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Anesthesiology  
67:266-268, 1987

## Hemodynamic Effects of Intermittent Pneumatic Compression of the Legs

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Venous return to the heart is one of the major factors controlling stroke volume.<sup>1</sup> Various physical and pharmacological interventions alter venous return, and, therefore, may have noticeable effects on stroke volume. Increases in stroke volume increase pulse pressure and arterial blood pressure.<sup>2</sup> We report a case in which changes in central venous pressure, pulmonary artery pressure, and pulse pressure were noted as a result of intermittent augmentation of venous return by pneumatic compression stockings.

### REPORT OF A CASE

A 67-yr-old man was admitted to the intensive care unit (ICU) for placement of invasive monitors and determination of a Starling curve the night prior to resection of an abdominal aortic aneurysm. His history was significant for a left ventricular aneurysm following a myocardial infarction in 1982. Coronary angiography showed diffuse coronary artery disease. The left ventriculogram demonstrated areas of hypokinesis, akinesis, and dyskinesis. His radionuclide ejection fraction was 25%.

A 20-gauge catheter was inserted percutaneously into the right radial artery, and a pulmonary artery catheter was placed *via* the right internal jugular vein. Pressures were monitored continuously and car-

diac output was determined by thermodilution. A Starling curve was determined (stroke volume and cardiac output *versus* pulmonary capillary wedge pressure (PCWP)) by altering preload using hetastarch and nitroglycerin (fig. 1). During this process, phasic variations in the pressure tracings were noted at intervals of almost exactly 1 min, and, on inspection, were seen to correspond to the inflation of the pneumatic compression stockings which were placed on the lower extremities for prophylaxis against deep venous thrombosis (DVT) (fig. 2). The timing of the inflation of the stockings was later measured by attaching a T-piece to the air hose of the instrument and recording the pressure on the chart recorder. The variation in pressures ceased when the compression stockings were turned off. Upon review of the hemodynamic tracings, maximal changes apparently were caused by the inflation of the pneumatic compression stockings when the PCWP was 6 mmHg. Pulse pressure increased by 20 mmHg, with a diastolic pressure increase of 10 mmHg. At a PCWP of 15 mmHg, the plateau of the patient's Starling curve, the inflation of the pneumatic compression stockings had virtually no effect on the above variables (fig. 2).

### DISCUSSION

Intermittent pneumatic compression of the legs is an effective technique for decreasing the incidence of deep venous thrombosis by preventing stasis in the venous system of the lower extremities.<sup>3</sup> Peak blood flow in the femoral veins, as measured by Doppler studies, is increased during compression. Factors which maximize the flow have been studied, including the optimal inflation pressures and optimal decompression period. Nicolaides *et al.*<sup>3</sup> demonstrated higher peak blood flows and more rapid clearance of iv radiographic contrast with the sequential compression stockings, which sequentially inflates separate compartments from the

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Received from the University of California, San Diego, UCSD Medical Center, Department of Anesthesia, H-770, 225 Dickinson Street, San Diego, California 92103. Accepted for publication March 16, 1987.

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Key words: Heart: myocardial function. Veins: pneumatic compression device; prevention; thrombosis.

ankle to the thigh to produce a "milking" action. These are the type of stockings used on our patient.

In our study, the hemodynamic effect of the pneumatic compression stockings appears to be predominantly an augmentation of venous return. Both central venous pressure and pulmonary artery pressures were increased. While there was a slight increase in diastolic pressure, there was a larger increase in the pulse pressure. Although we could not measure stroke volume during the short time of stocking inflation, the increased pulse pressure suggests that stroke volume was increased. The demonstration in the previous studies of increased femoral vein blood flow indicates that blood volume is moving centrally. The important relationship between preload and stroke volume is described by the Starling curve. When a subject has a low preload, a small increase in central blood volume produces a large increase in stroke volume and pulse pressure. At a higher level of preload, the same change in blood volume produces a smaller change in stroke volume and pulse pressure.<sup>2</sup> We demonstrated this effect in our patient.

Raising of the legs may be physiologically analogous to the inflation of the pneumatic compression stockings. The hemodynamic effect of passive leg raising has been examined by Gaffney *et al.*<sup>4</sup> They demonstrated transient increases in cardiac output and stroke volume of 8–10%, which disappeared in 7 min. Their study emphasized the important role of autonomic reflexes in cardiovascular responses. The intact reflexes of healthy volunteers may minimize the observed effect, and this may explain the disappearance of the changes in 7 min. Perhaps the large effect in this patient was partly due to his slow cardiovascular response; clearly, he did not have a normal cardiovascular system. The Kendall pneumatic compression stockings' inflation time of 15 s also decreases the time available for full reflex compensation.

Pneumatic compression stockings with a thigh compartment are physically similar to the leg portion of military antishock trousers (MAST suit). The hemodynamic effects of the MAST suit have been described previously, and one might initially assume that many of the same principles would apply. Interestingly, Gaffney *et al.*<sup>5</sup> demonstrated that the major effect of the MAST suit was an increase in afterload in supine volunteers. However, in a 60° head-up tilt, they were able to demonstrate an increase in stroke volume, presumably due to an increased venous return. A 60° head-up tilt is a situation in which there is a lower level of preload. There are several important differences between the pneumatic compression stockings and the MAST suit, which suggest that we observed a change in preload and not in afterload. Lower pressures are used in the compression stockings, approximately 40 mmHg; therefore,

STROKE VOLUME VS PULMONARY CAPILLARY WEDGE PRESSURE  
Δ PULSE PRESSURE VS PULMONARY CAPILLARY WEDGE PRESSURE

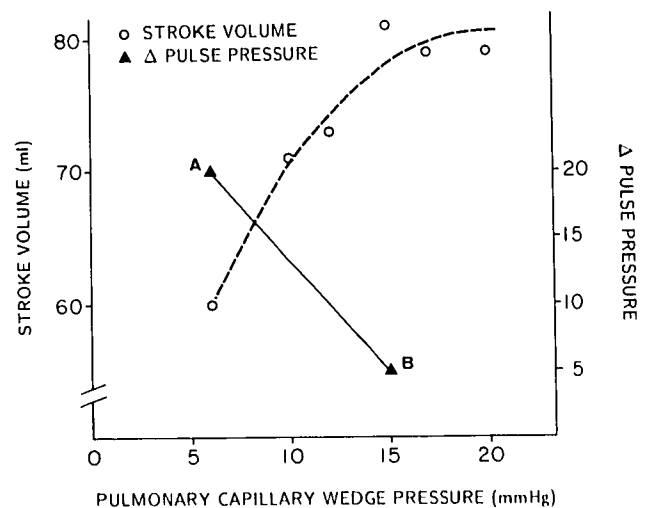


FIG. 1. Starling curve: stroke volume (SV) versus PCWP. The increase in pulse pressure caused by the pneumatic compression device is shown at a PCWP of 6 mmHg (20 mmHg) (point A), and at a PCWP of 15 mmHg (5 mmHg) (point B).

the same degree of afterload increase should not occur, as has been reported with the MAST suit, which is inflated with pressures of up to 100 mmHg. There is no abdominal compartment, which may actually cause a decrease in venous return. Compression of abdominal veins and increased intrathoracic pressure create resis-

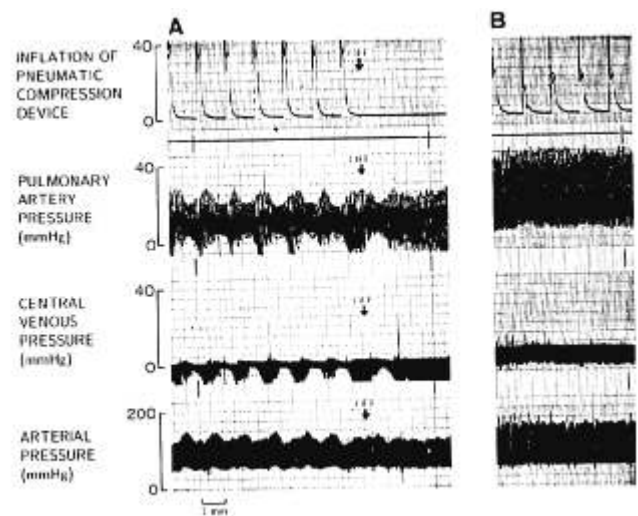


FIG. 2. Pressure tracings at a PCWP of 6 mmHg (A) and a PCWP of 15 mmHg (B). The arrows indicate when the pneumatic compression device was turned off to test the observed effect. Paper speed is 10 mm per minute. Hemodynamic data at time "A": cardiac output 4.5 liters/minute, stroke volume 60 cc, heart rate 75 bpm; at time "B": cardiac output 5.3 l/min, stroke volume 81 cc, heart rate 65 bpm.

tance to venous return and prevent any net augmentation of preload.<sup>6</sup> Finally, if our observations were due to changes in afterload, similar changes in pressures would occur at both high and low levels of preload.

The pressure variations observed with the pneumatic compression stockings are similar to the systolic pressure variations observed with intermittent positive pressure ventilation. The phasic changes in venous return that occur with positive pressure breaths, with an increase in venous return during the expiratory phase, have long been known to cause an observable pulsus paradoxus. This effect is larger in hypovolemia and nearly disappears during euolemia.<sup>7</sup> A similar effect was observed in our case, with the pressure variation most marked when the patient was venodilated.

The effect of changes in preload is useful during assessment of cardiovascular function. The MAST suit has been used to create a reversible change in preload.<sup>8</sup> Considering Gaffney *et al.*'s<sup>4</sup> data, the actual effect of the MAST suit may be a change in afterload. The systolic pressure variation seen with positive pressure ventilation has similarly been used to analyze a patient's volume status.<sup>7,9,10</sup> We demonstrate the hemodynamic effects of the pneumatic compression stockings at various levels of preload.

In conclusion, pneumatic compression stockings may cause variations in venous return and arterial pressures, which is an important fact to be aware of for those working in the ICU or operating room. The device appears to work predominantly by augmenting venous return. The observed hemodynamic effects of the pneumatic compression stockings provide another clinical

illustration of the physiologic principles described in the Starling curve. Intermittent reversible augmentation of preload may also have value in assessing cardiovascular function.

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Anesthesiology  
67:268-272, 1987

## Sequential One-lung Ventilation for Bilateral Bullectomy

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The pathologic endpoint of alveolar destruction in emphysema is the formation of a bulla. Bullectomy is indicated when the chest roentgenogram shows local-

ized bullae, dyspnea is intolerable despite maximal medical therapy, and that the bulla is compressing normal adjacent lung tissue.<sup>1-3</sup> Lung compression can be assessed by various combinations of a plain chest roentgenogram, a perfusion scan, angiography, and bronchography. The potential for the compressed lung to have normal function can be demonstrated by a relatively normal ventilation washout of intravenously administered <sup>99m</sup>Tc. Hypoxemia and hypercapnia are not contraindications to bullectomy, and, indeed, such patients may be the ones who benefit the most from surgery.<sup>3,4</sup>

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Received from the Anesthesia Research Lab, University of California, La Jolla, California 92093. Accepted for publication March 18, 1987. Supported by the Department of Anesthesiology, University of California San Diego.

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Key words: Anesthesia: thoracic. Lungs: obstructive pulmonary disease. Ventilation: one-lung; pattern.