Influence of cover characteristics on prosthetic feet energy store and restitution mechanism

E. Pavan [1,*], D. Bonacini [2], P. Cecini [2], C. Frigo [1]
[1] *Laboratory of Movement Biomechanics and Motor Control - TBM Lab Bioengineering Department, Politecnico di Milano, Milan, Italy*
[2] *Roadrunnerfoot Engineering Srl, Milan, Italy*

Introduction: Most advanced prosthetic feet for lower limb amputees are designed to exploit the elastic properties of different materials (carbon fiber and other composite materials) in order to recover part of the elastic energy stored along the stride cycle during walking. However, in order to improve cosmetics and wearing suitability, prosthetic feet for walking are usually enclosed in a plastic cover that, due to specific viscoelastic characteristics of the material, can modify the original energy-store and restitution mechanism of the foot and cause energy dissipation. Hence, not only the material and structural properties of the prosthetic feet but also the characteristics of the cover are critical for proper foot functioning. The whole prosthetic foot may be modeled as a combination of springs and dampers [1] whose coefficients (stiffness and viscosity) may be experimentally identified by means of material testing machines. However these testing conditions are very different from walking, and to analyze the effect of different foot covers in a operative condition, the analysis of the elastic energy store and restitution have to be directly performed in the amputees during walking. It must be considered, though, that common models of gait analysis are not suitable to this purpose, as they usually consider the foot as a rigid body, and do not keep into account foot deformations under load. In this work, a different approach, based on the analysis of power transmitted from the ground to the rigid pylon above the foot has been used which allows to compute the energy flow through the elastic foot structure and the changes induced by different covers.

Materials and methods: A young male amputee (22 yrs old, 1.67m, 60kg), wearing a carbon fiber prosthetic foot (Roadwalking, Roadrunnerfoot Engineering, Italy), was analyzed during walking in six different conditions: bare foot (without cover) and with five different covers (3 models in polyurethane PU, one in silicone and one in EVA). Leg length discrepancies were compensated by regulating the pylon length. The six degree-of-freedom of the shank pylon were analyzed from the movement of 3 markers placed on it and acquired by an optoelectronic motion system (Smart, BTS, Italy). The ground reaction forces were measured by means of a force platform (Kistler 9286). The force vector was moved at the basis of the pylon, where a transfer moment was also applied. The translational and rotational velocities of the pylon were computed and multiplied by the force and the moment respectively, as to obtain the power [2]. Then, by time integration, the energy flow was computed. Minimum and dissipated energy values obtained from each condition were then compared by using a Student's test analysis.

RESULTS: The courses of the elastic energy obtained during stance phase (in Fig. 1: black- without the cover, gray- PU1 cover) were similar to those reported in [3] for old prosthetic feet models. The results showed two phases in which the prosthetic foot stores energy, and two in which it returns a portion of that energy, mainly in the phase preceding the toe off. The final level of energy (negative) represents the energy dissipated during one cycle. The values obtained for each condition analyzed are reported in Table 1. No differences in stride length were observed, even though stance phase duration was increased and mean velocity was slightly reduced.

DISCUSSION: Energy dissipation were similar, except for one cover (PU 1) in which it increased significantly when compared with barefoot condition (* $p < 0.01$), instead, temporal parameters were different for all covers considered. Hence, not only material and structural properties of the feet but also characteristics of the covers remain critical to foot function. The effect of shoes would also need to be considered. By using the 6-DOF approach, limits and assumption related to conventional gait analysis were overcome and neither feet testing nor viscoelastic model assumptions were necessary.

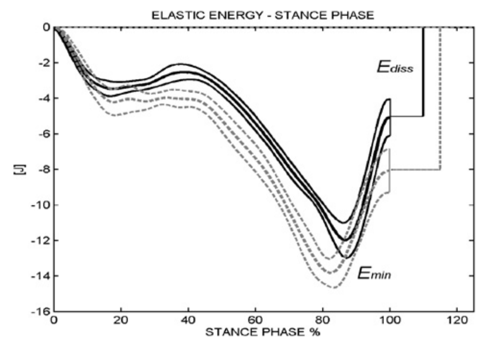

Fig. 1.

Table 1

	E_{min} [J]	E_{diss} [J]
Barefoot	−12.1 ± 1.0	−5.1 ± 1.1
PU 1	−14.2 ± 0.9 *	−8.1 ± 1.3
PU 2	−11.90 ± 6	−5.4 ± 0.3
PU 3	−11.50 ± 4	−5.0 ± 0.3
Silicone	−12.50 ± 5	−5.2 ± 0.2
EVA	−11.30 ± 8	−4.9 ± 1.3

Reference

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