHORT REVIEW

Contribution of strain gauge plethysmography and photoplethysmography to the quantification of the hemodynamic disturbance in varicose vein disease

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Abstract The significance of strain gauge plethysmography and photoplethysmography in the diagnostics of hemodynamic disturbance in primary varicose veins is discussed. Both methods have the ability to measure volume changes induced by calf pump activity and to quantify the pre-treatment hemodynamic disorders, the immediate post-treatment hemodynamic improvement, as well as the post-treatment deterioration occurring during the follow up. The most frequently used parameters are refill times t-90 and t-50; they yield precise and reliable results. For this reason, plethysmography is a rational supplement to duplex ultrasonography in the diagnostic investigation of varicose vein disease.

Keywords strain gauge plethysmography; photoplethysmography; varicose veins; venous reflux; hemodynamic disorders.

Introduction

Plethysmographic methods detect blood volume changes that occur in the lower legs during calf pump activity. They are able to quantify the degree of hemodynamic disorders, the hemodynamic amelioration after therapeutic procedures, and the progressive deterioration occurring during the follow up.

There are principally three types of venous plethysmography; strain gauge plethysmography (SGP), photoplethysmography (PPG), and air plethysmography (APG). This article deals with the contribution of SGP and PPG to the quantification of the venous hemodynamic disorders caused by saphenous reflux in primary varicose veins, as well as with the quantification of the therapeutic results.

Following parameters are measured: refill time t-90, refill time t-50 (SGP, PPG), and refill volume (SGP). During calf pump activity, a part of the venous volume of the calf is pumped out toward the heart. After stopping the calf pump activity, the time necessary to refill the ejected venous volume is registered. The parameters t-50 and t-90 display the time necessary to refill 50% and 90% of the ejected volume. The parameter t-90 is more precise than t-100 because the form of the refilling curve is considerably flattened at its end. The parameter refill volume indicates the venous volume that must be refilled after stopping the calf pump activity; it corresponds to ejected volume.

Normal values are: t-90 > 20 s; t-50 > 8 s; refill volume > 0.8 ml/100 ml of tissue.

Because the venous plethysmography provides quantitative information on the status of the venous hemodynamics in the lower extremity, it is an important complementary examination method to duplex ultrasonography (DUS). Both methods complete each other and enable precise exposition of the hemodynamic situation of the lower extremities in varicose vein disease; both should be used during the examination of varicose vein patients.

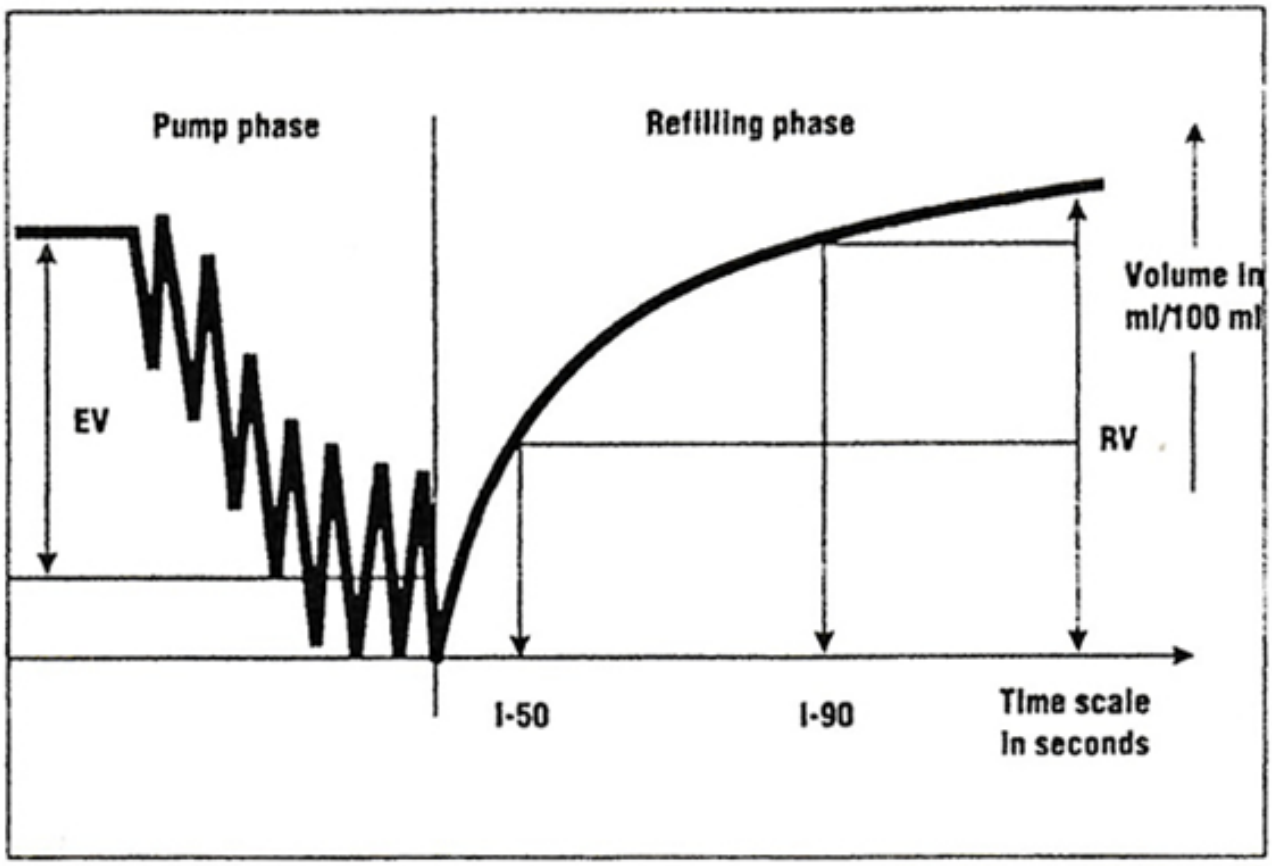

Figure 1 - SGP curve.

Strain gauge plethysmography

The mercury-in-silastic strain gauge is applied around the circumference of the calf; it measures changes in calf volume caused by ejected venous blood and expresses them as refill volume in ml/100 ml of tissue. In addition, it indicates the values of refill time t-90 and t-50 (fig. 1). The measurement is performed in the standing position.

The objective of the study presented by Skeik et al.[1] was to clear whether SGP with and without tourniquet application is able to distinguish between deep and superficial venous incompetence. The study was conducted using SGP on 62 patients/85 limbs. Based on the DUS results, patients were diagnosed with superficial, deep, and mixed superficial and deep incompetence. The authors concluded that application of a tourniquet is a fast and reliable technique that can identify patients with superficial venous incompetence, based on significant improvement of SGP values after tourniquet application. Recek[2] examined 37 limbs with distinct signs of chronic venous insufficiency caused by great saphenous vein reflux and compared SGP parameters with reflux, after elimination of reflux using a pneumatic cuff placed in the thigh, and one week after crossectomy. The values of refill time t-90 and t-50 recorded after preoperative elimination of saphenous reflux and after crossectomy were very similar; the values of refill volume were identical (1.1 ml/100 ml of tissue, fig 2). All three parameters displayed a highly significant difference between preoperative and postoperative values ($p < 0.0001$).

It follows that preoperative elimination of saphenous reflux can confirm that the hemodynamic disorder is really caused by saphenous reflux; in addition, it can predict the postoperative result. Hirai et al.[3] reported that with application of the tourniquet, the refilling times normalized in limbs with primary varicosities. Limbs with strong saphenous reflux showed a higher expelled volume than limbs with uncomplicated varicosities. The calf pump performance can be compensatory increased due to the higher preload (venous congestion). In varicose vein patients, the calf pump must propel toward the heart, in addition to the normal circulating blood volume, the refluxing saphenous volume streaming centrifugally into the deep lower leg veins, which can induce increased calf muscle performance[4].

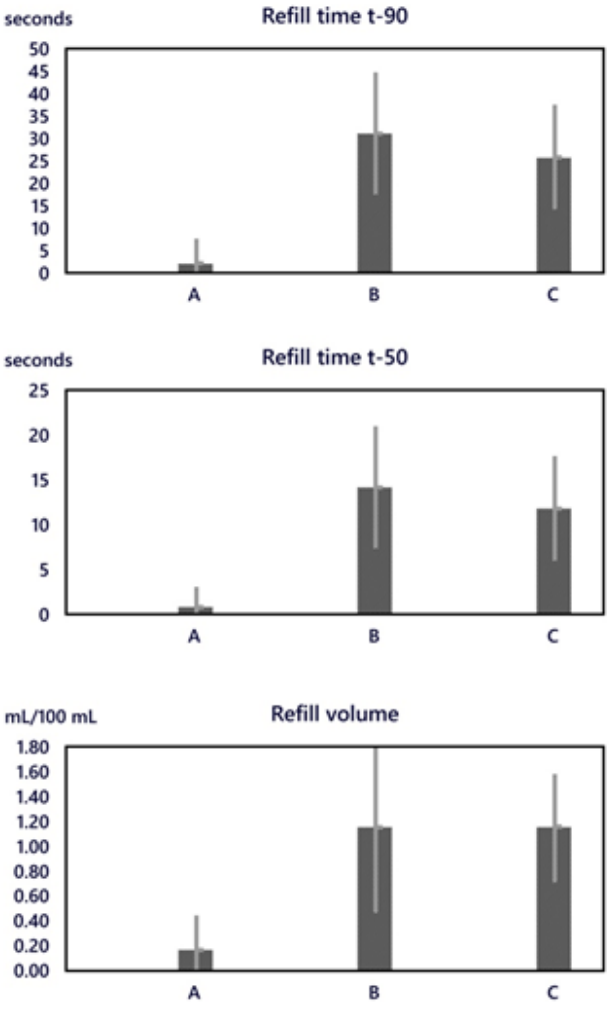

Figure 2 - SGP parameters refill time t-90, t-50, and refill volume in varicose vein patients with severe hemodynamic disturbance (A), after the pre-operative elimination of saphenous reflux using a pneumatic cuff applied in the thigh (B), and one week after crossectomy (C). After the pre-operative elimination of saphenous reflux all parameters returned to normal values. The values of refill times t-90 and t-50 recorded after pre-operative elimination of saphenous reflux and after crossectomy are very similar; the values of refill volume are identical (mean values with standard deviations).

The comparison of the SGP findings with ambulatory venous pressure and the role of SGP in evaluating post-treatment results are discussed in the appropriate paragraphs.

Photoplethysmography

Photoplethysmography (PPG) is a low-cost device that is able to detect blood volume changes in the microvascular bed of tissue using infrared rays. It uses a small probe placed on the skin above the ankle. The probe contains an infrared light-emitting diode and a sensor. The intensity of the reflected infrared light is proportional to the amount of blood in the skin. PPG offers a reproducible technique for evaluating the effectiveness of the calf muscle pump and for quantifying the degree of venous insufficiency. The measurement is performed in the standing or sitting position. The results are displayed as refilling times t-90 and t-50.

Barthelemy et al.[5] performed PPG in 170 limbs with superficial and deep venous incompetence. Applying a tourniquet in the thigh helped to discriminate the two conditions. Sam et al.[6] stated that digital PPG performed in the seated position in patients with isolated superficial venous reflux provides a reproducible method for noninvasive assessment of the lower limb venous function for both clinical and research purposes. According to Fronek[7] the refilling time is the most useful parameter; values higher than 22 seconds are considered normal. Sarin et al.[8] investigated PPG findings in 152 patients with suspected lower limb venous disease. The parameters investigated were the refilling time t-95 and t-50 and the initial gradient of the refilling curve. The authors found that the 95% refilling time of less than 15 seconds indicated venous dysfunction with the greatest sensitivity and specificity. PPG readings correlated well with the presence of clinical disease.

Comparison of ambulatory venous pressure measurements and plethysmographic findings

Rooke et al.[9] compared results obtained by SGP and venous pressure measurements. Exercise-induced changes in the volume of the calf as well as refill times correlated well with simultaneously determined changes in venous pressure. The type of performed exercise had little effect on results. With the tourniquet placed in the thigh it can be differentiated between superficial and deep venous incompetence. Nicolaides and Miles[10] examined forty-two patients (62 limbs) with venous problems using simultaneous recordings of ambulatory venous pressure and PPG during tiptoe exercise.

A linear relationship was found between the PPG refill time and venous pressure refill time, both in the standing and sitting positions ($r = 0.88$). Abramowitz et al.[11] performed simultaneous venous pressure and PPG measurements in the sitting position. The data displayed a correlation coefficient of great significance ($r = 0.898$). Post exercise recovery times clearly separated the normal from the postphlebitic limbs.

The authors concluded that PPG evaluation provides information comparable to venous pressure studies. In a similar study, Norris et al.[12] correlated ambulatory venous pressure with PPG refill time and found a close correlation between them ($r = 0.98$, $p < 0.001$).

Post-treatment results and follow up studies

Struckmann[13] presented a prospective study displaying improvement of the hemodynamic situation after radical surgery performed in 21 varicose veins patients. SGP was investigated before and 3 and 60 months after surgery. Expelled volume increased postoperatively by 58% ($p < 0.001$); the improvement was still present 60 months after surgery. Darvall et al.[14] presented the results of 246 patients (317 limbs) after ultrasound guided foam sclerotherapy for symptomatic superficial venous reflux. The refill time improved from 11 to 31 seconds ($p < 0.0005$) six months after the procedure. Abnormal refill time (<20 s) correlated well with the presence of saphenous reflux on DUS (sensitivity 75%, specificity 94%). Before treatment, there was a significant relationship between reduced refill time and increased CEAP clinical grade ($p < 0.0005$). Neto et al.[15] reported on results of 29 patients treated with ultrasound-guided foam sclerotherapy. Venous filling time was measured using PPG before and 45, 180, and 360 days after the procedure. The results showed statistically significant improvement in venous filling time. Recek[16] presented a prospective study of 70 patients undergoing crossectomy and postoperative sclerotherapy. In 40 of them, SGP was performed and reassessed one week and 1, 2, and 4 years after surgery. Before treatment, SGP detected severe hemodynamic disturbance in all patient. One week after crossectomy, all measured parameters (refill times t-90 and t-50, refill volume) returned to normal values. During the 4-years follow up, SGP parameters showed a progressive decline. Nevertheless, the hemodynamic situation remained markedly improved 4 years after surgery; all three parameters showed highly significant improvement in comparison to preoperative values (refill time t-90, refill volume: $p < 0.0005$; refill time t-50: $p < 0.001$). Konschake et al.[17] performed endoluminal catheter-based steam vein sclerosis on 167 veins (124 great saphenous veins, 43 small saphenous veins). The patients were investigated using PPG before, six weeks and one year after the intervention. The refill time increased significantly 6 weeks after treatment ($p < 0.0001$); it displayed similar values one year after treatment. The improvement of patients' symptoms correlated well with the improvement of the venous function assessed using PPG.

Nevertheless, elimination of saphenous reflux has a dark side: it inevitably creates preconditions for the development of recurrent reflux, which restores and progressively worsens the hemodynamic disorder in the post-treatment period. Although the intensity of the restored hemodynamic disorder is individually variable, the progressive deterioration is a general event. This phenomenon has been called *hemodynamic paradox*[18]. Elimination of saphenous reflux starts the same trouble while fixing the problem.

Plethysmography is a useful supplement to DUS examination

DUS is excellent in measuring blood flow conditions; it provides diagnostic information on the presence and anatomic distribution of reflux but does not permit an overall quantification of the hemodynamic situation. Plethysmographic measurement has the advantage of enabling quantitative evaluation of the venous hemodynamics; therefore, it is a rational supplement to DUS. Both methods complement each other and enable very precise exposition of the hemodynamic situation of the lower extremities in varicose vein patients. Both of them should be used for the examination of varicose vein disease, as well as for checking the immediate post-treatment improvement and the progressive deterioration of the hemodynamic situation, which occurs due to recurrent reflux.

Basbug et al.[19] included 432 patients with symptomatic chronic venous insufficiency into the study. All participants underwent DUS examination. SPG was performed to evaluate the calf pump function and to assess the degree of the hemodynamic disturbance. SGP measurements, including venous volume, venous emptying, expelled volume ratio in four seconds, half refilling time t-50 and refilling volume of each lower extremity were done. The authors concluded that SGP is highly reliable procedure for quantitative functional assessment of patients with chronic venous insufficiency. In the study by Nelzen et al.[20] SGP was used in combination with DUS in the pre- and postoperative assessment. Radiofrequency ablation and high ligation and stripping were performed in 62 patients (65 limbs) and 58 patients (65 limbs), respectively. SGP measured refilling time after knee bends. The results of SGP, DUS and quality of life were assessed before and one month after treatment. Refilling time increased significantly after both radiofrequency ablation and high ligation and stripping ($p < 0.001$). In another study the same authors[21] performed DUS and SGP examinations in 164 limbs with superficial vein incompetence. SGP refilling times were closely related with DUS volume flow and with clinical severity.

Measurement of saphenous reflux intensity in ml/s using DUS may be contributory. Nevertheless, it must be taken into account that the actual degree of the hemodynamic disorder is the result of interaction of two forces/factors acting against each other: the calf pump performance and the intensity of venous reflux. Calf pump performance determines the amount of the ejected venous volume; reflux refills the ejected volume. That means that the same intensity of saphenous reflux can produce different severity of hemodynamic disorders. The deleterious effect of saphenous reflux can be mitigated by increased calf pump performance[4], and, on the other

hand, accentuated by reduced calf pump performance, e.g. in patients with stiffness of the ankle joint (arthrogenic congestion syndrome). The specific field of action of plethysmography is even the evaluation and quantification of the resulting severity of the hemodynamic disturbance.

Conclusion

SGP measures volume changes in the calf occurring during calf pump activity and express them as refill volume in ml/100 ml of tissue. In addition, it indicates the time necessary to refill the expelled volume and expresses it as t-50 and t-90, i.e. the time necessary to refill 50% and 90% of the refill volume. PPG is a low-cost device able to detect blood volume changes in the microvascular bed of tissue using infrared rays; the most frequently used parameters are t-90 and t-50. Both plethysmographic methods are able to quantify the degree of the hemodynamic disturbance, to evaluate the efficiency of the calf muscle pump, to assess the immediate therapeutic result and the hemodynamic effect of recurrent reflux during follow up. Suppressing the saphenous reflux with a tourniquet is a reliable means suitable for distinguishing superficial from deep venous incompetence. Plethysmography should be used as a rational supplement to DUS during examination of patients with primary varicose veins.

Expression of thanks

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