THE MECHANICAL CHARACTERISTICS OF LOWER LIMB PROSTHETIC FEET ANALYSED THROUGH GAIT ANALYSIS


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INTRODUCTION
Lower limb prosthesis have achieved a high level of functionality thanks to the availability of new materials, such as titanium and carbon fiber textile, which are currently included in a modern modular prosthesis. This technological evolution permits the amputee to achieve a rather independent life, and even perform a sport practice, when the stump has no suffering conditions [1,2,3].

The socket is the most important prosthesis component: it has the function to contain the residual limb of the amputee, to support the body weight during gait, and must assure both stump comfort and prosthesis functionality. Another important component is the prosthetic foot. Most of the traditional prosthesis assemble SACH (Solid Ankle Cushioned Heel) feet, because of their easy construction and relatively good acceptance for walking. However, with the introduction of dynamic energy storing feet, realized by carbon fibres, the range of feet choice has greatly increased and their performance dramatically improved. A proper adaptation requires to consider body weight, general health conditions (and specifically the stump and lower limb joints), and the mobility attitude of patient. In the present work the main kinematic and kinetic parameters of walking in transtibial amputated subjects were analysed. In particular the mechanical characteristics of the prosthetic feet was analysed to the purpose of defining criteria for proper sizing and adaptation.

PATIENTS AND METHOD
The subjects analysed in this work were four transtibial amputees, three men and one woman (age range 27 to 40 years, body mass from 58 to 101 Kg, height from 1.63 to 1.87 m).

All of them had been wearing prosthesis for more than 10 years. Four prosthetic devices, one for each subject, were specifically manufactured for this study and equipped with the same model of foot (Otto
Bock-1C30 Trias®). The prosthetic feet were assembled without the cover, and used without the shoe, in order to allow detecting the deformation of the prosthetic foot leaves.

Data acquisition was made in a gait analysis laboratory (MBMC Lab) equipped with a stereophotogrammetric motion analyzer (Smart Motion Capture System, BTS SrL, Italy), and a dynamometric platform (Kistler, Winterthur, Switzerland), which allow to analyse both kinematic and kinetic gait parameters. The retro-reflective markers (N=22, 15 mm in diameter) were attached to the main anatomical landmarks and to the prosthesis as depicted in Figure 1 and 2. As to the prosthetic foot, a model of angle computation was defined in order to quantify the deformation under load of the upper leaf, lower leaf and rear leaf, as depicted in Figure 2.

The acquisition protocol consisted in walking on level at natural speed, and a number of different exercises that will not be presented here: walking over a foot block, squatting, rising from a chair).

RESULTS AND DISCUSSION

Stride velocity was in the range 1.2-1.6 m/s; the duration of the stance phase was on average 66.5% of the stride cycle for the healthy limb and 64.7% for the affected one. So it was longer than normal and exhibited a tendency for a prolonged duration on the healthy limb (the difference was significant at the paired Student t-test with p<0.05).

Joint angles, joint moments and powers were computed and analysed for both the healthy and the amputated limb. In general the time course of these variables were similar to the ones described in literature for the healthy subjects, although an enhanced knee flexion was observed at the healthy limb at load acceptance, which corresponded to an increased moment at the hip, knee, and ankle joints.

Figure 3. Moments of the external forces at hip, knee, and prosthetic ankle

At the prosthetic side, instead (see Figure 3), the hip joint moment was increased but the knee joint moment decreased and the ankle joint moment was (with the exception of one subject) quite exactly in the normal range. The variables reported below (Figure 4) document the deformation of the three main leaves that constitute the prosthetic foot. It clearly appear that the upper leaf undergoes an elastic deformation at push off, the rear leaf at heel strike, and the lower leaf remains almost undeformed for most of the stance phase. Putting in relation these deformations with the forces applied to the foot can provide an estimation of the energy storing effectiveness. However, for an accurate estimation of these energy exchanges, a more focussed mechanical model needs to be implemented.

Figure 4. Deformation of the three prosthetic leafs corresponding to the scheme of Figure 2

REFERENCES