Proceedings of the 12th International Symposium on Computer Simulation in Biomechanics
Cape Town, South Africa
2 – 4 July 2009

Protea Hotel Breakwater Lodge, V&A Waterfront, Cape Town, SA
INTRODUCTION
The evolution of the prosthetic lower limbs supported in recent years significant improvement of athletes’ performances and comfort. This is mainly due to use of new composite materials and of new elastomers which allow designing lighter, stronger and less dissipative new structures (fig.1).

On the other hand a correct design of these prosthetic systems which are in general not much anthropomorphic is quite complex because many requirements must be taken into account. Very few athletes that use this kind of prosthesis are bi-laterally amputated thus, in most cases, the prosthetic system must be optimized on the characteristics of the subjects’ contralateral limb.

One of the aims of a prosthesis for monolateral amputation is, indeed, to try to equilibrate the work of the two legs.

METHODS
The strength requirement is extremely important because breaking the prosthesis during a competition can lead to disastrous consequences for the athlete. The artificial feet design can be quite different (fig.2) and is mostly related to the modulation of the propulsion action during the stance phase.

The design of the structure of the prosthetic foot can not be completely repeated for each subject, because it is too long and expensive procedure – and includes also the fatigue tests - but the subjective adaptations can change enormously the performances of the prosthetic system which must be analyzed and possibly simulated case by case. The procedure for tuning the system is based on the knowledge of the patient anatomy and on his/her way of using the non amputated limb. The level of amputation and the quality of stump are among the most important subjective variables.

The tibial stump in fact can vary from only a few centimeters up to the length of the whole tibia. Sometimes the length of the stump can be chosen during the amputation surgery, thus the surgeon must also be aware of the possible chance of the subject to practice sport.

The composite lamina can be produced by each company in series only in a limited number of shapes and sizes but can be adapted to the characteristics of different subjects.

The length of the stump and the characteristics of the “cuff” that is the interface between the stump and the socket, remarkably affects the performances of the artificial foot. Also the length of the “tibial part” of the prosthetic foot and the position of the element binding it to the stump can be significantly changed (fig.3).
Therefore these are elements that must be taken into account in the computer simulation of the specific cases.

By studying the swing phase of the running step it is possible, for instance, to obtain important information for the prosthetic system calibration.

For the simulation of this phase, FE models have been built and solved with implicit and explicit solver, using as input the toeoff conditions and the contralateral leg kinematic during its whole swing phase.

RESULTS AND DISCUSSION

The analysis of the vibrations of the whole system shows that some natural frequencies are of same order of magnitude of the cadence of running, thus they can have relevant influences on both comfort and performance. The parameters that mainly affect these low frequency modes are the mass of the lamina and the dimension and properties of the stump and of the cuff. Preliminary F.E. analyses (Fig.4 and Fig.5) show that in many cases the effects of the lowest frequencies modes of vibration can be studied also with a simplest approach, based on multi-body models with finite spring ad damper elements. This method is more affordable by the orthopedic laboratory which has to adapt the feet to the athletes. As an example fig.5 show the displacement of the prosthesis relative to the stump, corresponding to one of the most important vibration mode of the system. The color distribution (in Fig.5: displacement 0= blue) shows that the same motion can be obtained by using a multibody model with a torsional spring on a point of the socket. The spring stiffness can be tabled in function of the characteristics of the cuff, as calculated by means of preliminary finite element tests which only require simple approximated data on stump geometry.

CONCLUSIONS

Some structural components of the artificial foot for the competitions must be produced in series and tested for safety thus they can also be designed with a refined approach; on the other hand the customization process required for each athlete can drastically affect the system performance. The dynamic simulation of the system can be useful also to optimize the customization results. In most cases it is possible to obtain adequate results using simplified approaches which are also affordable for the everyday practice of a technical laboratory.

REFERENCES
