

Sequential Pneumatic Compression for Lymphedema

A Controlled Trial

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• We examined prospectively the effect of a new compression device for lymphedema, which utilizes a short duration and high-pressure cycle, that provides a sequential milking pattern to the limb through multiple compartments. Twenty-five patients (seven patients for upper-extremity and 18 for lower-extremity problems) underwent 24 hours of treatment. All extremities showed a decrease in circumferential measurements with the maximal reduction occurring at the wrist (45%) for the upper extremities and at the mid-calf (47%) for the lower extremities. Lower-extremity leg volume was reduced by 45%. Despite the high pressures no elevation in serum muscle enzyme levels was noted. This device reduced lymphedematous limbs rapidly and safely.

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Secondary lymphedema is the most common form of lymphedema and usually presents as a sequela to oncologic surgery. Primary lymphedema is less frequently encountered by the surgeon and is related to a developmental abnormality in the lymphatic system. Both forms of lymphedema lead to an insufficient number of lymphatic vessels and nodes for fluid transport. The resultant accumulation of lymphedema fluid in the subcutaneous tissue and skin leads to a cosmetically displeasing enlargement of the extremity, but limb heaviness and a predilection for recurrent infections also limit the life-style of the patient with lymphedema. The chief surgical method of treating lymphedema consists of removing the subcutaneous fat (reduction operation) with or without burying a dermal flap within the muscle to encourage superficial to deep lymphatic anastomoses. The results of this procedure, however, have never been examined in a prospective and objective manner. In a retrospective review Chilvers and Kinmonth¹ showed that only 30% of patients had good results, generally those with the most massive edema; moreover, many patients may regress to preoperative girth measurements three to four years following the original reduction surgery.

Finally, the surgical morbidity associated with major skin necrosis (23%) may result in both prolonged hospitalization and time lost from work.

Most physicians, therefore, have chosen to treat lymphedema by nonsurgical measures, ie, maintenance of skin nutrition, eradication of bacterial and fungal infection, and compression therapy to reduce the size of the limb. Other studies²⁻⁴ have shown that intermittent external pneumatic compression (EPC) reduces both limb girth and volume. There is, however, a 30% to 40% incidence of limbs that are resistant to EPC therapy and the thigh and arm (shoulder to elbow), in particular, appear refractory to reduction of girth. There are three important variables in controlling the response of lymphedema to EPC treatment: (1) absolute pressure, (2) compression cycle, and (3) the sequence and distribution of compression. Most units employed presently in the United States are unicompartamental, ie, they compress the entire segment under the inflated sleeve at the same time. Pressure is distributed both centripetally and centrifugally. Zelikovski et al⁵ have developed a method for intermittent, high-pressure, sequential compression. This technique employs a series of overlapping cells or compartments that apply a sequential pattern of compression to the limb, permitting a physiologic milking action of the lymphedematous limb. In addition to the centripetal massaging effect of the multiple cells, the pressures developed during compression are greater than those used in other techniques and range up to 110 mm Hg for the upper extremity and 150 mm Hg for the lower extremity. In preliminary trials Zelikovski and co-workers⁶ have shown encouraging reduction in limb girth. The purpose of the present study is to assess objectively by limb-girth and volume-displacement measurements the effects of intermittent sequential-pneumatic-compression therapy in patients with lymphedema in a controlled environment.

PATIENTS AND METHODS

Patients with primary or secondary lymphedema of the upper or lower extremity were hospitalized for a one- or two-day study period in our National Institutes of Health Clinical Study Unit at New England Medical Center, Boston. Prior to treatment a detailed history was taken with emphasis on the duration of lymphedema, prior surgical procedures, and frequency of infec-

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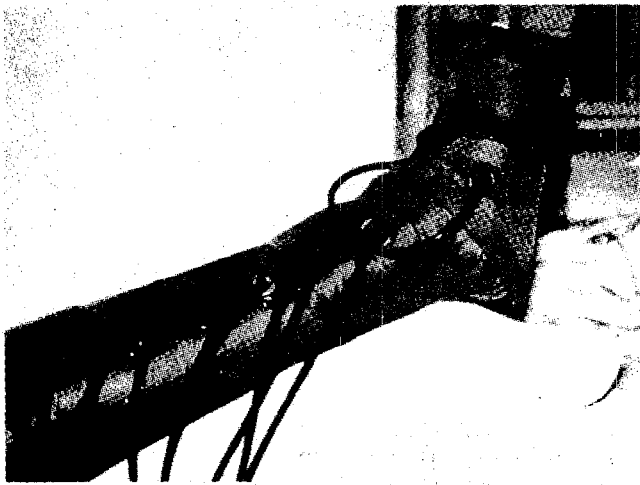


Fig 1.—Lymphedematous lower extremity under treatment with multicompartamental sleeve (Lympha-Press). Each cell is supplied by separate compression hose as shown diagrammatically in Fig 2.

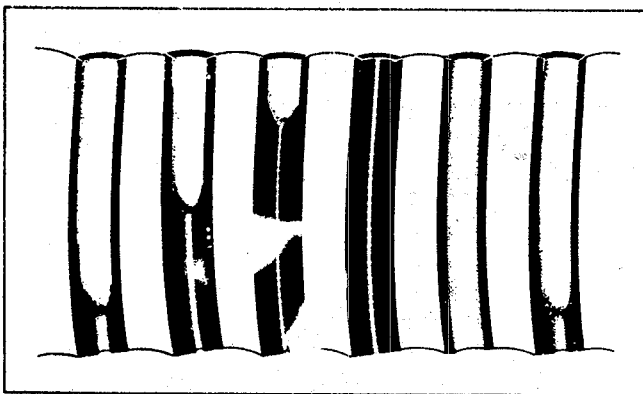


Fig 2.—Schematic representation of sequential pneumatic compression. Each cell is inflated separately to peak pressure adjusted by operator. The sequence of cell filling promotes gentle milking or massaging action in a centripetal direction.

tion. In addition, previous treatment by pressure stocking or sleeve and use of unicompartamental pressure devices were noted. Prior to therapy, limb girth measurements were recorded at the ankle, mid-calf, and thigh for lower extremities and at the wrist, mid-forearm, and mid-arm for upper extremities. Lower-extremity limb volume was measured by volume displacement.² Prior to therapy, 5 mL of venous blood was withdrawn for measurement of serum glutamic-oxaloacetic transaminase (SGOT), creatine phosphokinase (CPK), and aldolase levels.

Treatment

Each patient was confined to bed with the affected extremity elevated. The multicompartamental sleeve (Lympha-Press) was then applied. The sleeve contained nine to 12 overlapping cells that were fitted to the limb according to size (Fig 1). For the lower extremities, an additional one-cell boot was applied to the foot. The cells were inflated progressively, starting from the most distal cell and working proximally (Fig 2). Each cell was powered separately by a compressor via a distributor so that each successive inflation created a milking mechanism.⁶ When the entire sleeve was filled with air, the cells automatically and simultaneously deflated. The

compression period lasted 20 s for the first (distal) cell and only 2 s for the last (most proximal) cell. This short cycle permitted the application of high pressure to the limb (80 to 130 mm Hg) without causing pain. Moreover, the pressure could easily be adjusted by the patient and altered to individual tolerance. Following six to eight hours of compression, the sleeve was removed and the limb allowed to air dry. The sleeve was again reapplied depending on the time required to produce the clinical result desired. Following compression therapy, limb-girth and volume-displacement measurements were repeated for comparison.

Measurements

The percentage of reduction of lymphedema at each point of measurement was calculated by the formula:

$$\frac{(\text{Pretreatment Circumference} - \text{Posttreatment Circumference})}{(\text{Pretreatment Circumference} - \text{Normal Contralateral Circumference})} \times 100$$

Similarly, the percentage of reduction of leg volume was calculated by the formula:

$$\frac{(\text{Pretreatment Leg Volume} - \text{Posttreatment Leg Volume})}{(\text{Pretreatment Leg Volume} - \text{Normal Contralateral Volume})} \times 100$$

At the end of treatment, 5 mL of venous blood was again drawn for measurement of SGOT, CPK, and aldolase levels. Each patient was then fitted for a thigh-length, pressure-gradient elastic stocking (60 to 70 mm Hg) or sleeve and gauntlet (30 to 40 mm Hg). Instructions were given regarding elevation, skin care, and protection against infection. Follow-up data were obtained every three months where possible.

RESULTS

Clinical Characteristics

Twenty-four patients with 25 lymphedematous limbs were studied. Sixteen patients were female and eight patients were male. The type of lymphedema in the 18 lower extremities was evenly divided (nine extremities each) between primary and secondary cases. In the nine patients with secondary lower-limb lymphedema, radiation and radical inguinal lymph-node dissection for malignant disease preceded symptoms in seven instances (six patients). The cause of secondary lymphedema was multiple infections in one patient and unknown in another. Among the seven patients with upper-extremity lymphedema, six cases followed radical mastectomy with or without postoperative radiotherapy and one resulted from multiple infections. Recurrent infection was a prominent problem in four patients with lower-extremity and three patients with upper-extremity lymphedema. Low-dose, prophylactic, antibiotic therapy prevented infection in all but one of those patients with recurrent infections. This patient had undergone a contralateral above-knee amputation for uncontrollable infection at another institution.

Prior therapy of lymphedema consisted of elastic compression in 15 of 18 lower extremities and two of seven upper extremities. Unicompartamental EPC was employed in eight of 18 lower extremities and in one of the seven upper extremities. Surgical reduction (Charles procedure) had been performed in one patient with lower-extremity lymphedema. The majority of patients who used unicompartmen-

Extremity	Measurement, cm (Mean ± SEM)		
	Wrist	Mid-Forearm	Mid-Arm
Upper (n=7)	2.0±0.7	6.7±1.5	5.4±1.3
Lower (n=18)	Ankle 10.2±2.9	Mid-Calf 12.1±2.9	Mid-Thigh 6.7±1.4

*Measurements of upper and lower extremities based on limb girth measurements; lower extremity based on volume displacement (see text for formulas).

tal EPC devices did so infrequently. They felt their limb reduction had plateaued and were disappointed with the poor subjective results and excessive time required to obtain some reduction of limb girth. Patients with lower-extremity lymphedema were symptomatic for a mean duration of approximately 13 years while those with upper-extremity lymphedema were symptomatic for a mean of 3.5 years.

Pretreatment Measurements

Table 1 demonstrates that the greatest excess of lymphedematous tissue, as determined by abnormal girth minus normal contralateral limb girth, occurred at the level of the mid-forearm for the upper extremity; this value was approximately 1 cm greater than the girth measurement of the arm. In the lower extremity both ankle and calf girths were markedly increased and averaged nearly 1½ times the thigh-girth measurement. The hand had the least amount of excess lymphedematous tissue.

Effect of Sequential Pneumatic Compression

Tables 2 and 3 demonstrate the effect of sequential-pneumatic-compression therapy on both absolute (Table 2) and relative (Table 3) reductions in limb-girth measurements. For the seven upper extremities the greatest absolute reduction in limb girth was observed at the forearm and arm levels. For the lower extremities the absolute reduction in foot and calf girth averaged 8 cm, a value four times that of the thigh level. It is not surprising that a greater absolute reduction in lymphedema occurred in the lower extremity because the normal leg is composed of a greater amount of subcutaneous tissue than the arm and because the 18 legs in the study had the greatest amount of excess lymphedematous tissue before treatment. Although the foot and calf levels showed the greatest absolute reduction in circumference, their relative (percent) reduction in limb girth was comparable to the thigh level (Table 3). The relative reduction in hand girth was approximately twice that of the forearm and arm (Table 3).

Lower-Extremity Volume Reduction

The lower-extremity volume as measured by water displacement was reduced by approximately 45%.

Serum Enzyme Levels

There was no biochemical evidence of muscle damage because CPK, aldolase, and SGOT levels were within normal limits both before and after compression therapy.

Extremity	Limb-Girth Measurements, cm*		
	Wrist	Mid-Forearm	Mid-Arm
Upper (n=7)	0.9±0.2	1.9±0.3	1.4±0.3
Lower (n=18)	Ankle 8.4±1.5	Mid-Calf 8.1±1.4	Mid-Thigh 1.5±0.3

*Mean ± SEM.

Extremity	Limb-Girth Measurements, %*		
	Wrist	Mid-Forearm	Mid-Arm
Upper (n=7)	45±14	28±7	25±13
Lower (n=18)	Ankle 37±6	Mid-Calf 47±5	Mid-Thigh 36±7

*Mean ± SEM.

Clinical Follow-up

Repeated measurements were obtained three to six months after treatment in four of seven patients with upper-extremity lymphedema. All four patients retained 50% or more of their postcompression-therapy reduction in limb girth, but these patients compulsively wore a well-fitted elastic sleeve and gauntlet. Another patient living out of state purchased a sequential compression device and used it three to four times per week for several hours. She reported a marked reduction of lymphedema and has required several changes to smaller compression sleeves since her initial treatment. Two of seven patients living at a distance were not readily available for follow-up. Long-term follow-up data were also obtained on eight of 18 patients treated for lower-extremity lymphedema. Three patients had complete return of pretreatment girths. One patient refused to wear an elastic compression stocking, and the second patient discontinued its use after suffering anginal attacks precipitated by attempting to put on the elastic stocking; the third elderly patient could not apply her stocking because of severe arthritis involving her hands. A fourth patient had a reaccumulation of most of the lymphedema in her lower extremity when she allowed her stocking to wear out without promptly replacing it. The patient was retreated with sequential compression, a new stocking was applied, and she has since maintained her reduction. Four patients maintained greater than 50% reduction of lower-limb-girth measurements three to six months after a single treatment. These patients practiced elevation of the affected leg nightly and wore an elastic compression stocking daily.

COMMENT

Surgical reduction of the lymphedematous limb has had limited success and is reserved, in general, for patients with more extensive, bulky, lymphedematous tissue. Most physicians, therefore, favor the nonsurgical management of

lymphedema.⁷ Fundamental to this form of management is removal of excess lymphatic fluid from the subcutaneous tissue and skin. In addition to the cosmetic benefits of a more normal limb contour and limb girth, symptomatic relief of limb heaviness and reduction of subsequent tissue fibrosis both result from eliminating lymphatic fluid. Compression with external devices promotes flow through existing lymphatics and perhaps increases transcapillary exchange of extravascular protein and water into the intravascular space.² Specially fitted elastic stockings provide a means of applying external pressure to the limb in an upright position. Since these stockings were designed primarily for venous disease, the maximum pressure is applied at the ankle level.⁸ To reduce a lymphedematous leg, ideally the pressure should be applied in small decrements from the foot progressively up to the entire calf and thigh. Although elastic compression garments are an integral part of the therapy for lymphedema, the low compression at the thigh and the limitation of knee movement mitigate against a widespread acceptance of above-knee garments as the only form of treatment for moderate lymphedema.

Van der Molen and Toth⁹ have used a more vigorous method of external elastic compression with a continuous soft-rubber tube (10 mm in diameter) wound around the leg from ankle to knee. They showed that it was possible to remove up to 10 L of lymphedema fluid from one extremity under this high-pressure (500 mm Hg) compression treatment. The high pressure developed by the extubation process is quite painful for most patients and usually requires general anesthesia. In a selected series of patients with lymphedema, it has been shown that intermittent, external pneumatic compression by a device originally developed for the prophylactic treatment of deep venous thrombosis can reduce limb girth.² In that study, tissue compressibility or compliance, as well as the form and peak pressure of the compression cycle, were related to the degree of circumferential reduction. Patients with fibrotic or ligneous tissue, significant of more advanced lymphedema, responded the least to compression. Subsequent use of this device has demonstrated that 30% of patients are not candidates for this form of compression therapy. In addition, it has been observed that the thigh and arm levels respond poorly to this low-pressure, unicompartamental device. Although the device employed in the initial study utilized a short cycle, the peak compression pressure that developed was low (60 mm Hg). Furthermore, the effect of the single-compartment, pneumatic compression technique is to distribute pressure in all directions *distally* as well as proximally. These limitations lead to dissatisfying results in a certain percentage of cases.

Zelikovski and associates⁶ reported dramatic improvements in lymphedematous tissue reduction following the application of a multicompartamental, high-pressure, pneumatic compression device. By use of a high peak pressure (100 to 110 mm Hg), a short cycle, and distal-to-proximal milking action of the multiple cells, large volumes of edema fluid were rapidly mobilized. These preliminary results contrasted with our experience with unicompartamental compression devices that reduced a small amount of lymph-

edematous tissue per unit of time. Our present controlled trial confirms Zelikovski and colleagues' preliminary results. Each limb in our trial, irrespective of the condition of the subcutaneous tissue, showed a reduction in limb girth. Despite the high-pressure compression, patients did not experience cutaneous, neurologic, or muscular complications. Moreover, the effect of compression was achieved rapidly. Although the situation would be highly unusual, sequential-pneumatic-compression therapy should not be used in patients with suspected acute deep venous thrombosis. The danger of proximal embolization from the forces of external compression is a contraindication to application of this device to the limb with deep venous thrombosis.

The ability to maintain the lymphedematous extremity in its reduced state following compression therapy is dependent on the patient's adherence to a compulsive regimen of elevation, skin care, prevention of infection, and elastic hose compression.⁷ Our study has demonstrated that even after one treatment with sequential pneumatic compression, approximately half of the patients will maintain most of the reduction over several months. The benefits from the long-term use of this device, ie, several short, supplemental treatments each week, were demonstrated in one patient who purchased the device shortly after it became commercially available. She maintained the best reduction in limb girth of all study patients. Further experience will clarify the issue of how cost-effective the device is for home use. It is of prime importance, however, to follow patients carefully to reinforce instructions on maintaining compression therapy.

On the basis of our experience, the vast majority of patients with lymphedema can be managed nonsurgically.⁷ We limit reduction surgery to those patients with massively enlarged limbs or with asymmetric lymphedema who cannot be fitted with compression devices and/or elastic stockings. Sequential compression prior to reduction surgery may be beneficial in reducing massive accumulation of tissue fluid.

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