Prevention of Venous Stasis in the Lower Limb by Transcutaneous Electrical Nerve Stimulation

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Abstract

Objectives: This study aims to investigate the effects of thromboprophylactic transcutaneous electrical nerve stimulation (TpTENS) of the peroneal nerve on venous blood flow in the limbs of volunteers. TpTENS might be considered for use in preventing venous stasis during surgical treatment.

Methods: In 10 volunteers, peak venous velocity (PV) and flow volume (FV) in the popliteal vein were measured using duplex ultrasonography during calf-muscle stimulation. The effects of TpTENS of the peroneal nerve were compared with those of other mechanical methods, including electrical muscle stimulation, intermittent pneumatic compression, active ankle motion and calf squeeze, used to prevent venous stasis and achieve thromboprophylaxis.

Results: TpTENS had similar effects on popliteal vein blood flow in comparison with other established methods of thromboprophylaxis. The PV increased its basal flow by 3.9 times (p < 0.01) and FV by 2.7 times (p < 0.01), respectively, compared with baseline values.

Conclusions: TpTENS is as effective as other electrical and mechanical methods of calf-muscle pump activation in achieving acceleration of venous flow in the lower limb.

Introduction

Intermittent pneumatic compression (IPC) devices are widely used both intra-operatively and postoperatively to prevent deep-vein thrombosis (DVT). They are unsuitable for limbs undergoing operation because they obscure the surgical field.

We have examined the possibility of using transcutaneous electrical nerve stimulation (TENS) to promote blood flow in lower limb veins. This type of stimulation increases flow velocity in the deep veins in a way analogous to that of electrical muscle stimulation and IPC. We refer to our technique as thromboprophylactic TENS (TpTENS). TpTENS is similar to regular TENS (transcutaneous nerve stimulation), which is widely used for alleviating pain, but TpTENS differs from TENS in that it is designed to stimulate muscle motor nerves while TENS is designed for stimulating sensory nerves.1 We based our concept in part on the historical use of electrical stimulation applied to muscle.2–6 The purpose of this study

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was to examine the flow enhancement of TpTENS compared with other mechanical methods of thromboprophylaxis.

Materials and Methods

Ten healthy volunteers, between the ages of 22 and 48 years, were recruited to participate in the study. Ethics committee approval from our institutional review board and informed written consent were obtained prior to the study. All examinations were performed inside the same silent room. Room temperature was maintained at 25 ± 1 °C. Body mass index of the subjects was 21.4 ± 1.8. The subjects were placed in the prone position on a table with their feet off the table and their knees extended. We used an ALOKA Prosound 7.5 MHz linear array probe to locate the popliteal vein in the left lower limb in a longitudinal image. After a 5-min rest period, baseline measurements were recorded. The cross-sectional area (mm²) of the popliteal vein was measured using B-mode. The peak venous velocity (PV) (cm s⁻¹) and the mean venous velocity (cm s⁻¹) were measured using pulsed-wave Doppler ultrasonography. The venous flow volume (FV) (ml min⁻¹) was calculated as cross-sectional area × mean venous velocity. The angle between the popliteal vein and the Doppler beam (θ) was maintained at 60°. The Doppler sample gate size was matched to the diameter of the popliteal vein. After the baseline scan, five different thromboprophylactic measures were evaluated for their effect on popliteal vein flow. The pulsed Doppler mode was used to record the blood flow continuously during the application of each method of flow stimulation. Measurements were made from a 5-s period coinciding with the flow stimulation. Three measurements were made for each type of stimulation and an average taken, allowing PV and FV to be calculated. The interval between successive measurements was at least 1 min, during which volunteers were instructed to sit on the table with their legs dependent to restore the venous blood pool. We waited for venous flow to return to the baseline before each measurement. The IPC devices used in this study have an inflation and deflation cycle of 1 min. When IPC established a stable effect after a few cycles, measurements were made for 5 s from the start of the inflation phase. All ultrasonographic measurements were performed by a single experienced investigator (T.M.).

Thromboprophylactic transcutaneous electrical nerve stimulation (TpTENS)

A pair of surface electrodes with a diameter of 7 mm (NM-31, NIHON KOHDEN, Tokyo, Japan) was placed over the left common peroneal nerve close to the head of the fibula (Fig. 1). Transcutaneous electrical stimulation was performed using an electrical stimulator (SEN-5201, NIHON KOHDEN, Tokyo, Japan). The stimulator was set to deliver a square-wave pulse of the same duration and intensity as the electrical nerve stimulation, at a rate of 50 Hz. A higher pulse frequency was needed in EMS to produce brisk dorsiflexion of the ankle in preliminary trials (data not shown), and electrical stimuli were applied at multiple sites to locate the best point of stimulation.

Intermittent pneumatic compression (IPC)

An intermittent calf compression device (FLOWTRON DVT AC500, Huntleigh Healthcare, UK) was applied to the leg. A compression pressure of 40 mmHg was used.

Active motion of the ankle

The subjects were instructed to perform, as strongly as possible, a dorsiflexion of the left ankle.

Muscle squeeze

The examiner squeezed the volunteer’s calf muscle by both hands with a grip strength of approximately 30 kg. The grip strength was calibrated with a grip dynamometer immediately prior to squeezing.

Statistical analysis was carried out using SPSS, Version 16.0 (SPSS Inc., Chicago, IL, USA). Wilcoxon signed-rank test was used for paired samples in all analyses. Values were given as median and range. A p-value of <0.05 was considered statistically significant.

Results

The median (range) values of the PV were 26 cm s⁻¹ (19–38) at rest, 102 cm s⁻¹ (49–148) following TpTENS, 97 cm s⁻¹
(36–123) following EMS, 65 cm s\(^{-1}\) (54–109) in IPC, 75 cm s\(^{-1}\) (40–152) with active motion of the ankle and 90 cm s\(^{-1}\) (69–117) following a muscle squeeze. Fig. 2 shows the PV measurement results. All methods of calf-muscle stimulation resulted in >2.5 times increase in flow compared with the baseline, and the increases were all statistically significant (\(p < 0.01\), Wilcoxon signed-rank test). Among all methods, the median PV of TpTENS was greatest while IPC was least. There were significant differences between TpTENS and IPC (\(p = 0.022\), Wilcoxon signed-rank test) and muscle squeeze and IPC (\(p = 0.007\), Wilcoxon signed-rank test). The median (range) of the PV were 69 ml min\(^{-1}\) (41–118) at rest, 185 ml min\(^{-1}\) (105–355) after TpTENS, 145 ml min\(^{-1}\) (78–258) after EMS, 164 ml min\(^{-1}\) (100–284) after IPC, 172 ml min\(^{-1}\) (41–323) with active motion of the ankle and 154 ml min\(^{-1}\) (102–304) with a muscle squeeze. Fig. 3 shows the PV measurement results. All methods increased the flow from baseline (\(p < 0.01\), Wilcoxon signed-rank test). The median PV in each prophylaxis was 2.1–2.7 times greater than baseline. Although there were no significant differences among the five stimuli used, PV in TpTENS was greatest (2.7 times higher than the baseline). The median (range) of subjective pain VAS in TpTENS was significantly lower than in EMS (21 mm (0–64) vs. 41 mm (3–64); \(p = 0.02\)). Furthermore, the discomfort VAS under TpTENS was also lower than under EMS (26 mm (0–65) vs. 54 mm (0–63); \(p = 0.02\)).

Discussion

The results of this study showed that all five methods of calf-muscle stimulation produced significant venous flow enhancement. According to previous reports, which examined flow enhancement at the popliteal vein, the mean PV increased to 55–57 cm s\(^{-1}\)\(^{17,8}\) with IPC and 43–120 cm s\(^{-1}\)\(^{19,10}\) with EMS. Our results showed that the median (range) of PV was 65 cm s\(^{-1}\) (54–109) with IPC and 97 cm s\(^{-1}\) (36–123) with EMS, which were consistent with previous reports, confirming the validity of our observations.

This is the first report to examine the flow enhancement of electrical stimulation on the nerve instead of the muscle. Although there were no significant differences in flow enhancement between TpTENS and EMS, we observed some advantages that TpTENS has over EMS. First, less pain and discomfort were associated with TpTENS than EMS. Second, it was easier to locate the optimal point of stimulation through TpTENS than through EMS, which usually required time to locate the motor point. Taken together, TpTENS is a more efficient measure, evoking muscle contraction more consistently with less pain and discomfort than EMS. In addition, this method could potentially be used during surgery where it was shown to be effective at preventing DVT.

Muscle squeeze is another possible alternative available for legs undergoing operation. Although some surgeons squeeze the calf muscle intra-operatively as a DVT prophylaxis (personal communication), there is, to our knowledge, only one report referring to the haemodynamic effects of calf-muscle squeeze.\(^{11}\) The authors reported that strong muscle squeeze produced a significant increase in PV, which compared favourably with active ankle motion. However, they did not compare its effects with IPC or electrical muscle/nerve stimulation. In our study, we found that calf-muscle squeeze did accelerate flow in the popliteal vein to the same extent as the other methods. However, this would not be a feasible method to use in clinical practice.

There are some hurdles to overcome for the clinical trial of TpTENS. First, our results, which were obtained from young healthy volunteers, might not be applicable to older patients. Second, the sustained effects of TpTENS, not only the haemodynamic effects but also pain and discomfort, should be evaluated. Third, in an operation on the lower
leg, brisk ankle motion due to TpTENS may disturb the operative procedure. Lastly, all examinations were performed in the prone position, which is not a typical position during orthopaedic surgery except for spinal operations. Our volunteers lay in the prone position because of: variable respiratory effects on the velocity at the femoral vein,12 higher sensitivity of ultrasonographic measurement at the popliteal vein for the detection of subtle differences among the different methods of stimulation7 and easier application for all prophylactic measures, especially calf squeeze. Our results indicate that TpTENS promotes popliteal vein blood flow to the same or greater extent as IPC. We are currently planning to conduct a clinical study in adult patients undergoing hip and knee surgery to study safety and efficacy.

Conflict of Interest/Funding

None. No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References
