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A Comparison of Compression Pumps in the Treatment of Lymphedema

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ABSTRACT

Purpose: This study was done in order to ascertain which methods of mechanical compression would be optimum in treating patients with primary and secondary lymphedema.

Materials and Methods: Thirty-five patients (26 women, 9 men) were enrolled in the study. The women ranged in age from 36 to 82 years (mean 56.9 years). The men ranged in age from 31 to 83 years (mean 56.4 years). Ultimately, 32 patients completed the study. Each patient was treated by random assignment to each of the three types of compression pumps. The treatment arms were as follows: (1) unicompartmental nongradient pump with pressure of 50 mm Hg, (2) a three-compartment pump with segmental, nongradient pressures of 50 mm Hg in each of three cells, and (3) a multicompartmental gradient pressure pump with ten cells ranging in pressure from 80 at the most distal to 30 at the most proximal. There were 35 extremities treated by each of the three methods. Eleven had primary lymphedema and 24 had secondary lymphedema.

Results: The mean percentage volume change was +0.4% in the limbs treated with the unicompartmental pump, +7.3% in the three-compartment pump, and -32.6% in the ten-compartment pump. By use of Kruskal and Wallis, one-way ANOVA on ranks, a significant difference between the three treatments was detected ($p < 0.001$). In treatment of

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(Abstract continued)
primary lymphedema there was no difference between the subgroups with regard to the effect of the three compression pumps. In treatment of secondary lymphedema, there was no reduction in the size of the limbs treated with the single-compartment, there was a -4.65% reduction in the three-compartment pump treatment, and -28.4% in the ten-compartment pump. There were no differences in treatment of secondary limbs with and without radiation. In an analysis comparing primary to secondary lymphedema with and without radiation, the results were not statistically different from one another. Other factors such as severity of lymphedema, gender, duration of lymphedema, history of infection, and presence of radiation could not be implicated as having prognostic significance or having any effect on response to therapy.

Conclusions: Mechanical external pneumatic compression can produce a reduction in treated limb volumes in primary and secondary lymphedema. This is best achieved by multicompartment sequential compression. Limb volume reduction by single- or three-compartment devices is decidedly less effective in treatment of lymphedema.

Introduction

While the diagnosis of lymphedema is usually not difficult, its management is. This is because the accumulation of protein-rich fluid in the interstitial spaces produces a self-perpetuating increase in tissue fluid. Also, an anatomic or functional obstruction in lymphatics or lymph nodes makes fluid transport difficult.

Fundamentally, the pathologic buildup of fluid and solute in interstitial tissues comes either from an impaired or an overburdened lymphatic drainage system. Whatever the cause, lymphedema is divided into primary lymphedema, in which there is lymphatic hypoplasia or aplasia, and secondary lymphedema, in which there is ablation or obliteration of lymph nodes and trunks.[1] Improvement in lymphedema depends on redistributing extracellular fluid by restoring the balance between formation and absorption of lymph. Management of either form of lymphedema often includes efforts to reduce lymph formation by dietary salt restriction and mobilization of fluid by diuretic drugs, but these methods are rarely successful. The protein content of edema fluid mentioned above produces an osmotic draw that tends to retain salt and water in the interstitium. Therefore, the mainstay of treatment of lymphedema is directed at the difficult task of improving lymph transport. While this can be done by manual massage, external mechanical compression has a certain appeal because it can be managed by self-administration and applied during times that are otherwise unoccupied by physical activity. As a number of mechanical devices are available in the treatment of lymphedema, the following study was done in order to ascertain which method would be optimum in treating patients with both primary and secondary lymphedema.

Patients and Methods

A total of 35 patients (26 women and 9 men) were enrolled in the study. The women ranged in age from 36 to 82 years (mean 56.9 years). The men ranged in age from 31 to 83 years (mean 56.4). Ultimately, 32 patients completed the study. A 37-year-old woman with left arm lymphedema secondary to surgery and radiation encountered a work conflict that prevented her from completing the study. An 83-year-old man with secondary lymphedema due to surgery and radiation had a similar work conflict, and a 45-year-old man with primary lower extremity lymphedema required emergency hospitalization for a medical problem unrelated to the lymphedema.

The degree of lymphedema was graded by use of a simplified classification (Table I). Factors that might have affected the response to the cur-

Table I

Simplified Classification for Lymphedema

Class 1	Little clinical fibrosis, pitting reduces with elevation
Class 2	Former class 1, much clinical fibrosis, nonpitting, does not reduce with elevation
Class 2^+	Massive swelling, skin changes, no skin excrescences or ulcerations

rent treatment, such as duration of lymphedema, history of radiation, presence of prior infection, whether the lymphedema was primary or secondary, and the presence and type of prior therapy, were collected, tabulated, and analyzed for correlation with response to treatment.

Of the total 35 extremities entered into the study, 11 limbs had primary lymphedema with five afflicting the right lower extremity and six afflicting the left lower extremity. There were 24 extremities with secondary lymphedema with 11 afflicting the left arm (nine women), six afflicting the right arm (five women), two affecting the left lower extremity (one woman), and five affecting the right lower extremity (three women). Nineteen of 35 limbs had a prior infection in the limb in the 36 months prior to entry into the study. A total of 14 extremities had lymphedema associated with radiation therapy. There were no patients with primary lymphedema of the upper extremity in this study.

Lymphedema in these patients had been present from 1 to 53 years and had been present an average of 7.3 years for upper extremity lymphedema and 21.7 years for lower extremity lymphedema. Only four limbs had experienced lymphedema for less than 1 year while 12 limbs had lymphedema for 20 years or more.

A total of 28 of the 35 patients (80%) had received some form of therapy in the 36 months prior to the study. Seven of 17 (41%) patients with upper extremity lymphedema had worn compression garments. Ten had used one or another form of pump therapy, seven had used compression bandaging, nine had experienced massage therapy (MLD), and five had received no therapy whatsoever. Of the 18 patients with lower extremity lymphedema, 11 had used compression garments, 11 had used one or another form of pump therapy, eight had used bandaging, and 10 had experienced massage therapy (MLD). Seven patients had not used any therapy in the prior 36 months.

Treatment Arms

Each patient was treated by random assignment to each of three types of compression pumps. The treatment arms were as follows:

1. 7000 Unicompartmental pump: A segmental, nongradient pump with a single-cell pressure of 50 mm Hg
2. 7500 Three-compartmental pump: A segmental, nongradient pump with cell pressures of 50 mm Hg in each of three cells
3. 2100 Multicompartmental graduated pump: A segmental pump with gradient pressure (SCG) in each of 10 cells. The cell pressures (all mm Hg) were cell 1 (most distal), 80; cell 2, 74; cell 3, 69; cell 4, 63; cell 5, 68; cell 6, 52; cell 7, 47; cell 8, 41; cell 9, 36; and cell 10 (most proximal), 30.

Limb Volume Measurement

Treatment was for 2 hours with each pump. Upper and lower extremity limb volume was measured by pretreatment and posttreatment volume displacement. The volumeter was filled to a preset level and the limb was inserted to an inscribed mark. Displaced water flowing into a separate column was measured and a recording was made. Accuracy of each measurement was enhanced by a variable-position foot platform or a hand-hold bar, which insured that the limb could be inserted to the predetermined position for each measurement. The degree of limb size reduction was expressed as a percent decrease in the volume displaced by the affected limb after treatment compared with the displacement by the same limb before treatment. Percentage change in edema was calculated by the formula % change in edema = $(V_f - V_i)/V_i - V_n) \times 100$ where V_i = initial volume, V_f = final volume and V_n = normal limb volume.

Statistical Analysis

The data were analyzed by use of ANOVA and ANOVA on ranks, and all pairwise multiple comparisons were performed with Tukey's test or Dunn's method. A two-tailed t test was utilized for comparison between groups. The α value was set at 0.05. All analyses were performed with SigmaStat statistical software (Jandel Scientific, San Rafael, California).

Results

There were 32 limbs, each of which were treated with the 7000, the 7500, and the 2100 compression pumps. The mean percent volume change was +0.4% in the 7000 arm, +7.3% in the 7500 arm, and -32.6% in the 2100 arm. The 2100 pump had significantly better reduction in limb size than the 7000 or the 7500 ($p > 0.01$). More importantly, the median percent volume change was -2.85% in the 7000 arm, -6.9% in the 7500

Table II

Patients with Primary Lymphedema

				Percent Volume Reduction		
Age	Sex	Limb	Duration of Lymphedema (yr)	7000	7500	2100
31	M	LL	42	0.0	-3.1	-15.5
42	F	RL	31	-2.8	-6.1	-26.9
42	F	LL	26	+12.8	+2.5	-37.5
45	M	LL	20	DNF	DNF	-17.6
49	F	RL	52	0.0	-6.9	-28.3
54	F	LL	37	0.0	-21.6	-56.7
69	F	LL	2	0.0	0.0	-12.7
72	F	RL	44	+4.9	0.0	-23.7
74	M	LL	53	-5.2	-21.6	-58.9
82	F	RL	25	0.0	-2.4	-19.5
82	F	RL	45	0.0	16.3	-45.9

LL = left lower extremity, RL = right lower extremity, DNF = did not finish.

arm, and -28.4% in the 2100 arm. By use of Kruskal Wallis One-Way ANOVA on ranks, a significant difference between the three treatments was detected ($p < 0.001$).

Multiple pairwise comparisons were then performed using Dunn's method. The 2100 arm had significantly better reduction than the 7000 or the 7500 arms ($p < 0.05$). There was no significant difference between the 7000 and the 7500 arms.

Primary Lymphedema

Table II displays the results of the three treatment protocols on limbs with primary lymphedema. There were five limbs with right lower extremity lymphedema and six with left lower extremity lymphedema. There was no difference between these two subgroups with regard to the effect of the three compression pumps. The average age of this cohort was 54.9 years (median age 49.5 years). The average duration of the presence of lymphedema was 8.4 years ±5.9 years. In this group, the average change in limb volume was +0.970% ±4.86 in the 7000 arm, -7.55% ±9.03 in the 7500 arm, and -31.2% ±16.33 in the 2100 arm ($p < 0.05$, 2100 arm versus 7000, 7500 arms).

Secondary Lymphedema

Without Radiation. There were 10 patients with secondary lymphedema who had not received radiation (Table III). Secondary lymphedema was a result of a surgical procedure in each case. The mean age of this group was 54.9 years ±17.5 years and the mean duration of lymphedema was 8.4 years ±7.5 years. The percent reduction of limb volume was +0.83% ±5.895 in the 7000 arm, -7.690% ±7.357 in the 7500 arm, and -32.54% ±15.14 in the 2100 arm ($p < 0.05$, 2100

Table III

Patients with Secondary Lymphedema: Without Radiation

Age	Sex	Limb	Duration of Lymphedema (yr)	Percent Volume Reduction 7000	7500	2100
74	F	LA	27	-8.5	-16.3	-50.1
41	M	LA	6	+6.6	-3.8	-28.3
39	F	LA	6	+8.7	0.0	-47.2
79	M	LA	1	-1.9	-7.1	-19.8
44	F	RA	12	0.0	-4.1	-9.6
55	F	LL	2	-3.3	-19.6	-42.4
73	F	RL	6	0.0	-5.2	-17.9
37	M	RL	13	+8.6	0.0	DNF
71	M	RL	6	+3.4	-3.2	-28.4
36	F	RL	5	-5.3	-17.6	-49.2

LA = left arm, RA = right arm, LL = left lower extremity, RL = right lower extremity.

arm versus 7000, 7500 arms). These results were paralleled when the median scores were analyzed. There was no reduction in the 7000 arm, -4.65% in the 7500 arm, and -28.4% in the 2100 arm ($p < 0.05$).

With Radiation. There were 14 patients with secondary lymphedema who had radiation (mean age 57.0 years ±17.1) (Table IV). The average duration of lymphedema was 6.9 years ±7.22 years. The average reduction of limb volume in the 7000 arm was +1.579% ±5.44, -4.97% ±9.441 in the 7500 arm, and -29.21 % ±12.24 in the 2100 arm ($p < 0.05$ for the 2100 arm versus 7000, 7500 arm). The median reduction in this group was 0 for the 7000 arm, -4.6% in the 7500 arm, and -28.86% in the 2100 arm.

Primary Lymphedema Versus Secondary Lymphedema

The results of treatment of primary and secondary lymphedema with the 2100 multiple-cell graduated pump with and without radiation were analyzed. The mean reduction in limb volume in the primary lymphedema group was 31.2% ±16.33 whereas the reduction in the secondary

Table IV

Patients with Secondary Lymphedema: With Radiation

Age	Sex	Limb	Duration of Lymphedema (yr)	Percent Volume Reduction		
				7000	7500	2100
45	F	LA	2	-4.8	-11.2	-19.4
79	F	LA	21	+1.6	+10.0	-10.0
71	F	LA	1	0.0	-4.3	-29.6
37	F	LA	13	+8.6	0.0	DNF
38	F	LA	2	+7.9	0.0	-32.4
44	F	LA	3	+6.2	+15.2	-26.7
69	F	LA	2	-1.7	-14.5	-46.8
75	F	RA	1	0.0	-15.4	-25.0
74	F	RA	2	-6.3	-11.1	-44.4
83	M	RA	9	-2.1	DNF	DNF
44	F	RA	17	0.0	-4.1	-9.6
55	F	RA	18	+12.7	-10.8	-36.3
47	M	LL	2	0.0	+13.8	-42.3
38	F	RL	4	+3.2	+4.6	-28.1

LA = left arm, RA = right arm, LL = left lower extremity, RL = right lower extremity, DNF = did not finish.

lymphedema group was 30.64% ±13.30 (p = ns). Thus, there was no difference in the effectiveness of compression therapy with regard to primary versus secondary lymphedema.

An analysis was carried out comparing primary to secondary lymphedema with and without radiation. The results were not different. The mean reduction in limb volume in the primary lymphedema group was 31.2% ±16.33 versus 32.54% ±15.14 in the secondary lymphedema group without radiation and 29.21% ±12.24 in the secondary lymphedema group with radiation. There was no statistically significant difference between these groups. The efficacy of the 2100 compression pump treatment was not affected by the etiology of the lymphedema.

Statistical analysis was performed to determine whether the response to therapy was affected by the presence of other factors such as severity of lymphedema (gauged by the simplified classification), gender, duration of lymphedema, history of infection in the limb, or the presence of radiation. With ANOVA, it was determined that none of these variables could be implicated as having prognostic significance or having any effect on response to therapy.

Discussion

It is generally agreed that extrinsic forces are important to the propulsion of lymph.[2,3] Research done as long as 60 years ago established the fact that lymph fluid had a high protein content and that extrinsic movement increased lymph flow.[4] McHale's research on the lymphatic circulation is summarized in his Conway Review Lecture and published in the *Irish Journal of Medical Sciences.*[5] Within this research was proof that intermittent compression at a frequency of 2 seconds on, 2 seconds off dramatically increased lymph flow and that this external compression did indeed enhance fluid propulsion,[6] especially if sufficient fluid was provided so that the lymphatic reservoir was not completely drained.

There has been progression in the use of mechanical devices for reduction of limb volumes. Single-compartment intermittent external pneumatic compression was shown by Raines[7] in the late 1970s to reduce limb circumference. Further experience revealed that approximately 30% of the patients were not candidates for this form of compression therapy, and although no explanation was given, in fact, it was thigh and upper arm levels of lymphedema that responded poorly to the low-pressure unicompartmental device. In time, it became understood that the effect of single-compartment compression was to distribute pressure in all directions. This meant that pressure was distributed distally as well as proximally. This led to the development of the multicompartment, high-pressure pneumatic compression device by Zelikovski.[8] This used a 100 to 110 mm Hg short-cycle, distal-to-proximal milking action of multiple cells.

Pneumatic compression has been criticized by those advocating massage therapy.[9] Among the criticisms is the theory that though the sequential devices do move more lymphatic fluid from the limbs to the trunk, residual protein is left behind. It is theorized that this leads to recurrence of edema and acceleration of "fibrosclerotic hardening of the tissues." Proof of this theory is lacking. In practice, patients treated have not experienced cutaneous, neurologic, or muscular complications in trials using the multicompartment device. With high pressures, favorable results in limb volume reduction were achieved rapidly.[10]

Further criticism of mechanical pumping has cited development of genital edema during such therapy. Explanation for this is found in Kubik's detailed description of the anatomy of the lymphatic system.[11] He shows that ventromedial lymphatic trunks communicate with superomedial lymph nodes of the groin and these, in turn, with genital lymphatics. Relief of such edema can be obtained by physiotherapeutic massage to direct lymph flow into lower truncal lymphatics.

Ultimately, lymphedema treatment must be a lifetime activity. Therefore, patient acceptability becomes a dominant factor. In this group of patients, all 19 who had tried massage therapy for limb volume reduction had abandoned that therapy. Objections were cost, time required in treatment, and unsatisfactory bandaging.

The present study is of value because of the objective measurement of the extremities, each of which was subjected to each method of therapy. The unicompartmental pump was shown to reduce the limb volume very little and, in fact, increased limb volume in a number of patients. Examples are found in the secondary lymphedemas without radiation. The three-compartment pump performed its function to a greater degree of efficiency than the single-compartment pump, but the best reduction in the volume was achieved by the multicompartment pump. This was true even though high pressures were not used to produce the distal-to-proximal milking action.

The spectrum of lymphedema studied and the varying forms of the lymphedema allowed subgroup analyses. This produced the surprising finding that the treatment modalities were equally effective in primary lymphedema and secondary lymphedema. Analyses that compared treatment in primary versus secondary lymphedema with and without radiation produced the also surprising finding that the mean reductions in limb volumes were not statistically different. Clearly, reduction in limb volume produced by the multicompartment pump was not affected by the etiology of the lymphedema.

Conclusion

Mechanical external pneumatic compression can produce a reduction in treated limb volumes in primary and secondary lymphedema. This is best achieved by multicompartment, sequential compression, which produces a distal-to-proximal milking action. Limb volume reduction by single- or three-compartment devices is decidedly less effective in treatment of lymphedema.

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