

Venous haemodynamics after total knee arthroplasty

EVALUATION OF ACTIVE DORSAL TO PLANTAR FLEXION AND SEVERAL MECHANICAL COMPRESSION DEVICES

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We performed a crossover study to evaluate the haemodynamic effect of active dorsal to plantar flexion and seven pneumatic compression devices in ten patients who had a total knee arthroplasty. Using the Acuson 128XP/10 duplex ultrasound unit with a 5MHz linear array probe, we assessed the augmentation of peak venous velocity and venous volume above and below the junction of the greater saphenous and common femoral veins in order to study both the deep and superficial venous systems.

The pneumatic compression devices evaluated included two foot pumps (A-V Impulse System and PlexiPulse Foot), a foot-calf pump (PlexiPulse Foot-Calf), a calf pump (VenaFlow System) and three calf-thigh pumps (SCD System, Flowtron DVT and Jobst Athrombic Pump). The devices differed in a number of ways, including the length and location of the sleeve and bladder, the frequency and duration of activation, the rate of pressure rise, and the maximum pressure achieved. A randomisation table was used to determine the order of the test conditions for each patient.

The enhancement of peak venous velocity occurred primarily in the deep venous system below the level of the saphenofemoral junction. The increases in peak venous velocity were as follows: active dorsal to plantar flexion 175%; foot pumps, A-V Impulse System 29% and PlexiPulse 65%; foot-calf pump, PlexiPulse, 221%; calf pump, VenaFlow, 302% and calf-thigh pumps, Flowtron DVT 87%, SCD System 116% and Jobst Athrombic Pump 263%.

All the devices augmented venous volume, the greatest effect being seen with those incorporating calf compression. The increases in ml/min were found in the deep venous system as follows: foot pumps, A-V Impulse System 9.6 and PlexiPulse Foot 16.7; foot-calf pump, PlexiPulse, 38.1; calf pump, VenaFlow, 26.2; calf-thigh pumps, Flowtron DVT 61.5, SCD System 34.7 and Jobst Athrombic Pump 82.3. Active dorsal to plantar flexion generated 8.5 ml for a single calf contraction.

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A number of studies have demonstrated that mechanical devices designed to reduce venous stasis are effective in decreasing the rate of deep-venous thrombosis (DVT) after total joint arthroplasty.¹⁻³¹ Varying designs are marketed, such as foot pumps, foot-calf pumps, calf pumps, and calf-thigh pumps. These devices differ in the length and location of the sleeve and bladder, the frequency and duration of activation, the rate of pressure rise and the maximum pressure achieved.

The optimal characteristics of these devices are not yet known. They decrease venous stasis or accelerate venous emptying but may also increase fibrinolysis.^{1-18,21-32} The relative contribution of these two mechanisms is unknown. Devices that produce pulsatile pumping, as opposed to a slow rise in venous return, are thought to induce a more significant increase in the peak venous velocity.

Most mechanical compression devices are initially tested on young healthy volunteers and not on postoperative patients in whom they are most likely to be used. Using impedance plethysmography in patients with total hip arthroplasty McNally and Mollan³³ showed that both venous outflow and venous capacitance were decreased with a prolonged return to baseline that could persist for up to six weeks. Our study was designed to assess the haemodynamic effects of active dorsal to plantar flexion (DPF) and seven different mechanical devices in patients after total knee arthroplasty (TKA). We selected a crossover design to define the augmentation in peak venous velocity and venous volume for each patient during each test condition. By studying the haemodynamic effects we aimed to

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Table I. Specifications of the various devices

	Left/Right	Sizes	Chamber	Cycle alternating sides	Inflation pressure (mmHg)	Hold time (s)	Time (s)	Time (s)
Foot-pumps								
A-V Impulse System	Yes	Large/Regular	1	Yes	120 to 160*	20	0.4	2.6*
PlexiPulse (Foot)	Yes	Std	1	Yes	160*	20*	0.7*	2*
Foot-calf pump								
PlexiPulse (Foot-Calf)	Yes	Std	2	Yes	160*	20*	0.7*	2*
Calf pump								
VenaFlow System 30A	No	Std	2	No	52/45	60	0.6	6
Calf-thigh pumps								
Jobst Athrombic Pump	No	Std	4	Yes	50 (calf1) 45 (calf2) 40 (thigh1) 30 (thigh2)	60	0 to 11†	30‡
Flowtron DVT AC500	No	Std	1	Yes	40*	60	3.0	12
SCD System	No	Small Medium Large	3	No	45 (ankle) 40 (calf) 30 (thigh)	72	2.5 (ankle) 3.0 (calf) 5.5 (thigh)	8.5 (ankle) 5.5 (calf) 0 (thigh)

* adjustable

† variable based upon pressure

‡ variable based upon volume (30 maximum)

understand the role of mechanical compression in the prophylaxis of thromboembolic disease.

Patients and Methods

We included in the study ten patients who were about to have a primary unilateral knee arthroplasty for osteoarthritis. Ethical approval and written consent were obtained. Patients with a history of DVT, pulmonary embolism, congestive heart failure, peripheral vascular disease, prior arterial reconstruction, saphenous vein stripping, vasculitis, varicose veins, venous insufficiency, or morbid obesity (over 140% of ideal body-weight) were excluded.

All patients had regional anaesthesia with an epidural anaesthetic infusion consisting of either 0.75% bupivacaine or 2% lidocaine with epinephrine (adrenaline). The epidural catheter remained in place postoperatively for epidural patient-controlled analgesia with Fentanyl and 0.75% bupivacaine. The operations were performed with the patients supine and using a thigh tourniquet. A cemented posterior stabilised (Insall-Burstein II) prosthesis was used.

We recorded age, gender, weight (kg), height (cm), preoperative anaesthesia grade (American Society of Anesthesiology Score), the duration of the operation, estimated intraoperative blood loss, and postoperative wound drainage using a closed drainage system. The patients had a mean age of 68 years (SD 6, range 61 to 80) and a mean weight of 85kg (SD 20, range 63 to 130). The mean operating time was 77 minutes (SD 22, range 50 to 134).

After the operation the patients were monitored by ECG, a radial artery pressure transducer and pulse oximetry. Each patient received one unit of autologous blood and additional appropriate fluid replacement according to the hospital protocol. Vasopressors were discontinued

one hour before beginning the study.

The study commenced when the Bromage score had fallen to zero.³⁴ This measures active movement of the lower limbs with return of sensation. Patients were horizontal on their bed. Postoperative dressings remained in situ but elastic stockings were removed.

The pneumatic compression devices evaluated included two foot pumps, a foot-calf pump, a calf pump, and three calf-thigh devices. The foot pumps studied were the A-V Impulse System (Kendall Company, Mansfield, Massachusetts) and the PlexiPulse (NuTech, San Antonio, Texas). The foot-calf pump was also the PlexiPulse system (NuTech) with a combination foot-calf sleeve. The calf pump studied was the VenaFlow System 30A (Aircast Incorporated, Summit, New Jersey) and the three calf-thigh devices included the SCD Sequential Compression System (Kendall Company), the Flowtron DVT AC500 (Huntleigh Healthcare, Manalapan, New Jersey) and the Jobst Athrombic Pump (Beiersdorf-Jobst Incorporated, Charlotte, North Carolina) (Table I). A computer-generated randomisation table was constructed which included these seven devices, as well as active DPF for a total of eight test conditions for each patient. This table was used to determine the order in which each of the eight conditions was tested on each patient.

We used an Acuson 128XP/10 duplex ultrasound unit, with a 5MHz linear array probe to locate the common femoral vein of the operated limb above and below the junction of the greater saphenous and common femoral veins. The skin was marked with an indelible ink marker. The cross-sectional area (mm²) of the common femoral vein and the baseline venous velocity (m/s) were determined. Three separate baseline measurements of venous velocity and time average velocity were obtained and the

mean values computed. The pneumatic compression device was then placed on the leg. After several pump cycles of compression (minimum five minutes) at the manufacturers' specifications, a wave tracing of venous blood flow consistent with inflation of the pump was recorded on screen and on video tape using pulsed-wave Doppler on the ultrasound unit. Selected images were saved on a magnetic optical disk. Using the proprietary software within the Acuson system, the baseline venous velocity, the peak venous velocity, and the time average velocity (over the duration of the waveform, see Table I) were measured. All observations were recorded for three trials and a mean was computed for each value. In each patient, the cycle of baseline measurements, application of the device and resultant assessment of venous blood flow were repeated for each test condition, as per the randomisation table, until all eight test conditions were obtained.

Great care was taken to ensure that the ultrasound probe was positioned properly for each successive measurement. It was always placed over one of the two locations on the common femoral vein and the angle between the common femoral vein and the Doppler beam (Θ) was always maintained between 45 and 60°. The Doppler sample gate size was matched to the diameter of the common femoral vein. Before each measurement, the position of the gate was verified to ensure uniform insonification (ultrasonic saturation), reproducibility of the placement and lack of venous compression by the probe. An experienced vascular technologist ensured that the probe was not moved during the three examinations.

The application of each pneumatic compression device was undertaken with care and conformed to the manufacturers' specifications and the device pressure, cycle time, inflation time, and hold time were set to the respective manufacturers' recommended settings (Table I).

Initial analysis of the data included a computation of the

percentage increase in peak venous velocity after a compressive pump cycle compared with the baseline venous velocity for each patient with each device according to the formula:

Percentage increase in peak venous velocity
(during a pump cycle)

$$= \frac{(\text{Peak velocity}_{\text{pump}} - \text{Peak velocity}_{\text{Baseline}})}{\text{Peak velocity}_{\text{Baseline}}} \times 100$$

where 'pump' is over a pump cycle and 'baseline' is with the pump inactive.

The mean percentage increase in peak venous velocity, as well as the standard deviation, was then determined for each pneumatic compression device. Data from each device were recorded above and below the junction of the greater saphenous and common femoral veins to compute the relative contribution of venous return through the deep and the superficial venous systems.

The time average velocity and duration of venous augmentation were compared with the baseline values. The product of the cross-sectional area of the common femoral vein and the number of pump cycles per minute produced the total augmented volume per minute. The mean increase in augmented volume per minute, as well as the standard deviation, was then determined for each pneumatic compression device according to the formula:

Augmented volume (ml/min)

$$= (\text{TAV}_{\text{pump}} - \text{TAV}_{\text{Baseline}}) \times \text{Time}_{\text{pump}} \times \text{Area}_{\text{vein}} \times \text{Pump cycles/min}$$

where TAV = line average velocity, 'pump' is over a pump cycle and 'baseline' is with the pump inactive.

We used repeated measures analysis of variance for statistical comparison. Additional models evaluated the order in which the devices were tested as covariates. For all test conditions 95% confidence intervals (CI) with p set at 0.05 were calculated. In the figures, where 95% CIs do not

Table II. Mean (+ SD) peak velocity augmentation above and below the junction of the saphenous and common femoral veins

Device	Increase (%)	95% CI	
		Lower limit	Upper limit
Above the junction			
Dorsal to plantar flexion (DPF)	150 ± 86	88	212
A-V Impulse System	25 ± 25	7	43
PlexiPulse Foot	37 ± 26	18	56
PlexiPulse Foot-calf	120 ± 50	84	156
VenaFlow	255 ± 91	190	320
Flowtron DVT	69 ± 65	23	116
SCD System	88 ± 66	41	135
Jobst Athrombic Pump	177 ± 90	113	241
Below the junction			
Dorsal to plantar flexion (DPF)	175 ± 116	92	258
A-V Impulse System	29 ± 39	1	57
PlexiPulse Foot	65 ± 76	11	9
PlexiPulse Foot-Calf	221 ± 75	167	275
VenaFlow	302 ± 125	213	391
Flowtron DVT	87 ± 69	38	136
SCD System	116 ± 53	78	154
Jobst Athrombic Pump	263 ± 245	88	438

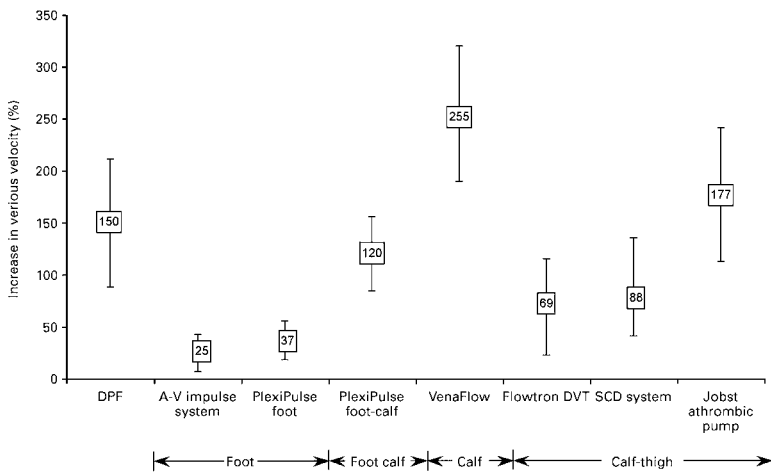


Fig. 1a

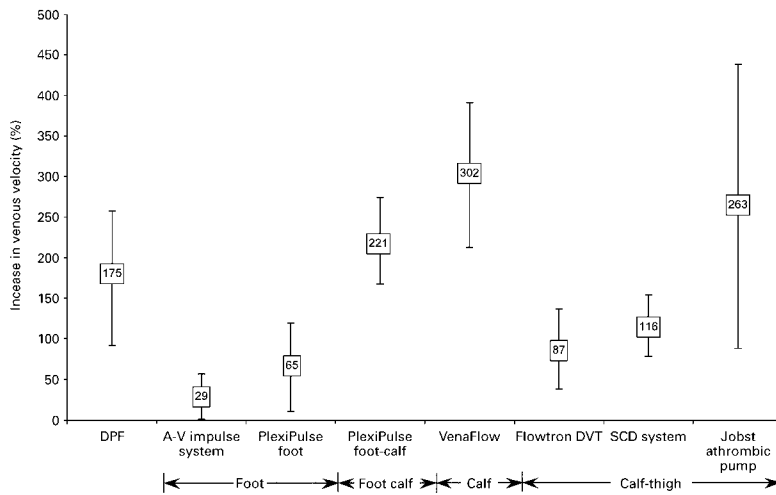


Fig. 1b

Figure 1 – Increase in venous volume a) above and b) below the junction of the greater saphenous and common femoral veins. Where 95% confidence intervals do not overlap, the difference can be assumed to be statistically significant at below the 0.05 level.

overlap, the difference can be assumed to be statistically significant below the 0.05 level.

Results

The mean arterial pressure and heart rate showed no statistically significant differences during the investigation. All patients had adequate analgesia postoperatively, and none developed hypotension during the study. Augmentation of peak venous velocity and venous volume were shown in all the tests. Before activation of the devices, the common femoral vein was checked for acute thrombosis; none was noted.

Peak velocity augmentation. The mean percentage increase in peak venous velocity measured above the junction of the greater saphenous and common femoral veins for each device is shown in Table II and Figure 1a. Active DPF enhanced peak venous velocity by 150%. The peak venous velocity increased with all the devices: with the foot pumps this ranged from 25% to 37% and with the addition of the calf wraps to 120%. The calf-only device showed the greatest

increase at 255% while with the calf-thigh pumps the increase ranged from 69% for the single-chamber device to 177% for the sequential, multi-chamber devices. The order in which the devices were applied did not give a statistically significant difference. Analysis of variance without covariates was statistically significant ($p < 0.0001$).

The mean percentage increase in peak venous velocity measured below the junction of the greater saphenous and common femoral veins for each device is shown in Table II and Figure 1b. Active DPF enhanced peak venous velocity by 175%. Most of the augmentation of venous velocity was noted below the entry of the greater saphenous vein, namely in the deep venous system. The peak venous velocity increased with all the devices: with foot pumps by 29% to 65%, with the foot-calf pump by 221%, with the calf pump by 302%, with single-chamber calf-thigh pumps by 87% and with the multi-chamber devices by 116% to 263%. The order in which the devices were used did not produce a statistically significant difference. Analysis of variance without covariates showed a statistically significant difference ($p < 0.0001$).

Table III. Mean (SD) venous volume augmentation above and below the junction of the saphenous and common femoral veins

Device	Increase (ml/min)	95% CI	
		Lower limit	Upper limit
Above the junction			
Dorsal to plantar flexion* (DPF)	13.1 ± 7.8	7.5	18.7
A-V Impulse System	20.5 ± 20.0	6.2	34.8
PlexiPulse Foot	14.5 ± 8.0	8.8	20.2
PlexiPulse Foot-Calf	45.3 ± 37.5	18.5	72.1
VenaFlow	32.0 ± 15.7	20.8	43.2
Flowtron DVT	49.9 ± 45.2	17.6	82.2
SCD System	44.8 ± 43.3	13.8	75.8
Jobst Athrombic Pump	81.2 ± 51.8	44.1	118.3
Below the junction			
Dorsal to plantar flexion* (DPF)	8.5 ± 5.4	4.6	12.4
A-V Impulse System	9.6 ± 13.5	0.0	19.3
PlexiPulse Foot	16.7 ± 13.6	7.0	26.4
PlexiPulse Foot-Calf	38.1 ± 17.6	25.5	50.7
VenaFlow	26.2 ± 8.7	20.0	32.4
Flowtron DVT	61.5 ± 62.3	16.9	106.1
SCD System	34.7 ± 24.5	17.2	52.2
Jobst Athrombic Pump	82.3 ± 55.4	42.7	121.9

* active dorsal to plantar flexion in ml per contraction

Venous volume augmentation. The mean increase in venous volume (ml/min) measured above the junction of the greater saphenous and common femoral veins for each device is detailed in Table III and Figure 2a. Active DPF enhanced the venous volume by 13.1 ml per contraction. All of the devices increased the venous volume above the patient's baseline volume. With the foot pumps this ranged from 14.5 to 20.5 ml/min, while the addition of the calf wrap increased the augmentation to 45.3 ml/min. The calf pump increased flow by 32 ml/min and with the calf-thigh pumps the increase ranged from 49.9 ml/min for the single-chamber device to between 44.8 and 81.2 ml/min for the multi-chamber devices. The order in which the devices were used did not produce a statistically significant difference. Analysis of variance without covariates showed a statistically significant difference ($p < 0.0001$).

The mean increase in venous volume measured below the junction of the greater saphenous and common femoral veins for each device is detailed in Table III and Figure 2b. Active DPF enhanced venous volume by 8.5 ml per contraction. The venous volume increased with all the devices. For the foot pumps, the increase ranged from 9.6 to 16.7 ml/min, while the calf wrap increased this to 38.1 ml/min. The calf pump gave an increase of 26.2 ml/min, the single-chamber calf-thigh pump of 61.5 ml/min and the multi-chamber pumps of 34.7 to 82.3 ml/min. The order in which the devices were used did not produce a statistically significant difference. Analysis of variance without covariates showed a statistically significant difference ($p < 0.0001$).

Discussion

After TKA, prophylaxis for DVT and subsequent pulmonary embolism is essential.¹⁻⁸⁶ Pharmacological treatment has side-effects and is costly.^{38,39} Low-molecular-weight

heparins have reduced the risk of thromboembolic disease in orthopaedic surgery, but disadvantages of their use include potential haemorrhagic complications, repeated injection and, rarely, the development of thrombocytopenia.^{38,39} Mechanical methods of prophylaxis are safe, inexpensive, and have proven efficacy in many surgical subspecialties.²⁻³¹ The use of pneumatic compression devices has been shown to give some of the lowest rates of DVT.^{2-4,11-15,18,24,28-30,62,68,80}

Studies on cadavers have shown that static venous blood accumulates in valve pockets during immobilisation and is a well-known risk factor for the formation of DVT.^{22,29} In theory, a pneumatic compression device which considerably augments venous velocity would not only increase turbulence behind valve pockets, but also increase endothelial shear stresses which have been shown to produce a reflex vasodilatation. Newer mechanical devices with pulsatile venous pumping have recently been developed but there has been no clinical study which has evaluated the haemodynamic parameters of these devices and compared them with those of their predecessors. Also, since thromboses in the deep venous system are the precursor of subsequent pulmonary embolism,^{11,64,65} pneumatic compression devices should direct their effect to the deep venous system rather than to the superficial veins.

The haemodynamic effects of several types of mechanical device vary in rate, method, and force of compression applied,^{18,72,74,75} while the formation of thromboses may not directly correlate with the changes in venous blood flow resulting from the application of a pneumatic compression device. Mechanical devices have been developed to compress the foot, calf, and thigh, yet the difference in venous enhancement from the location of the compression has not been evaluated. Furthermore, the number of compartments as well as the type of pressure applied (i.e., single or

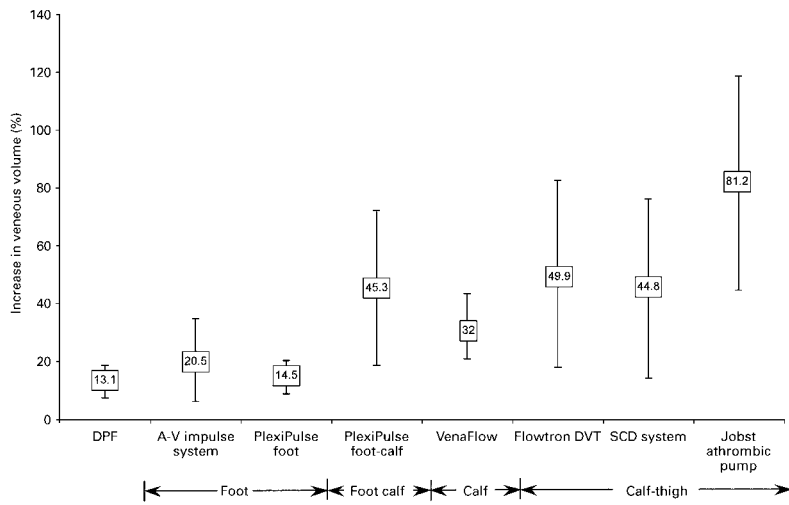


Fig. 2a

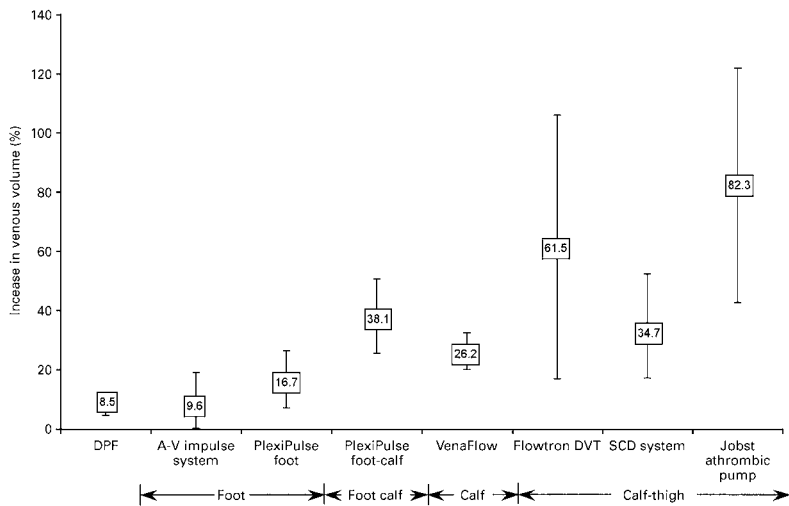


Fig. 2b

Figure 2 – Increase in venous volume a) above and b) below the junction of the greater saphenous and common femoral veins. Where 95% confidence intervals do not overlap, the difference can be assumed to be statistically significant at below the 0.05 level..

sequential wave-like pulsations) also vary, but there are only limited studies on the efficacy of these parameters.^{71,74,75} Nicolaides et al⁷¹ demonstrated an increased venous flow in the common femoral vein with intermittent calf compression and accelerated flow with sequential compression. Roberts et al⁷⁴ established that the rate of inflation was directly proportional to the increase in velocity of blood in the femoral vein, and that devices with a greater rate of inflation produced improved flow augmentation as compared with those with a slower rate of inflation.⁷⁴ Salzman et al⁷⁵ compared a graded-sequential filling device, a uniform multiple compartment device, and a uniform pressure single-chamber device in neurosurgical patients and found a similar incidence of DVT. While they noted that a larger study, with increased statistical power, might show graded sequential filling to be superior, they concluded that the cost-to-benefit ratio of the more complex system might not justify its use.⁷⁵ With the advent of newer pulsatile compression devices, impressive augmentation of venous velocity can be achieved with only a foot-calf or

calf-only mechanical compression device.

The true effect of augmentation of venous volume for the prophylaxis of DVT is unknown. Measurements of peak venous velocity are much more accurate and reproducible than determinations of volume, especially in the venous system.^{50,73} Veins are elastic and distensible, which makes calculations of volume less accurate.^{50,73} In addition, the measurement of turbulent flow, generated by pulsatile pneumatic compression devices, is more difficult and less predictable than that of laminar flow.⁷³ Sources of error in quantitative Doppler measurements of blood flow may occur, and the reduction of these errors depends on the exact assessments of the vessel diameter and time-average velocity.⁷³ This may be difficult in that measurement of blood flow is obtained with a hand-held transducer and alignment of the ultrasonic beam with the longitudinal axis of the vessel is imperative.^{50,73} Also, the exact positioning of the sample volume in the centre of the vessel is difficult to reproduce.⁷³

Pulsatile compression of the calf with a rapid inflation

time produced the greatest increase in peak venous velocity, while compression of the calf and thigh showed the greatest overall increase in venous volume. Since comfort and compliance of the patient and nurses are essential to the clinical success of mechanical prophylaxis, the less cumbersome, yet efficacious devices which still promote use over a long period appear to have a greater likelihood of success.³⁰

Analysis of designs

Active dorsal to plantar flexion. In evaluating DPF, we noted that the patients were able to produce an increase in peak venous velocity of 175% above the baseline. This increase was substantial, but they could not sustain this enhancement of venous return and both the venous velocity and volume augmentation decreased over a few repeated cycles of active DPF.

In the awake and alert patient therefore active repeated pumping of the calf muscles does produce augmentation of venous return similar to that of some of the pneumatic compression devices which we evaluated. During the period after an operation, however, patients would rarely be able to comply with a protocol of sustained, repeated calf pumping. We therefore support the use of pneumatic compression devices which reproduce similar physiological conditions of venous return throughout the postoperative period and when the patients are sleeping. Nevertheless, we would continue to encourage awake and alert patients to perform active DPF.

Pneumatic foot compression. This appears to be effective for the prophylaxis of DVT in total joint arthroplasty.^{2,3,5-9,28,30,77,87,88} After TKA, a reduction in proximal thrombosis from 19% to 0% was shown in a small study of 60 patients by Wilson et al.⁸⁷ Recently, in a series of 162 TKAs, Westrich et al.³⁰ showed an overall incidence of DVT of only 27% with no proximal thrombosis and an incidence of only 9.9% of major calf thrombosis.³⁰

The two foot pumps which we tested were the A-V Impulse System and the PlexiPulse. In the deep venous system, they increased peak venous velocity by 29% and 65%, respectively. With both devices, the augmentation of venous velocity was greater through the deep venous system. Gardner and Fox⁵⁻⁹ had previously observed that the return of venous blood with foot compression empties into the deep venous system from the plantar plexus to the deep or popliteal system and not through the superficial veins.

Pneumatic compression devices which compress the plantar plexus have a broad range of applicability and are not affected by a postoperative dressing or external immobilisation. They can be applied along with a foot or ankle brace or under a cast. Their simplicity and comfort give greater nursing and patient compliance. Unfortunately, they have a small stroke volume of 30 ml, and thus the increase in peak venous velocity in the common femoral vein was considerably less than in devices which pump the calf and the soleal sinus, giving a much greater stroke volume.⁵⁻⁹ Gardner and Fox⁵⁻⁹ observed an increase of 250% in peak

venous velocity in the popliteal vein with pulsatile foot compression. We suggest that this may explain the effectiveness of pneumatic foot compression in preventing DVT. Increasing the popliteal vein velocity causes a reduction in the formation and propagation of calf thrombosis, which may explain the observed clinical efficacy in reducing the rate of thromboembolism.^{5-9,30} The use of these devices appears justified after TKA in which calf thrombosis remains a major problem, and proximal clotting usually occurs from the propagation of a calf thrombus.

Pneumatic foot-calf compression. The only pneumatic foot-calf compression device which we evaluated was the PlexiPulse. This utilised the same pump mechanism as the foot device but with the addition of a calf component to the foot wrap, thus appearing to combine the benefits of foot compression with the advantage of compressing the soleal sinus in the calf. This addition gave a statistically significant increase in peak venous velocity from 37% to 120% above and from 65% to 221% below the sapheno-femoral junction and of venous volume from 14.5 to 45.3 ml/min above and 16.7 to 38.1 ml/min below the sapheno-femoral junction. The device not only produced a significant increase in peak venous velocity, but also provided a substantial enhancement of venous volume. In theory, the combination of velocity and volume enhancement appears to have potential for the prophylaxis of thromboembolic disease in TKA and warrants further clinically-based study.

Pneumatic calf compression. The VenaFlow device is a relatively new system that provides collateral calf compression through two calf-length rigid half shells that contain air bladders. The pump provides an intermittent pulsatile compression once a minute. The manufacturer suggests that collateral compression, as opposed to circumferential compression, gives a greater increase in peak venous velocity and more effective venous emptying (Aircast, personal communication). It is suggested that the rate of inflation has a profound effect on venous velocity, and in this design, rapid inflation is utilised to empty the calf veins.

The VenaFlow produced the greatest increase in peak venous velocity compared with all the other devices and active DPF. The increase in peak venous velocity measured in the common femoral vein below the saphenous inflow was over 300%, more than had been observed with the calf-thigh devices. Since the device only cycles once per minute, the augmentation in volume was not as extensive. The great increase in peak venous velocity indicates that the VenaFlow has great theoretical potential for the prophylaxis of thromboembolic disease and warrants further study.

Pneumatic calf-thigh compression. There are considerable design differences in the three calf-thigh devices which we assessed. While the Flowtron DVT is a single-chamber device, the SCD system has three chambers and the Jobst Athrombic Pump four with sequential compression. Nicolaides et al.⁷¹ demonstrated accelerated flow in the common femoral vein with sequential compression, but

Salzman et al⁷⁵ found a similar incidence of DVT when they compared a graded-sequential filling device, a uniform-pressure multiple-compartment system, and a single-chamber method. Haas et al¹¹ showed a significant reduction in the incidence of DVT using the SCD system (unilateral, 22%; bilateral, 48%) compared with aspirin alone (unilateral, 47%; bilateral, 68%). In our study, the augmentation of peak venous velocity was increased by 87% with the Flowtron DVT single-chamber device, by 116% with the SCD system, and by 263% with the Jobst Athrombic Pump. Augmentation in venous volume was greatest with the Jobst Athrombic Pump. This four-chambered sequential compression device had the second greatest increase in venous velocity and the greatest increase in venous volume.

After operation, nursing and patient compliance is imperative for the efficacy of a pneumatic compression device.^{30,41} In examining the reasons for failure of prophylaxis using external pneumatic compression, Comerota et al⁴¹ showed a rate of compliance of only 33% with the calf-thigh SCD system. The more simple, more comfortable, and less cumbersome a system, the more likely a patient or a nurse will comply with its continued use. While patients are able to walk with the sleeves in place, it is possible that their extensive length leading to heat, perspiration and discomfort may play a role in suboptimal compliance. The Jobst Athrombic Pump has only one size of sleeve, while the Flowtron DVT has two and the SCD System many. The patient's leg must be fitted appropriately in order to obtain maximal benefit, and the hospital must stock the necessary sizes. Based upon the results of our study, we doubt whether the addition of thigh compression is necessary. Pulsatile calf compression appears to be sufficient for augmentation of venous velocity.

Conclusion

After operation, patients have a marked decrease in pulsatile blood flow due to loss of normal physiological muscle contraction in the lower limbs. Active DPF is a normal physiological mechanism that increases venous return and should be the standard to which all pneumatic compression devices are compared. Unfortunately, continuous and forceful active DPF is not possible after operation, and pneumatic compression devices, which are capable of reversing venous stasis, are able to prevent DVT. All of the pneumatic compression devices which we studied augmented both peak venous velocity and venous volume. The greatest effect of these devices was observed below the junction of the greater saphenous vein and the common femoral vein, namely in the deep venous system. Pulsatile calf compression with a rapid inflation time produced the greatest increase in peak venous velocity, while sequential compression of the calf and thigh showed the greatest increase in venous volume.

The newer pulsatile devices such as the PlexiPulse foot-

calf device and the VenaFlow device appear to augment peak venous velocity significantly. The Jobst Athrombic Pump had a much greater increase in peak venous velocity than the other two calf-thigh devices tested, namely the Flowtron DVT and the SCD system.

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