ABSTRACT
Background: After the application of any compression device the pressure drops in a variable fashion.
Aim: to compare the pressure drop over time and the pressure-time integral (PTI) of inelastic short-stretch bandages (SSBs) with those of elastic four-layer bandages (4LBs)
Material and Methods: We treated 24 patients with venous leg ulcers with either SSBs or 4LBs and measured the interface pressure at the B1 point under the bandages daily for 1 week with the patients in the supine and standing positions. We defined the PTI as the area under the pressure curves calculated by summing the daily trapezoidal areas over 7 days.
Results: SSBs applied with initial pressure 56% greater than that of 4LBs resulted in only 16% greater PTI. SSBs produced lower PTIs than 4LBs applied with the same initial pressure, because SSBs lost pressure more rapidly than 4LBs.
Conclusion: SSBs need to be applied with 25% more initial pressure than 4LBs to achieve the same PTI. The PTI is more useful than the initial application pressure for characterising compression dosages.

INTRODUCTION
Most clinical trials with compression devices neglect the fact that the pressure exerted by a compression device corresponds to its therapeutic dosage. Several instruments are now available to measure the compression pressure on the extremities. Compression pressure is not a static parameter, however; it fluctuates with changes in body position and with movement, declining over time as a result of oedema removal and compression-material fatigue. The initial pressure dose applied by a compression device to an extremity diminishes to a variable degree after several days, depending on the textile properties of the device, the consistency and configuration of the extremity (oedema), and the mobility and activity of the patient. The pressure-time integral (PTI) is a more relevant estimate of the pressure dosage over time than is a single pressure measurement immediately following the application of a compression device, because the PTI describes the pressure applied by the device over the entire period during which the device is active.

METHODS
Twenty-four patients with venous leg ulcers gave informed consent to wear pressure sensors under their compression bandages, which were changed routinely every week. An experienced bandager (GM) applied short-stretch bandages (SSBs) (Rosidal sys®) to 12 patients and four-layer bandages (4LBs) (Profore®) to the other 12 patients. We attached flat plastic probes which filled with 2 mL air (Picopress®, Microlab Italia) to measure the pressure under the bandages at the B1 point where the muscular part and the tendinous part of the medial gastrocnemius muscle meet. We wrapped the stiff connecting tube of the probe in cotton wool to avoid skin irritation. We measured the pressure every afternoon for 1 week while the patients were supine and standing. Most patients were admitted to the hospital, and we encouraged them to walk as much as possible. We estimated the pressure dose applied each day by the compression devices by calculating the pressure-time integral (PTI): the sum of the daily trapezoidal areas under the daily pressure curves.
STATISTICS: We computed the mean PTIs with standard deviations and coefficients of variation and performed non-parametric statistical comparisons between the two bandage types using Mann Whitney tests. We defined statistical significance as: * p < 0.05; ** p < 0.01; *** p < 0.001.

RESULTS
We applied the SSBs with 56% more initial pressure than that of the 4LBs*** (Fig. 1). The mean pressure of the SSBs while the patients were supine dropped significantly more than that of the 4LBs over the course of the week*** (Fig. 1a). The coefficients of variation in the pressure trended higher for the SSBs than they did for the 4LBs, although the difference was not statistically significant. Both bandage types exerted more pressure while the patients were standing than they did while the patients were supine (Fig. 1b). The difference between the standing and supine pressures corresponds to the static-stiffness index (SSI), which was significantly higher for the SSBs than for the 4LBs***. All of the SSI values for the 4LBs were greater than 10, however, characterising the 4LBs as being rather stiff, although the components are all elastic3. The mean PTI per day of the SSBs (40, 75 ± 4, 04 mmHg) was higher than that of the 4LBs (35, 13 ± 2, 69 mmHg)*** (Fig. 2).

DISCUSSION
SSBs lose more pressure over time compared with elastic materials, because the recoiling ability of the elastic material allows them to adjust to volume changes in the leg. The pressure loss is a major disadvantage of inelastic short-stretch material and, combined with improper bandage application by persons unfamiliar with the material, is probably the main reason for unfavourable outcomes in ulcer-healing clinical trials. Even experienced nurses who lack specific training in SSB application often apply SSBs too loosely4. Moreover, although the difference was not statistically significant, we found that the coefficients of variation for the SSBs tended to be higher than those for the 4LBs, suggesting that reproducible pressures are easier to obtain using 4LBs.

The recommended initial pressure for a compression bandage on the leg is around 40 mmHg5. This is a good recommendation for elastic material, especially because higher pressures are not well tolerated and may even cause skin damage. Inelastic bandages should be applied with more initial pressure, however, because their initial pressure substantially declines after application. Inelastic bandages will have a lower PTI than elastic bandages applied with the...
same initial pressure, resulting in the need to change them more often, every 2-3 days.

In this study, we applied SSBs with a much higher initial pressure than we applied with 4LBs, leading to a significantly higher PTI for the SSBs over the 1-week period. All of the pressures that we used were, even 1 week after the initial application, in the high range (40-60 mmHg) or the very high range (> 60 mmHg) of well tolerated, haemodynamically efficient pressures6,7. From our PTI values, we calculated that an SSB would need to be applied with more than 50 mmHg initial pressure to achieve a PTI in the same range as that of a 4LB. To demonstrate, we applied an SSB to the leg of a patient in a sitting position and measured the interface pressure continuously for 1 h, showing that inelastic material (Coban 2®) with a starting pressure of 50 mmHg produced the same PTI as that produced by two elastic stockings (38 mmHg; Mediven ulcer kit®; Fig 3).

Two components, oedema reduction and material fatigue, are mainly responsible for the loss of compression-device pressure. We repeated the experiment shown in Fig. 3, wrapping a bottle instead of a patient’s leg with Coban 2 material, and found that the pressure dropped from 54 to 49 mmHg (-9%), which is much less than the pressure dropping from 52 to 37 mmHg (-29%) on the patient’s leg. Thus, we estimated that about 9% of the pressure drop on the patient’s leg was caused by material fatigue and the other 20% was caused by oedema reduction.

It is important to realise that the measured pressure values, SSI and PTI, are parameters describing the physical properties of compression systems and should not be automatically translated into parameters describing clinical efficacy. While higher pressures correlate significantly with improved venous pumping function8,9, limb-volume reduction may correlate negatively with very high bandage pressures in patients with oedema10.

CONCLUSIONS

Studies of compression therapies should not only measure the initial pressure as a snapshot, but they should also consider the distribution of the pressure dose over time by calculating the PTI. Inelastic material needs to be wrapped with an initial pressure greater than 50 mmHg to obtain PTI values over a 1-week period comparable to those of elastic materials applied with a starting pressure of 40 mmHg.