

Intermittent Pneumatic Compression for DVT Prophylaxis

Which device characteristics and hemodynamic metrics are important for physicians to consider in making the best patient-specific treatment decisions?

BY ANTHONY J. COMEROTA, MD, FACS, FACC



There is a large body of evidence documenting that intermittent pneumatic compression (IPC) is effective in preventing deep vein thrombosis (DVT) in hospitalized, high-risk patients.¹⁻⁸ Early randomized studies show a significant reduction in venographically proven

DVT following total hip and knee replacement.¹⁻³ Early trials compared IPC to no treatment,^{1,2} and subsequent trials compared IPC to pharmacologic (heparin) prophylaxis.^{3-6,8} When heparin was the comparator, IPC results continued to appear favorable, and as might be expected, wound drainage and bleeding complications occurred less often in patients in the IPC groups.^{3,4}

Subsequent studies of high-risk trauma patients have allowed insight into the relative benefit of IPC, the potential differences of foot compression versus calf-thigh compression, and the relative risk of IPC versus low-molecular-weight heparin (LMWH) prophylaxis.⁸ Knudson et al performed a randomized trial evaluating LMWH versus optimal compression in high-risk trauma patients. Patients who were eligible to receive heparin were classified as “the heparin group” and were randomized to either LMWH or optimal compression. Optimal compression was defined as a sequential compression device (SCD) applied over antiembolic stockings. If a patient could not wear an SCD because of associated wounds or other clinical factors, a foot arteriovenous impulse device was used.

The combined use of compression stockings and an IPC device was shown by Abu-Own and colleagues to produce more effective venous flow velocity and volumetric venous flow associated with a smaller diameter of the femoral vein.⁹

Patients who were not candidates for heparin were placed into a “no heparin group” and likewise were managed with optimal compression using the same decision matrix. Venous duplex imaging was performed every 5 to 7 days until discharge. The results are summarized in Figure 1. DVT was detected in 0.8% of the LMWH-treated patients, in 3% of the SCD patients, and in 6% of the arteriovenous

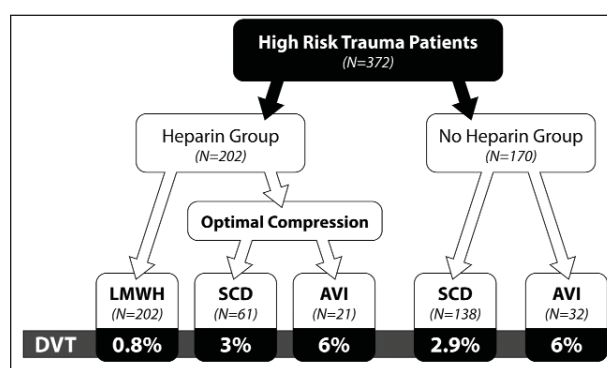


Figure 1. Design and outcomes of a randomized trial of DVT prophylaxis in trauma patients.⁸

impulse device patients. One major bleeding complication was potentially associated with the use of LMWH.

In addition to orthopedic patients undergoing total hip or knee replacement and high-risk trauma patients, those suffering neurologic trauma or stroke or those undergoing general surgery have benefited from IPC for DVT prophylaxis. When physicians evaluate methods of DVT prophylaxis, the question should not be whether IPC is effective but what characteristics (specifications) of IPC devices position them to be most effective.

THE PLEIOTROPIC EFFECTS OF IPC

Most health care professionals think of IPC in terms of the venous hemodynamics produced by the mechanical effects of compression on the soft tissue of the extremity. The hemodynamic consequences of moving venous blood include increased venous velocity, pulsatile venous volume, volume of venous blood returned per unit time (as a result of increasing arterial inflow), and shear on vascular endothelium.

There are other pleiotropic effects of IPC that have an important effect on clinical outcomes; however, to date, these additional effects have not been correlated with clinical outcomes. These include increasing fibrinolytic activity¹⁰

(not by increasing tissue plasminogen activator antigen release but by reducing plasminogen activator inhibitor), decreasing factor VIIa, increasing tissue factor pathway inhibitor,¹¹ stimulating endothelial-derived growth factor mRNA,¹² and stimulating the endothelium to alter production of at least three isoforms of nitric oxide synthase.¹³ These are the pleiotropic effects that have been studied. There are probably numerous others that have yet to be identified.

The clinical benefits of these pleiotropic effects include prevention of DVT, healing of venous ulcers, healing of arterial ulcers, improved management of patients with critical limb ischemia, improved blood flow through lower extremity bypass grafts, increased walking distance in patients with intermittent claudication, reduction in generic leg edema, improved management of lymphedema, and anecdotal improvement of causalgia (posttraumatic pain syndrome). Undoubtedly, there is a complex interaction of the hemodynamic parameters affecting endothelial and vessel wall response in addition to the variety of venous and arterial blood flow alterations. The remainder of this discussion will focus on the effect IPC has on venous hemodynamics.

CONSIDERATIONS REGARDING IPC

Just as there are differences in the outcomes of similar pharmacologic agents used to treat the same disease, one can expect there to be differences in outcomes when similar mechanical devices are used, depending on their device specifications and compression characteristics.

Importantly, it appears that the indication for the use of an IPC device may dictate the important hemodynamic characteristics. That is, patients with arterial ischemia may require different pump characteristics than patients with lymphedema, and the specifications required for both of these patient groups may be different than pump specifications for patients requiring DVT prophylaxis.

Focusing on the venous system in general, and DVT prophylaxis in particular, there is little argument that randomized clinical trials with objective endpoints related to venous thromboembolism are the ultimate arbiter in decision making, assuming the trial design and conduct are appropriate. Confounding variables must be clearly recognized and addressed. This is well illustrated in a study performed by Gallus et al,² who randomized patients undergoing total hip replacement to IPC versus no treatment. One of two opera-

tive techniques was used by the orthopedic surgeons, either the modified Charnley technique or the posterior approach. Fortunately, the two operative techniques were stratified when the patients entered the trial.

The investigators found that IPC was very effective in reducing DVT in patients who underwent the posterior approach (14% IPC vs 57% control). However, IPC was not effective in those patients who underwent the modified Charnley technique. Overall, venographically proven DVT occurred in 40% of patients who underwent the modified Charnley technique and 9% when the posterior approach was used. This is a graphic example of a confounding factor that may not be readily apparent but may substantially alter outcomes. This also alludes to the fallacy of comparing outcomes of one trial to another because internal controls in such analyses would be absent. When evaluating clinical trials, one must be aware of trial design and efforts to standardize all patient management except for the variable being examined.

HEMODYNAMICS OF IPC THAT DRIVE DECISION MAKING

What are the important characteristics of IPC that lead to prevention of DVT? Until trials are performed that address the important outcomes (ie, DVT and pulmonary embolism), one must look to the surrogate metrics of venous hemodynamics and perhaps some of the hematologic changes (although these add a significant level of complexity and labor). That raises the question of which hemodynamics are most likely to produce an antithrombotic environment. This important question is difficult to answer because few comparative studies have been performed on the same subjects.

One such study, however, serves as an example, which was performed by Griffin et al.¹⁴ They compared the hemodynamic effectiveness of three full-leg compression devices: (1) a circumferential sequential gradient device; (2) a posterior uniform compression device; and (3) a posterior sequential rapid inflation device. The hemodynamics measured included peak velocity in the common femoral vein, single-cycle venous volume flow, and refill time, and venous volume flow per hour was also calculated. The hemodynamic results are summarized in Table 1.

All devices significantly increased venous velocities and flow compared to baseline. Single-cycle volume expelled dur-

TABLE 1. HEMODYNAMIC RESULTS OF THREE FULL-LEG COMPRESSION DEVICES¹⁴

Device	Peak Velocity (cm/s)	Cycle Volume (mL)	Refill Time (s)	Volume Per Hour (mL)
CSG	37	104	28	7,800
PU	32	88	26	5,500
PSR	68	58	20	3,500

Abbreviations: CSG, circumferential sequential gradient; PSR, posterior sequential rapid inflation; PU, posterior uniform.

ing compression was 105, 85, and 58 mL in the circumferential sequential gradient, posterior uniform compression, and posterior sequential rapid inflation devices, respectively. The total venous volume per hour was 7,800, 5,500, and 3,500 mL, respectively.

It seems intuitive that increasing the total venous volume per hour would be the metric most likely to be associated with improved clinical outcomes (reduced risk of DVT). It was interesting to observe that the unit with the most rapid pressure inflation (pressure rise time) had the highest peak velocity but the shortest refill time, the lowest cycle volume, and the smallest volume per hour. This raises the question as to whether peak velocity is an important hemodynamic metric (although it is the easiest to measure). A characteristic not included in the previous analyses is bladder size. If the bladder in the device is small, it is easier to achieve a rapid pressure rise, resulting in a transiently high venous velocity but at the expense of a relatively smaller volume of blood being expelled. It would be helpful to know the bladder sizes of the devices used in addition to the other specifications reported. A small bladder should reduce expectations regarding the clinical effectiveness of the device.

Proctor et al¹⁵ performed a prospective observational cohort study using five IPC devices to determine relative clinical effectiveness in hospitalized patients. Devices included rapid gradient sequential compression of the calf; foot, calf, and thigh intermittent compression; two foot, calf, and thigh gradient sequential devices; and one intermittent calf compression device. The authors listed the manufacturers of the devices used in their study but blinded the reporting of device results.

Over 5 months, 1,350 patients were studied—1 month each in sequential fashion. They found that calf compression alone was inferior to devices that compressed the foot, calf, and thigh. However, their analysis was limited to peak venous velocity measurements, which is the easiest parameter to measure but may not be the most relevant hemodynamic parameter responsible for reduction of DVT risk. They also found that devices differed with regard to patient comfort and nurse satisfaction.

Technology is now available to sense postcompression refill time.¹⁴ It seems evident that the cycle time of the device should be linked to the venous refill time of the leg and that the efficiency of compression will improve if the next compression occurs as soon as the tissue refills with blood. This generally results in the highest volume of blood expelled per compression cycle and should result in the largest volume of venous blood expelled per hour, assuming appropriate bladder size. If there is one monitor per device, and if there is a different refill time in each leg, it would result in one of the legs being compressed either too early or too late.

The next technology question is: should the compression device read both legs independently, and therefore compress both legs independently, based upon their individual refill

times? Devices are now available to monitor individual leg refill times and be compressed independently.¹⁶ It would seem that this method should result in the most favorable clinical outcome.

CONCLUSION

It is common for authors to conclude articles with statements regarding the importance of additional randomized clinical trials. Of course that is also true here. However, if one were to design a definitive clinical trial to address specific hemodynamic parameters that optimally reduce DVT risk, correct for confounding variables, and target the relevant outcomes of symptomatic DVT, pulmonary embolism, and all-cause mortality, thousands of patients would be required. Until results of such studies are available, physicians must rely on the available literature. Reports of smaller randomized studies, prospective nonrandomized studies, and analyses of hemodynamic responses to IPC can assist physicians and patient care teams to make appropriate decisions regarding IPC for DVT prophylaxis. ■

Anthony J. Comerota, MD, FACS, FACC, is Director of the Jobst Vascular Institute, The Toledo Hospital in Toledo, Ohio, and Adjunct Professor of Surgery at the University of Michigan in Ann Arbor, Michigan. He has disclosed that he is a paid consultant to Covidien. Dr. Comerota may be reached at anthony.comerotamd@promedica.org.

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