A Hydrostatic Pressure Stocking for the Treatment of Ulcers due to Chronic Venous Insufficiency

By J. Edwin Wood, M.D.

Chronic venous insufficiency may be complicated by ulceration of the skin of the involved extremity. The ulcers appear to be caused by the prolonged elevation of venous pressure in the leg and the resultant edema. A device is described that counterbalances exactly the elevated pressure in the veins of the leg, regardless of the position of the patient. This hydrostatic pressure stocking prevents formation of edema without interfering with the flow of blood through the tissues. The use of this device in the treatment of ulcers due to chronic venous insufficiency is also described.

CHRONIC venous insufficiency is a relatively common syndrome that is caused by sustained elevation of the pressure in the veins of the dependent lower extremity. This high mean venous pressure results from inadequate closure of the valves in the veins during exercise of the muscles of the leg, especially if some of the venous channels are obstructed due to previous thrombophlebitis. The high venous pressure is associated with an abnormally high capillary pressure, which is responsible in turn for the formation of edema in the tissues of the extremity.

The skin overlying these edematous areas may break down either following a minor injury or without apparent cause. Subsequently these small breaks in the skin tend to become large superficial ulcers. The question then arises as to whether the edema per se causes these ulcers by direct mechanical destruction of tissue or by separation of living cells from their immediate blood supply. Alternatively, the primary cause of the ulceration may be infarction of the skin due to diminished flow of blood. A decrease in the flow of blood would presumably occur in the absence of proper functioning of the venous valves, which allow a contracting skeletal muscle to propel blood out of the veins of the leg. A further momentary reduction of blood flow and an increase in tissue pressure as well might occur with the sudden rise of venous pressure caused by coughing or the Valsalva maneuver.

Ulcers due to venous insufficiency will eventually heal with prolonged continuous bed rest and elevation of the involved extremity. The essential effect of this therapy appears to be one of marked lowering of venous pressure in the legs and consequent dissipation of the edema. Such results suggest that a patient might avoid hospitalization if it were possible to prevent the formation of edema by maintaining very low local transmural venous and capillary pressures by adequate but not excessive external compression of the extremity. Excessive external compression would reduce transmural arterial pressure without a further reduction of transmural venous pressure, thus diminishing the arterial-to-venous pressure gradient and reducing the volume of blood flowing through the tissues. Therefore, the pressure to be counterbalanced within the veins of the leg would be equal to that of a vertical column of blood (or for practical purposes, water) between any given point on the leg and the level of the right atrium, regardless of the position of the patient. It is the purpose of this communication to describe a device that has been designed to produce counter-pressure upon the extremity in just this manner. The use of this device in the treatment of ulcers due to chronic venous insufficiency is also described.
Methods

The primary component of the device* for compressing the leg was a knee-length, toeless stocking made of Nylon-cotton cloth. This stocking could be opened anteriorly with a zipper. It was fitted with laces along the lateral side to allow adjustment of its size. The size could also be adjusted across the dorsum of the foot. A watertight bladder was incorporated into the medial surface of the stocking. This bladder extended from the knee to a point just below the medial malleolus, and from the midline anteriorly to the midline posteriorly of the leg. A second smaller bladder was attached to the bladder in the stocking with 2 flexible rubber tubes 3 feet in length. There was an opening in the smaller bladder which was used to fill the entire system with 750 ml of water. After the air was removed from the system this opening was closed. There were no valves in the system and the water could flow through the tubes from one bladder to the other. A strap was attached to the smaller bladder so that it could be suspended beneath the axilla (fig. 1).

Pressures were measured beneath the hydrostatic pressure stocking from a 3-by-1.5 cm, flat, water-filled, plastic capsule that had been placed between the skin and the stocking. This capsule was attached to a rigid plastic tube leading to a Statham P23D strain gage. Records were obtained with a Sanborn direct-writing oscillograph. Pressures were measured with the subject in the recumbent, sitting, and standing positions. Twelve points were used for these measurements in 3 subjects. These points were at the top, middle, and lower aspects of the leg anteriorly, posteriorly, laterally, and medially. The data are reported in terms of the difference between the observed and the predicted pressures. Pressures were predicted on the basis of the vertical distance between the capsule and the level of the center of the bladder in the axilla.

The hydrostatic pressure stocking was used as a sole means of therapy for 10 ambulatory patients with leg ulcers due to chronic venous insufficiency. The ulcer was covered with a sterile dressing held in place with gauze and adhesive tape. A knee-length elastic stocking was worn over this dressing, then the hydrostatic pressure stocking was placed on the leg and the smaller bladder was strapped beneath the axilla. The patient was instructed to wear the hydrostatic pressure stocking from the time that he got up in the morning until he retired at night. Some of the female patients wore an opaque cotton stocking over the hydrostatic pressure stocking while others preferred to wear slacks. Male patients wore an ordinary sock over the hydrostatic pressure stocking. Since the tubes that connected the 2 bladders were small and flexible, the patient could conveniently wear the entire device beneath his clothing. Special shoes were not required. The dressings were changed only as often as was necessitated by exudation from the ulcer surface.

Results

Ten patients with chronic venous insufficiency associated with large ulcers of the skin of the leg were treated with the hydrostatic pressure stocking. All of the patients were urged to follow their usual daily routines.

Healing of the ulcers occurred in all of the patients. The rapidity with which the healing took place seemed to depend primarily upon the original size of the ulcer. The hydrostatic pressure stocking did not appear to shorten or lengthen the period of time

required for healing of the ulcers compared with the period of time which might have been required for healing had the patient been hospitalized. Seven of the patients had had thrombophlebitis while the remaining 3 were apparently suffering from ulcers due exclusively to varicose veins. Initially, the ulcers were 3 to 8 cm. in diameter. The time required for complete epithelialization of the ulcer surfaces varied from 2 to 5 weeks. Four of the patients had experienced considerable pain in the region of the ulcer during dependency of their legs. The hydrostatic pressure stocking relieved this pain completely. In all cases, the gross edema was dissipated within 3 to 5 days after initiation of the therapy. The patients found the stocking to be more bulky and noticeable than an ordinary elastic stocking. They grew used to it after several days, however, and said that it did not interfere with their activities in any way.

The device was worn by a school instructor virtually continuously for a period of 2 years without interruption of his teaching duties. His difficulties were initiated by severe thrombophlebitis in the deep and superficial veins of the leg. After this, but prior to use of the hydrostatic pressure stocking, he had been hospitalized at yearly intervals for 6- to 8-week periods over a span of 6 years, because of repeated and extensive ulcer formation. All of the indicated surgical procedures to the venous system of his legs had been performed 3 or more years prior to initial use of the hydrostatic pressure stocking. During the subsequent 2 years when he wore the stocking it was not necessary to hospitalize him. Two ulcers on one leg healed completely with this form of therapy. Following this it was necessary for him to be without the device on 2 occasions for 3-week periods and in each instance an ulcer appeared but healed again upon resumption of therapy.

A second patient continued to work as a cook in a restaurant while wearing the hydrostatic pressure stocking. His job required that he stand for most of the day. An ulcer 3.5 cm. in diameter, due apparently to varicose veins, healed during 4 weeks of treatment with the stocking. Then he stopped wearing the stocking and elected to defer surgical therapy of his varicose veins. When a second ulcer 0.5 cm. in diameter occurred 11 months later, he was hospitalized for ligation and stripping of his varicose veins.

A third patient was an obese, elderly woman who worked in a nursing home. She had had a deep ulcer 7 cm. in diameter on the anterior surface of her leg for a period of over 5 years. The ulcer was due to varicosities and previous thrombophlebitis. It had been treated with various forms of compression but to no avail. She had never been hospitalized however. The ulcer healed completely during a period of 5 weeks’ treatment with the hydrostatic pressure stocking. This patient had extremely large legs as a result of the obesity and edema. It was possible to adjust the stocking to fit her leg without special tailoring.

The remaining patients in the series had had ulcers of the lower extremity for relatively short periods of time. Their course of treatment with the hydrostatic stocking was uneventful. It was of interest to observe that secondary infection of the ulcers, even when severe, cleared promptly with this form of therapy. As noted above, antibiotic or other local applications were not used.

All of the patients studied had subcutaneous fibrosis, which was evident after dissipation of the edema. The extent of this fibrosis varied but it was marked in 4 of the patients. As with other forms of therapy for these ulcers, extensive subcutaneous fibrosis seemed to be associated with a slower rate of healing of the skin.

All of the patients apparently followed instructions faithfully as to the use of the hydrostatic pressure stocking.

Pressures beneath the hydrostatic pressure stocking relative to those predicted from the level of the bladder in the axilla, averaged $+1.2$ (range $-5.8$ to $+6.4$) cm. of water meas-
ured at 12 points beneath the stocking in the recumbent, sitting, and standing positions. The results obtained from 2 points beneath the stocking, in 2 positions are illustrated (fig. 2). The pressures were attained in 15 to 30 seconds with each change of position of the subject.

The durability of the stocking was outstanding in that the first patient referred to above demonstrated that it could be worn daily for at least a year without developing serious defects. Since numerous modifications of the stocking were made from the time he first began its use, he did not wear any single stocking for longer than 1 year. Three of the stockings have been filled with water for 2½ years and have shown no evidence of leaking.

**DISCUSSION**

Patients with large ulcers of the leg caused by chronic venous insufficiency often have to be hospitalized before healing can be achieved. These ulcers apparently occur as a result of the high venous pressures in the leg associated with the erect posture. The high pressure is not lowered significantly by walking, especially if the chronic venous insufficiency has resulted from previous thrombophlebitis.⁸-⁷ Presently available methods for treatment of such patients on an ambulatory basis involve the application of some form of compression that imparts essentially a constant pressure to the ulcer. Occasionally, such methods of treatment are quite effective, but in general the results are unpredictable. The reason for this variation undoubtedly lies in the difficulty of selecting or applying a single pressure to the extremity that would be reasonably effective in all situations. For example, the external pressure needed to counterbalance the venous pressure that occurs at the level of the ankle of a patient 6-feet tall in the standing position would be approximately 130 cm. of water. Ordinary elastic compression imparts about 25 cm. of water pressure to the tissues. If a pneumatic cuff¹² were used to produce the needed counterpressure of 130 cm. of water (96 mm. Hg), the patient would experience a significant decrease in blood flow to the foot when he assumed the sitting or supine position. This factor would be especially important if the patient were also suffering from arterial insufficiency. The presence of arterial insufficiency should lead the physician to use any form of external compression cautiously. However, a pressurizing device that adjusts itself to counterbalance exactly the venous pressure of the leg is the safest of the available methods for use in this circumstance. This form of compression reduces the effective local arterial pressure to the same extent that it reduces the effective local venous pressure, so that the effective gradient of pressure from artery to vein would not be altered. If the pressure used on the leg greatly exceeded that needed to counterbalance local venous pressure, then it would result in a further decrease in effective local arterial pressure without a further decrease in effective local venous pressure so that the arterial-to-venous gradient of pressure would be reduced and consequently a reduction of blood flow would occur.¹⁰

It is evident that it would be theoretically advantageous to pressurize the leg of a patient with chronic venous insufficiency and ulceration of the skin from a column of water whose height is governed by the position of the patient. It was possible to incorporate a hydrostatically pressurized bladder into a stocking that could be worn for long periods of time without serious inconvenience to the patient. In fact several patients continued to be employed in full-time occupations during treatment with this hydrostatic pressure...
HYDROSTATIC PRESSURE STOCKING

stocking. All of the patients treated with this device had complete healing of the ulcers. In some no further surgical procedures were indicated while others entered the hospital for definitive corrective surgery to the veins as soon as the ulcers were healed.

The pressures actually reflected onto the surface of the leg by the hydrostatic pressure stocking were, with minor variations, those that were predicted for the position of the patient. Venographic studies of the lower extremity have shown that external local compression of the leg results in a narrowing of deep as well as superficial veins. Direct measurements of tissue pressure and studies of changes of venous volume with external compression have also indicated that the pressure is transmitted to the deep as well as the superficial tissues.

The results of the studies here reported suggest that edema per se plays a decisive role in the perpetuation of the ulcers of chronic venous insufficiency. The primary effect of the hydrostatic pressure stocking would seem to be one of maintaining a low transmural pressure within the veins and capillaries of the leg with a resultant diminution of edema formation. It is at least theoretically possible, however, that blood flow was improved with use of this device. The lower effective venous pressure and the associated lower venous volume might have allowed the leaflets of the small number of venous valves to come into apposition, so that the normal "venous heart" mechanism operated to some extent to remove blood from the exercising calf. Finally, the brief rises of venous pressure that occur with coughing or with the Valsalva maneuver might have been partially counterbalanced by the hydrostatic pressure stocking.

SUMMARY

A device is described that reflects counter-pressure onto the surface of the leg in such a way that the pressure is equivalent to that of a vertical column of water between any point on the leg and the level of the right atrium regardless of the position of the patient. This device, the hydrostatic pressure stocking, could be conveniently worn by patients.

Ten patients with ulcer of the skin of the leg due to chronic venous insufficiency used the hydrostatic pressure stocking as a sole means of therapy while pursuing their usual daily activities. All of the ulcers healed completely with this treatment. The rate of healing was as rapid as might have been expected with complete bedrest and elevation of the extremity.

The hydrostatic pressure stocking does not obviate the necessity of indicated surgery to the local venous system. This device may serve as a useful adjunct to surgery in that an ulcer can be healed prior to entrance into the hospital, thus reducing the chances of subsequent wound infections. The hydrostatic pressure stocking appears to be of special value to patients who have chronic venous insufficiency with repeated formation of ulcers, when all forms of surgical therapy have been exhausted.

The results of these studies suggest that the primary value of the hydrostatic pressure stocking in the treatment of ulcers of chronic venous insufficiency is prevention of the formation of edema. Improved blood flow and counterbalancing of sudden rises of local venous pressure with coughing cannot be ruled out as additional beneficial effects however.

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SUMMARIO IN INTERLINGUA

Es describite un dispositivo que reflecte un contrapression contra le superficie del gamba in un tal maniera que su effecto es le equi-\lante del effecto pressori de un column de aqua inter non importa qual puncto super le gamba e le nivello del atrio dextere, sin reguardo al postura occupate per le patiente. Iste dispositivo, le calcea de pression hydrostatic, pote esser portate per le patiente sin inconveniente.

Dece patientes con ulceres cutaneae al gam- ba causate per chronic insufficiencia venose usava le calcea de pression hydrostatic como
le exclusive mesura therapeutic durante que illes esesua ingagiare in lor usual activitates quotidian. Sub iste tractamento omme le ulcers se sanava complemente. Le rapiditate del sanation esesua lo que on haberea expectate sub le conditiones de allettamento complete con elevation del extremitate.

Le caldea de pression hydrostatic non elimina le necessitate de chirurgia local in le sistema venose quando un tal es indicate. Illo pote esser usate como adjuncto benefic al chirurgia, in tanto que un ulcer poe esser sanate ante le hospitalisation del paciente de manera que le risco de subsequente infectiones del vulner es reduite. Il pare que le caldea de pression hydrostatic es de valor special in le caso de patientes con chronic insufficientia venose in qui ilha repetite formation de ulcer e in qui omne formas de therapia chirurgic ha essite exhaustione.

Le resultatos de iste studios suggere que le prime valor del caldeo de pression hydrostatic in le tractamento de ulceres causate per chronic insufficientia venose es le prevention de omne formation de edema. Tamen, un melioration del fluxo de sanguine e le equalisation de subite augmentos de local pression venose quando le patiente tussi non pote esser negate como benefic effectos additional.

REFERENCES

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J. EDWIN WOOD

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