ORIGINAL ARTICLE

Effects of Supine Intermittent Compression on Arterial Inflow to the Lower Limb

Rhys J. Morris, PhD; John P. Woodcock, OBE, PhD, CPhys, FInstP, FIPEM

Hypothesis: Intermittent pneumatic compression will affect the arterial blood flow in the lower limb at moderate pressure, without requiring dependency.

Design: Before-after trial.

Setting: Vascular ultrasound unit of a university hospital.

Patients: A volunteer sample of 19 healthy subjects without symptoms or history of vascular disease and 17 patients with peripheral arterial disease were studied. Six patients and 1 healthy volunteer were not included in the study group because of measurement difficulties or refusal when approached.

Interventions: Common femoral artery blood flow velocities were measured with Doppler ultrasound during 10 minutes of intermittent compression of the calf and thigh at 60 mm Hg, while the subject was supine. The data were collected every 5 seconds from 4 minutes before to 4 minutes after the therapy period, and toe temperatures were also measured with an infrared radiometer.

Main Outcome Measures: Resting to postcompression percentage increases in flow velocity were measured, along with more representative measures of the total flow change during the intermittent compression period.

Results: On compression, the blood flow velocity decreased slightly (15% in healthy subjects and 6% in patients) and increased on release (21% and 29%, respectively). Overall, blood flow did not decrease during therapy as expected (increases of 1% and 2%, respectively), and the toes of the patients warmed (by 2.2°C).

Conclusions: This work confirms the initial hypothesis in both subject groups. There appears to be physiological justification for investigating intermittent compression as a therapy for patients with intermittent claudication and rest pain in the supine position as well as seated.

Arch Surg. 2002;137:1269-1273

From the Department of Medical Physics and Bioengineering, University of Wales College of Medicine, Cardiff.

INTERMITTENT PNEUMATIC compression of the lower limbs is an accepted method of prophylaxis for deep vein thrombosis[1-4] and lymphedema control.[5-8] The earliest use of the therapy, however, was in treating arterial insufficiency, with apparent improvement in intermittent claudication, rest pain, ulcers, and gangrene.[9-11] Anecdotal clinical evidence was not sufficient to gain the method widespread acceptance in recent times, although more objective observations and results have since been published.[12,13] In recent decades, investigations have also found that intermittent compression of the calf or foot can produce acute increases in arterial inflow to a limb.[14-23] Most research was on foot[15-17,19-23] or calf[18-22] compression, typically at pressures of 100 to 120 mm Hg. Increases in blood flow were measured when the subjects were seated with calves dependent (hanging down, and not outstretched and supported)[14-23]; supine or prone positions were determined to be less effective or ineffective.

If intermittent compression is to be used as a therapy for home use, it must be comfortable to ensure patient compliance, which has been reported as a problem with rapidly inflating, high-pressure foot compression in prophylaxis for deep vein thrombosis.[24] Since lesions associated with peripheral arterial insufficiency also often occur on the feet, we investigated thigh and calf intermittent compression, with moderate inflation times, and a lower pressure (60 mm Hg). Although thigh compression has not proved popular with other investigators in this area, our preliminary investigations have shown that, in combination with calf compression, it has a greater effect on arterial hemodynamics than calf compres-

©2002 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 05/05/2016

sion alone.[25] Thigh-length cuffs are also the standard in many hospitals for prophylaxis for deep vein thrombosis, and because the ischemia occurring in intermittent claudication after exercise will affect all of the limb, it would seem logical to attempt to maximize any effect of intermittent compression by covering with the cuff as much of the muscle as possible.

Dependency has been assumed to be a condition for a compression cuff to increase blood flow effectively, but this might not be practicable for all patients, and with use of a thigh cuff, dependency of the whole limb (rather than seated with only the calves dependent) for long periods would be uncomfortable. By keeping subjects supine, we aimed to test, with Doppler ultrasound, whether any increase in blood flow velocity could be discerned in conditions that previous studies would predict were inadequate but would be applicable to a greater range of potential users.

There are, broadly, 2 different patient groups that might benefit from a passive therapy to increase arterial blood flow. First, there are those with serious arterial disease (ie, rest pain, diabetic ulcers, or gangrenous changes), for whom surgery is inappropriate or has not yielded optimal results. Second, there is the milder group, with intermittent claudication, where surgery would not yet be indicated but whose lifestyle is significantly impaired. We chose this second group for this trial, since poor compliance with exercise therapy has been demonstrated, especially when unsupervised, even though it is generally accepted as beneficial.[26,27] Intermittent compression—a "passive exercise"—can be used at home without supervision, requires no effort by the patient, and is well tolerated; if compliance were to become an issue, recording devices could easily be installed in the pump to monitor use. Only among the second group has intermittent compression *recently* been shown to be clinically effective,[13] and any hemodynamic investigation of a system must acknowledge that it has potential only if clinical improvements can be demonstrated.

METHODS

Nineteen healthy volunteers and 17 patients with peripheral arterial disease were studied. Each of the volunteers (mean age, 34 years; SD, 11 years) had ankle-brachial pressure indexes measured (mean, 1.2; SD, 0.2; minimum, 1.0; maximum, 1.6), and details about general health were collected. The patients were recruited from among the outpatients of the University Hospital of Wales, Cardiff, who were sent for investigations of peripheral arterial disease (mean age, 65 years; SD, 11 years). Informed consent was given by each subject, and the research was approved by the Bro Taf local research ethics committee.

The patients selected for the study were those with symptoms of intermittent claudication, whose routine color flow Doppler ultrasound scans, performed by experienced clinical scientists, showed evidence of significant stenoses, occlusion, or general calcification of the arteries of one or both limbs. Fourteen of the 17 patients had ankle-brachial indexes less than 1.0 (mean for the whole group, 0.7; SD, 0.3; minimum, 0.3; maximum, 1.3), 8 had an occlusion or stenosis of the superficial or common femoral arteries or in the adductor region, and 6 had an occlusion of the external or common iliac arteries. All subjects were male, were nondiabetic, and had no heart conditions or previous arterial grafts. An additional 6 patients and 1 healthy volunteer were approached to take part in the study; 2 patients declined, 1 patient and 1 volunteer were withdrawn because of venous signals disrupting the arterial velocity measurement, and 3 patients were withdrawn with irregular heartbeats, which prevented the equipment from calculating cycle-dependent indexes derived from the velocity measurements.

Subjects rested in a supine position with heads slightly raised on pillows for 10 minutes, and then the temperatures of the big toe and thigh of the limb under investigation were measured with an infrared radiometer. Changes in the temperature of the toes could indicate whether increases or decreases in the inflow to the limb were affecting blood flow in the tissue of the most distal parts.[28-30] When a patient had bilateral disease, the limb with the lowest ankle arterial blood pressure was chosen. The subjects were fitted with thigh and calf cuffs (DVT-30; Huntleigh Healthcare Ltd, Luton, England), and a blanket was placed over the legs to prevent cooling when trousers were removed. A 4-MHz probe of a Doppler frequency spectrum analysis system (QVL-120; SciMed Ltd, Bristol, England) was held over the common femoral artery of the subject (the site determined by the best obtainable signal) while fixed in a block of expanded polystyrene to hold it at a constant angle (so that the measured frequency change would be proportional to volume flow rate, if there was no change in the vessel diameter). The common femoral was chosen as the major supply artery of lower limb, and for the ease of access for scanning in the supine position.

For 18 minutes the time-averaged mean (a continuously calculated moving average of 3 cardiac cycles) of the maximum frequency change was recorded every 5 seconds. After 4 minutes, an air pump was activated for 10 minutes to inflate the cuffs to 60 mm Hg for periods of 10 seconds, with 50 seconds deflated. The skin temperatures were measured again at the conclusion of the test.

Common femoral arterial diameters were additionally measured with a duplex ultrasound system (Powervision 7000; Toshiba Medical Systems Ltd, West Sussex, England) in a subset of 9 of the healthy volunteers before, during, and after compression at 60 mm Hg to determine whether any changes in flow velocity would similarly affect the cross-sectional area of the vessel.

To assess objectively the changes in blood flow, a mathematical index was developed. The fraction of blood flow lost or gained by intermittent compression (the "fractional change") was calculated by creating a theoretical "baseline" flow during the intermittent compression period, ie, the blood flow there would have been had the pump not been operated. A line was extrapolated for the period, the first point being the mean frequency change value for the initial resting period, and the second point, the mean for the final resting period (**Figure 1**). The area under the theoretical baseline (T) was subtracted from the area under the actual curve of each test (A), and the total was divided by T to give the fractional change.

RESULTS

The average response of both groups is displayed in **Figure 2** and **Figure 3**. The data from individual responses were normalized by dividing the values by the mean value of the 2 minutes immediately before the activation of the pump (considered the baseline) and then averaged. The absolute value of frequency changes recorded depended on many factors, including probe position and individual anatomy and physiology; therefore, direct comparisons between subjects were unhelpful. Since frequency changes were proportional to blood flow

©2002 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 05/05/2016

velocity, and no flow disturbances were detected, and since measurements showed that the common femoral artery diameter did not change during inflation and deflation (median diameter during compression, 100% of resting diameter [to nearest 1%]; interquartile range, 99% to 102%; difference [during–resting], $z=-0.09$, $P=.93$ [Wilcoxon, 2-tailed]; median diameter after compression, 99% of resting diameter [to nearest 1%]; interquartile range, 99% to 100%; difference [after–resting], $z=-0.93$, $P=.35$ [Wilcoxon, 2-tailed]), it is reasonable to consider changes in frequency to represent changes in blood volume flow rate.

During compression, particularly in the healthy volunteers, a small reduction in flow was observed, which occurred normally within a single cardiac cycle of the inflation of the cuff. This was associated with a change in the frequency spectrum pulse shape, with the second, reverse-flow phase increasing in magnitude, indicating an increase in peripheral resistance (**Figure 4**A). On release, the flow increased substantially in both groups, and hyperemia persisted for up to 40 seconds (Figure 4B). Apart from a general amplitude increase, this was characterized by the abolition, or diminution, of the second (reverse flow) phase of the pulse velocity profile, characteristic of peripheral vasodilation.

An impression of the magnitude of the changes could be gained by comparing the time-averaged means of the maximum frequency change for each of the 10-second periods immediately before, during, and immediately after compression. Percentage changes compared with a baseline (the 10 seconds before compression) were calculated for each compression for each subject, and then averaged to give a median of –15% during compression (mean, –17%; interquartile range, –25% to –10%) and +21% on deflation (mean, +29%; interquartile range, +17% to +26%) in the healthy volunteers. For the patients with peripheral arterial disease, the equivalent values were –6% (mean, 0%; interquartile range, –9% to +7%) during compression and +29% (mean, +43%; interquartile range, +15% to +54%) after compression. A comparison of those percentage changes during compression showed a significant difference between healthy subjects and patients (Mann-Whitney test, $z=-3.68$, 1-tailed $P<.001$), but much less significance in the difference between the percentage increases on release of compression (Mann-Whitney test, $z=-0.40$, 1-tailed $P=.35$).

The acute changes in flow were obvious; however, it had been assumed previously, after both arterial and venous occlusion, that the succeeding hyperemia would not compensate for the flow "lost" during compression.[31] The median fractional change for the healthy volunteers was +0.01 (mean, +0.03; interquartile range, –0.05 to +0.10), and for patients it was +0.02 (mean, +0.04; interquartile range, 0.00 to +0.07). Both indicated slightly more blood flow than would have been expected had no intermittent compression taken place (ie, +1% and +2%, respectively). The patient figure was higher, although there was no statistically significant difference (Mann-Whitney test, $z=-0.78$, 1-tailed $P=.22$). When only patients with ankle-brachial pressure indexes less than 1.0 were considered, median fractional change was still +0.02 (mean, +0.04; interquartile range, –0.01 to +0.07).

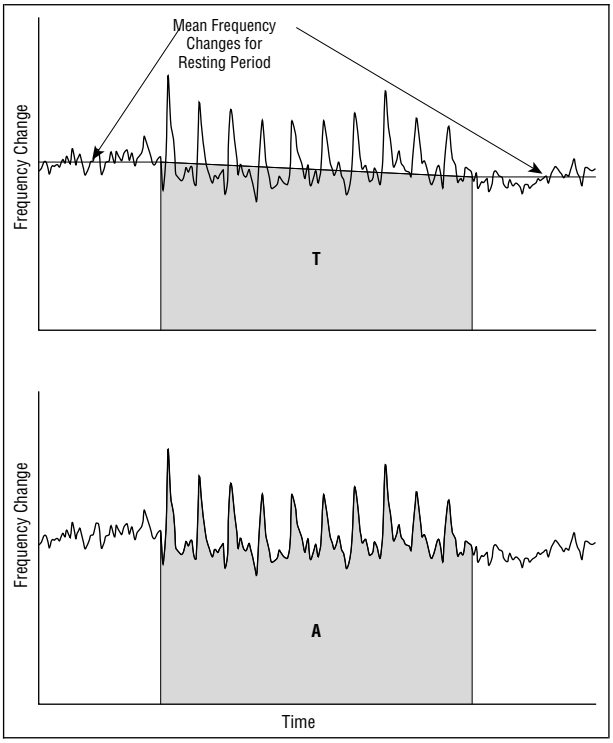

Figure 1. Illustration of the theoretical (T) and actual (A) areas under the curve for the therapy period.

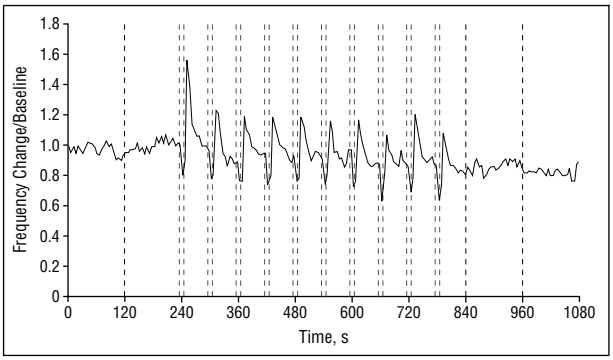

Figure 2. The averaged response in the common femoral artery of 19 healthy volunteers to intermittent compression for 10 minutes. The compression took place between each pair of gray dotted lines.

The median change in toe and thigh skin temperatures for the patients was also higher: volunteer thigh, –1.1°C (mean, –1.0°C; interquartile range, –1.8°C to +0.1°C); volunteer toe, –0.1°C (mean, –0.3°C; interquartile range, –0.9°C to +0.7°C); patient thigh, +0.9°C (mean, +1.0°C; interquartile range, –0.5°C to +1.4°C); and patient toe, +2.2°C (mean, +2.7°C; interquartile range, +0.8°C to +4.2°C); the difference between the patient and normal responses reached the 1% significance level at both sites (Mann-Whitney test; thigh, $z=-3.00$, 2-tailed $P=.003$; toe, $z=-3.57$, 2-tailed $P<.001$). In 7 of the patients, a cuff was placed on the contralateral limb but left uninflated throughout the test, with the same temperature measurements taken. In the toes of the treated limb, the median temperature change was +1.4°C (mean, +1.6°C; interquartile range, +0.2°C to +2.2°C), and in the untreated limb, –0.4°C (mean, –0.6°C; interquartile range, –1.2°C

©2002 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 05/05/2016

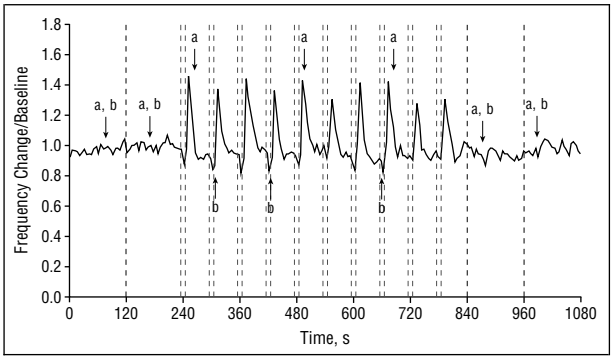

Figure 3. The averaged response in the common femoral artery of 17 patients with intermittent claudication to intermittent compression for 10 minutes. See "Comment" section for explanation of a and b.

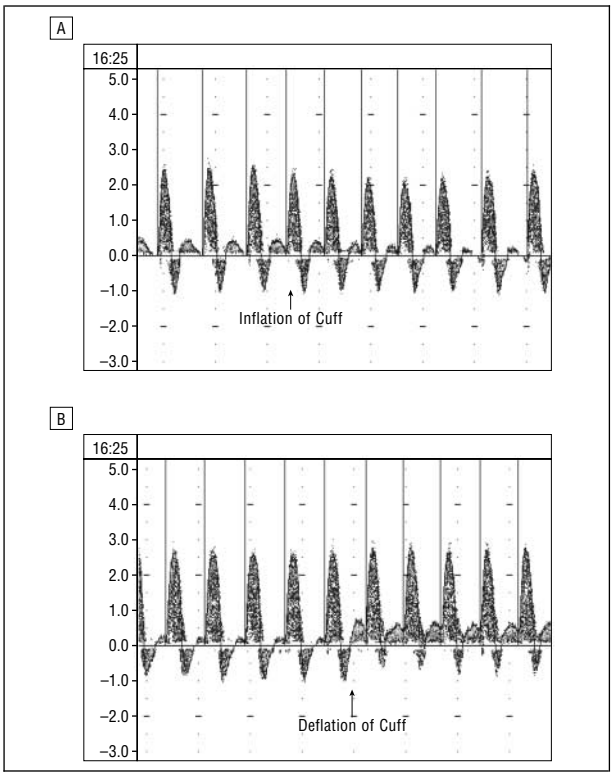

Figure 4. A, Increase of reverse flow on compression at 60 mm Hg from Doppler ultrasound frequency spectrum analyzer output. Frequency change (kilohertz) vs time (seconds), 1 second per dotted vertical line. B, Increase in forward flow after release of compression at 60 mm Hg.

to +0.1°C). The thigh changes were +1.0°C (mean, +1.4°C; interquartile range, +0.5°C to +2.3°C) for the treated limb and −0.6°C (mean, −0.9°C; interquartile range, −1.7°C to −0.1°C) for the untreated limb. The difference in the toe changes (Wilcoxon test, $z=-1.86$, 1-tailed $P=.03$) and thigh changes (Wilcoxon test, $z=-2.20$, 1-tailed $P=.01$) was significant.

COMMENT

Surgical procedures or a percutaneous transluminal angioplasty or stent will remain, for many patients, the best hope of overcoming lower limb arterial insufficiency. However, in patients in whom successful surgery is difficult, because of previous revascularization, graft infections, or unsuitable sites for anastomosis,[18] or those whose disease is not yet advanced enough for surgery, therapeutic methods of increasing the flow to the limb will have a place. A common therapy recommended to such patients is exercise, which is thought to enhance peripheral circulation in addition to improving the biomechanical efficiency of walking.[26] However, while exercise has been shown to be effective, consistent compliance is an issue and many patients, particularly the elderly, are unable to exercise regularly because of social, physical, and environmental conditions

Since as early as the 1930s, intermittent pneumatic compression has been suggested as the solution. The initial idea was that periods of compression of the veins result in the accumulation of metabolic products in tissue, and this would effect an increase in blood flow on release.[9-11] Cycles of increased flow over time would produce improvements in the peripheral circulation and healing of skin lesions. However, at the time, there were no direct noninvasive methods of measuring blood flow, and the method fell out of favor.

The more recent revival of interest in the therapy, using radionuclide and Doppler methods of assessing blood flow, has concentrated on a different possible cause of the flow increase.[14-23] When the lower limbs are dependent, the hydrostatic pressure in the arteries and veins of the feet is high. Compression of the veins will reduce their pressure as they empty and temporarily increase the arteriovenous pressure gradient and, therefore, the volume flow rate. Some have also suggested that liberation of nitric oxide because of flow or pressure changes in veins could cause dilation in arterioles.[16,18-23]

This study demonstrates that, while all recent work has involved dependent limbs, increases in arterial inflow are observed when subjects are supine. The mechanism of the increases in flow recorded in the past cannot then be wholly due to the increased hydrostatic pressure. Peripheral vasodilation is more likely, since the observed changes in the velocity profile were consistent with a reduction in vascular resistance. Even though dependent limbs might produce apparently large increases in flow compared with the baseline on the release of compression, the normal venoarteriolar reflex will reduce that overall baseline blood flow to the limb,[32] so that the "gains" of hyperemia will be negated by the general reduction. While the reflex constriction may be diminished (although not abolished[17]) in patients with arterial disease, a supine therapy could ensure the maximal blood flow to the limb. The necessity for dependency effectively ensures that thigh compression cannot be used, as standing or perching to keep the whole limb dependent would not be comfortable for a long-term therapy. The results of this research could give more options to clinicians to find the most effective and comfortable therapy for a particular patient.

The methods of analyzing the response of blood flow to intermittent compression in this study are different from those in other publications. Previously, samples of the flow velocity, volume flow rate, or laser Doppler flux would be taken over a few cardiac cycles before, during, and after a period of intermittent compression.[17-19,21,23] The mean value during the therapy can then be com-

©2002 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 05/05/2016

pared with the resting value before therapy, yielding a "percentage increase" in flow. However, it has never been made clear in previous investigations *where* in the intermittent compression cycle the samples were taken. If, for instance the samples were taken from the data set that produced Figure 3, and had been taken at the points labeled *a,* a 40% increase in blood flow during intermittent compression could have been reported, giving the false impression that there was 40% more blood flowing in the arteries during that period. Samples could as well have been taken at points labeled *b* and yielded a 10% reduction. The problem is essentially one of aliasing—the sample rate must be at least twice the frequency of the compression cycle to ensure clarity in the results. In the example given, the intermittent compression has a frequency of 10 cycles per 10 minutes, but the sampling is only at a rate of 3 per 10 minutes—it would need to be more than 20. We believe that our method, based on the area under the curve during intermittent compression, gives a true picture that cannot be misunderstood, and that sampling at constant short intervals during the whole period of intermittent compression has allowed the most objective analysis possible.

The flow after compression releases is high (Figures 2 and 3) but decreases soon afterward, and in theory could reach levels below the baseline, leading to no net increase in flow at all during the therapy period. While episodes of high velocity flow may be important to improve collateral circulation, it must be shown that the overall effect of intermittent compression is not to reduce flow, particularly in those whose blood supply is initially compromised. These results show that there is no net reduction in flow; indeed, there is a slight increase with this regimen.

The evidence that the toes of the patients warmed during the procedure suggests that intermittent compression will indeed promote increased flow distal to the site of compression in those in whom the normal flow in insufficient. We therefore conclude that intermittent compression has potential as a therapy for lower limb arterial disease and does not require dependency or rapid inflation to high pressures.

Accepted for publication May 25, 2002.

Dr Morris received financial support during this work for a research fellowship from Huntleigh Technology PLC, Luton, England, which also supplied the intermittent compression garments used in the research.

Corresponding author: Rhys J. Morris, PhD, Department of Medical Physics and Bioengineering, University of Wales College of Medicine, Heath Park, Cardiff, CF14 4XN, Wales (e-mail: morrisrj@cf.ac.uk).

REFERENCES

1. Nicolaides AN, Fernandes é Fernandes J, Pollock AV. Intermittent sequential pneumatic compression of the legs in the prevention of venous stasis and postoperative deep venous thrombosis. *Surgery*. 1980;87:69-76.
2. Hull RD, Raskob GE, Gent M, et al. Effectiveness of intermittent pneumatic leg compression for preventing deep vein thrombosis after total hip replacement. *JAMA*. 1990;263:2313-2317.
3. Woolson ST. Intermittent pneumatic compression prophylaxis for proximal deep venous thrombosis after total hip replacement. *J Bone Joint Surg Am*. 1996;78:1735-1740.
4. Soderdahl DW, Henderson SR, Hansberry KL. A comparison of intermittent pneumatic compression of the calf and whole leg in preventing deep venous thrombosis in urological surgery. *J Urol*. 1997;157:1774-1776.
5. Allenby F, Calnan JS, Pflug JJ. The use of pneumatic compression in the swollen leg. *J Physiol*. 1973;231:65P-66P.
6. Richmand DM, O'Donnell TF Jr, Zelikovski A. Sequential pneumatic compression for lymphedema: a controlled trial. *Arch Surg*. 1985;120:1116-1119.
7. Pappas CJ, O'Donnell TF Jr. Long-term results of compression treatment for lymphedema. *J Vasc Surg*. 1992;16:555-564.
8. Franzeck UK, Spiegel I, Fischer M, Bortzler C, Stahel HU, Bollinger A. Combined physical therapy for lymphedema evaluated by fluorescence microlymphography and lymph capillary pressure measurements. *J Vasc Res*. 1997;34:306-311.
9. Collens WS, Wilensky ND. Intermittent venous occlusion in treatment of peripheral vascular disease. *JAMA*. 1937;109:2125-2130.
10. Brown JJM, Arnott WM. Treatment of obliterative vascular disease by intermittent venous occlusion: further observations. *BMJ*. 1938;1:616-618.
11. Evoy MH, de Takáts G. Place of intermittent venous hyperemia in the treatment of obliterative vascular disease. *Arch Intern Med*. 1948;81:292-300.
12. Dillon RS. Fifteen years of experience in treating 2177 episodes of foot and leg lesions with the Circulator Boot. *Angiology*. 1997;48(suppl):S17-S34.
13. Delis KT, Nicolaides AN, Wolfe JHN, Stansby G. Improving walking ability and ankle brachial pressure indices in symptomatic peripheral vascular disease with intermittent pneumatic foot compression: a prospective controlled study with one-year follow-up. *J Vasc Surg*. 2000;31:650-661.
14. Henry JP, Winsor T. Compensation of arterial insufficiency by augmenting the circulation with intermittent compression of the limbs. *Am Heart J*. 1965;70:79-88.
15. Gaskell P, Parrot JCW. The effect of a mechanical venous pump on the circulation of the feet in the presence of arterial obstruction. *Surg Gynecol Obstet*. 1978;146:583-592.
16. Morgan RH, Carolan G, Psaila JV, Gardner AMN, Fox RH, Woodcock JP. Arterial flow enhancement by impulse compression. *Vasc Surg*. 1991;25:8-15.
17. Abu-Own A, Cheatle T, Scurr JH, Coleridge Smith PD. Effects of intermittent pneumatic compression of the foot on the microcirculatory function in arterial disease. *Eur J Vasc Surg*. 1993;7:488-492.
18. van Bemmelen PS, Mattos MA, Faught WE, et al. Augmentation of blood flow in limbs with occlusive arterial disease by intermittent calf compression. *J Vasc Surg*. 1994;19:1052-1058.
19. Eze AR, Comerota AJ, Cisek PL, et al. Intermittent calf and foot compression increases lower extremity blood flow. *Am J Surg*. 1996;172:130-135.
20. Eze AR, Cisek PL, Holland BS, Comerota AJ Jr, Verramasuneni R, Comerota AJ. The contributions of arterial and venous volumes to increased cutaneous blood flow during leg compression. *Ann Vasc Surg*. 1998;12:182-186.
21. Labropoulos N, Watson WC, Mansour A, Kang SS, Littooy FN, Baker WH. Acute effects of intermittent pneumatic compression on popliteal artery blood flow. *Arch Surg*. 1998;133:1072-1075.
22. van Bemmelen PS, Weiss-Olmanni J, Ricotta JJ. Rapid intermittent compression increases skin circulation in chronically ischemic legs with infra-popliteal arterial occlusion. *Vasa*. 2000;29:47-52.
23. Delis KT, Labropoulos N, Nicolaides AN, Glenville B, Stansby G. Effect of intermittent pneumatic foot compression on popliteal artery haemodynamics. *Eur J Vasc Endovasc Surg*. 2000;19:270-277.
24. Warwick D, Harrison J, Glew D, Mitchelmore A, Peters TJ, Donovan J. Comparison of the use of a foot pump with the use of low-molecular-weight heparin for the prevention of deep-vein thrombosis after total hip replacement: a prospective, randomized trial. *J Bone Joint Surg Am*. 1998;80:1158-1166.
25. Morris RJ. *The Effects of Intermittent Compression on Lower Limb Blood Flow* [PhD thesis]. Cardiff: University of Wales; 2000.
26. Gardner AW, Katzel LI, Sorkin JD, et al. Exercise rehabilitation improves functional outcomes and peripheral circulation in patients with intermittent claudication: a randomized controlled trial. *J Am Geriatr Soc*. 2001;49:755-762.
27. Regensteiner JG, Gardner A, Hiatt WR. Exercise testing and exercise rehabilitation for patients with peripheral arterial disease: status in 1997. *Vasc Med*. 1997;2:147-155.
28. Astrup A, Bulow J, Madsen J. Skin temperature and subcutaneous adipose blood flow in man. *Scand J Clin Lab Invest*. 1980;40:135-138.
29. Baccelli G, Corbellini E, Walsh JT, Busca S, Boccaccini U, Zanchetti A. A noninvasive index of leg arterial perfusion pressure during walking, derived from cutaneous toe temperature. *Angiology*. 1985;36:528-540.
30. Rubinstein EH, Sessler DI. Skin-surface temperature gradients correlate with fingertip blood flow in humans. *Anesthesiology*. 1990;73:541-545.
31. Thompson JE, Vane JR. The effect of venous occlusion on arterial blood flow in the extremities: an experimental study. *Surgery*. 1952;31:55-61.
32. Henriksen O. Local reflex in microcirculation in human subcutaneous tissue. *Acta Physiol Scand*. 1976;97:447-456.

©2002 American Medical Association. All rights reserved.
Downloaded From: http://archsurg.jamanetwork.com/ on 05/05/2016