Original Contribution

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Effectiveness of anti-slip dots on the soles of elastic compression stockings

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Objective: Elastic compression stockings (ECSs) are worn to prevent lower extremity blood stasis; however, their slippery fabric poses a risk of falling. We designed ECSs with non-slip soles and compared their stabilities to that of bare feet.
Methods: Three types of ECSs were produced with acrylic resin dots to prevent slippage: type A, anti-slip coating on the toe side; type B, anti-slip coating on the heel side; and type C, open toe type with anti-slip coating on the heel side. A foot mannequin wearing an ECS was placed on an inclined table, the angle of slide-out (AS) values were measured in both the anterior and posterior directions, 5 times each, and the values were averaged.
Results: Type A had significantly lower AS values than did the barefoot model (48.2° vs. 60° anteriorly, 41.8° vs. 57.2° posteriorly; $P < 0.01$) as did type B (36.2° vs. 60° anteriorly, 51.2° vs. 57.2° posteriorly; $P < 0.01$). The AS of type C was not significantly different from that of the barefoot model in either direction (58.6° vs. 60° anteriorly, 53.8° vs. 57.2° posteriorly; $P > 0.05$).
Conclusions: The open toe ECS with anti-slip dots on the heel side was as sturdy as the barefoot control, while types A and B were more slippery.

Key words: elastic compression stocking, fall accident, anti-slip dots, barefoot, open toe

Introduction

Wearing elastic stockings (ECSs) is recommended for preventing venous thromboembolism (VTE) that is associated with bed rest and surgery.[1-3] On the other hand, wearing socks or stockings increases the risk of falling among elderly individuals compared to going barefoot.[4,5] Notably, ECSs are made of synthetic fibers that are more slippery than those of other sock products,[6,7] and patients wearing them are at a greater risk of falling when in direct contact with the floor or while wearing backless slippers. We recently produced ECSs with different sole shapes and tested their slipperiness by dressing a foot mannequin with them and placing this foot mannequin on an inclined board while slowly increasing the angle of inclination to determine the angle of slide-out (AS).[8] In that study, we found that the AS of the foot mannequin wearing the ECS was the lowest while that of the barefoot model (i.e., without an ECS) was the highest. This demonstrated that the standard ECS was slippery. At the same type, a Trenka-type stocking had high forward and backward AS values that were similar to those of the barefoot model. However, there remains a concern that the Trenka-type stocking will not be easily marketable because of the complexity of sewing. Therefore, we modified existing ECSs to include non-slip soles created using surface dot processing with silicon or acrylic resin (materials widely used for the anti-slip processing of gloves), and compared their slip resistance to those of the barefoot model and the original ECSs using the foot mannequin. We performed this study to determine whether or not this updated ECS with the simple anti-slip coating on the sole could reproduce the same level of slip resistance as that of bare feet.

Materials and Methods

Preparation of materials

An existing commercial ECS (Fine Support, small size; Toray Medical, Chiba) was used. The fabric was comprised of nylon and polyurethane with a circular knit that maintained compression levels of 18 mmHg (2.4 ×

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103 Pa) at the ankle and 14 mmHg (1.9 × 103 Pa) at the calves. Three types of modified ECS were produced, each with point-like anti-slip coating made of acrylic resin as shown in Figure 1. Type A was processed from the toe to the metatarsophalangeal joint. Type B was processed from the tarsometatarsal joint to the entire heel. And type C was cut with scissors to expose the metatarsophalangeal joint with non-slip coating on the heel.

The barefoot model was prepared using 0.5 to 0.8 mm thick, semi-transparent, skin-covering material (Duo Active ET; ConvaTec, Berkshire, England) attached below the ankle and sole of a foot mannequin (520 g). Anti-slip treatment consisted of the commercially available Bond Multi-Purpose Sealant (Water-based Acrylic Resin Filler; Konishi, Osaka), which was applied in dots of 5 to 10 mm^3 at intervals of approximately 1 cm (Figure 1).

Investigating slipperiness

We used our existing methodology as described previously.[8] Each type of ECS sole was attached to the foot mannequin, and its slipperiness was investigated when the heel was higher (forward) and when the toes

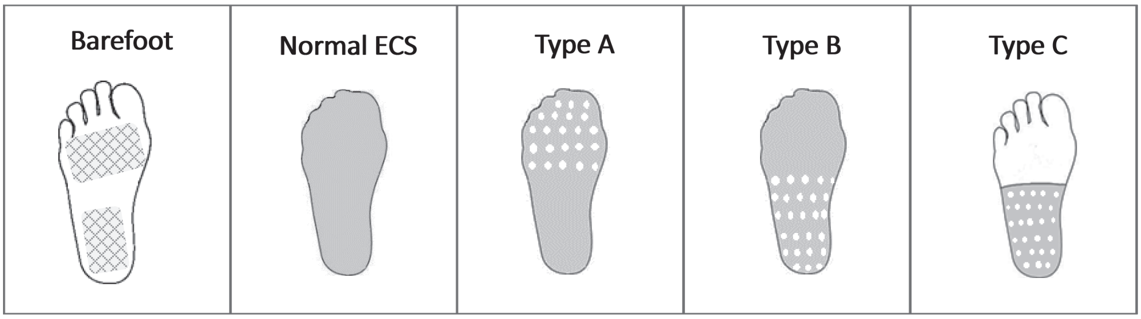

Figure 1. Diagram of prepared sole types

Barefoot: Skin-covering material attached below the ankle and the sole of a foot mannequin as shown (squares in a lattice pattern)
Normal ECS: equivalent to those commercially available (gray area)
Anti-slip treatment: the commercially available Multi-Purpose Sealant was applied in dots of 5 to 10 mm^3 at intervals of approximately 1 cm (white dots). Type A: anti-slip coating on the toe side. Type B: anti-slip coating on the heel side. Type C: open toe type with anti-slip coating on the heel side similar to Type B.

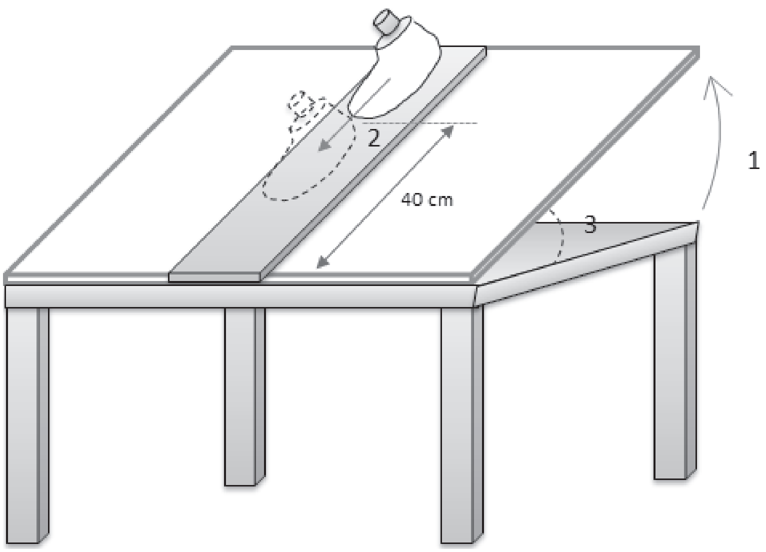

Figure 2. Diagram of the equipment used to measure the AS of each sole type. A stocking-covered foot mannequin was placed on top of the floor material at the center of the ramp. (1) The ramp was slowly raised (approximately 2°/s). (2) When the foot moved at least 100% of its length, (3) the AS was measured using a protractor.

were higher (backward) based on the position of the ramp (Figure2). The slope of the ramp was measured at the inclination at which the foot moved 100% or more of its length.

Floor material (4 × 150 × 900 mm) (One Park Floor Slim; Daiken, Osaka) was placed at the center of the ramp (Sanding board; Sakai, Osaka), and the foot mannequin wearing a stocking was placed on top; the distal point of the foot was placed at a mark 40 cm from the floor material. With the ramp operator's eyes closed, when the record keeper gave the signal, one side of the ramp was lifted slowly (approximately 2°/s). The operator was then signaled to stop once the foot mannequin slid 100% from its original position. The angle of the ramp at that point (i.e., the AS) was measured using a protractor and recorded. The staff member measuring the angle was careful to keep the ramp operator unaware of the recorded measurements. Slipperiness in both the forward and backward directions using the different types of ECS shapes as well as a barefoot mannequin were measured 5 times each with the toes facing upward and again with the toes facing downward, and the mean AS values were calculated for each position.

These mean AS values were compared between groups. "Non-repeated measures analysis of variance" with a post hoc paired-sample *t*-test (using the Student-Newman-Keuls correction) was used for statistical analysis. Values of $P < 0.05$ were considered significant.

Results

Slippage toward the front

The AS of the conventional ECS (23 ± 2.1°) was significantly smaller than that of the barefoot model (60 ± 1.0°) ($P < 0.01$). Type A (48 ± 0.4°), type B (36 ± 1.3°), and type C (58 ± 1.3°) had significantly greater AS values than did the conventional ECS ($P < 0.01$), while types A and B had significantly smaller AS values than did the barefoot model ($P < 0.01$). There was no significant difference in AS between type C and the barefoot model (Figure 3A).

Slippage toward the rear

Compared to the barefoot model (57 ± 1.8°), the conventional ECS (24 ± 2.0°) had a significantly smaller AS ($P < 0.01$). The AS values of type A (42 ± 3.9°), type B (51 ± 2.5°), and type C (54 ± 4.5°) were significantly greater than those of the conventional ECS ($P < 0.01$), while types A and B had significantly smaller AS values than the barefoot model ($P < 0.01$). There was no significant difference in AS between type C and the barefoot model (Figure 3B).

Discussion

The AS of the conventional (unaltered) ECS was significantly smaller than that of the barefoot model. This was clearly due to the ECS material having lower friction. Our results showed that changing the sole of the ECS and increasing friction could reduce slipperiness and prevent falls. The AS values of the types A and B models (with the non-slip treatment) were significantly greater than that of the conventional ECS in the slip-out direction but were not as high as that of the barefoot model. Quantitatively, the difference in the forward AS between type A and conventional ECS was approximately

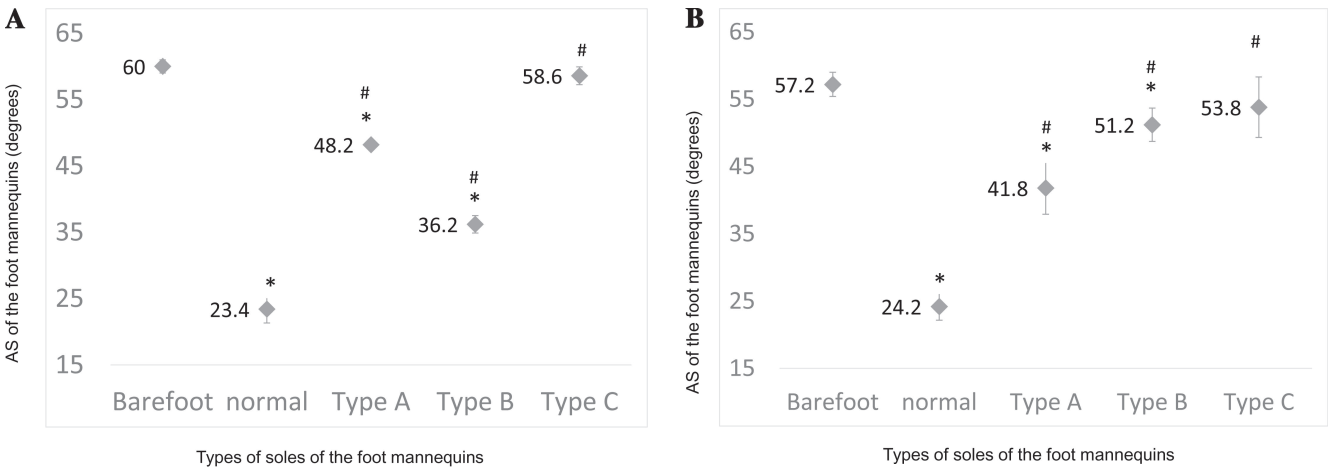

Figure 3. (**A**) AS values of forward slipperiness of barefoot and the 4 foot mannequin sole types. *$P < 0.001$ vs. barefoot; #$P < 0.01$ vs. conventional ECS. (**B**) AS values of backward slipperiness of barefoot and the 4 foot mannequin sole types. *$P < 0.001$ vs. barefoot; #$P < 0.01$ vs. conventional ECS

25°, while the difference in backward AS between type B and the conventional ECS was 27°. Although we did not modify the ECS to include non-slip coating on the entire surface of the measurement, we could deduce that the effect of non-slip coating in the sliding direction were increases in the AS values of +25° to +27° over that of conventional ECSs.

As for whether the slip resistance observed in the type C model was due to the acrylic dots or simply the open toe shape, we consider it to be both. In our previous study,[8] we found that the forward slip resistance of the open toe model was the same as that of the barefoot model, but the backward slip resistance was significantly smaller than that of the open toe model, indicating that the anti-slip effect was insufficient. In the present study, we postulated that we could maintain the friction coefficient at the same level as that of the barefoot model by applying acrylic resin dot processing to the remaining sole fabric.

The key mechanism for preventing VTE when using ECSs is thought to be the compression of the lower extremities with the stockings; this decreases the total cross-sectional area of the veins, thereby increasing venous blood flow velocity and decreasing venous stasis in the lower extremities.[9-11] In our previous study,[8] we examined the peak velocity and blood volume in the popliteal vein when wearing Trenka-type stockings, and found no significant difference compared to conventional ECS. Therefore, we deduce that the open toe modified ECS with a smaller cut area is optimal to prevent slipping. Hübscher et al.[12] compared the slip resistance of non-slip socks, conventional socks, backless slippers, and barefoot, and concluded that non-slip socks are equivalent to barefoot in terms of the coefficient of friction (i.e., less slippery). However, their study was methodologically different from ours because they used acceleration sensors and other devices worn by human subjects.

Limitations

Our modified ECS may not necessarily be effective in preventing falls because the study did not involve actual people walking on a floor; rather, our model compared the friction between the resin dots on the soles of the ECSs and the floor material. Falling is caused by a decrease in the shear force between the forefoot, heel, and the ground surface during the heel contact phase.[6] When the forefoot slips, compensatory movements by the back of the foot occur to restore balance. Elderly patients and individuals with lower limb paralysis are more likely to fall owing to their inability to perform these coordinated movements.[12] To prevent falls, it is necessary to evaluate coordinated motions using actual persons.[12] Another limitation is that we did not consider whether or not acrylic resin or other resins such as silicon could be used as anti-slip materials for the dots to increase friction. Moreover, we did not test using applied weight. Lastly, it remains unknown whether or not these socks are comfortable.

On the other hand, the advantages of our method were as follows. 1. No ethical issues were involved. 2. Results were not affected by preconceived bias or fatigue of the subject. And 3. implementation and measurements are not complicated. This is a new and original method to evaluate slip and friction for which the validity warrants further examination.

In conclusion, an open toe ECS with anti-slip coating on the heel was found to have the same sturdiness as the barefoot model. These findings suggest that this ECS type may be useful for preventing falls.

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Conflicts of Interest: None

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