Biarticular structures to strengthen the push-off in lower leg prosthesis

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SUMMARY

The aim of this study was to test whether an elastic biarticular structure in a lower leg prosthesis (ortho-prosthesis ankle-knee, OPAK) can improve the push-off during walking. The spring stiffness was estimated from human walking data. The OPAK concept was successfully applied to a below knee amputee. The phases of muscle activity during the gait cycle were partially reproduced by the springs (Fig. 1). The activity phase can be shifted in time by changing the specific spring properties. A better push-off was not achieved with the current construction. To better represent muscle function during human walking, a switchable, non-linear viscoelastic muscle behaviour should be implemented.

INTRODUCTION

Above- and below knee amputees lack the ability to push the foot actively off the ground resulting in significant deficits in their walking patterns [1]. One possibility to reduce these inequalities is shown by studies of van den Bogert [2] and Seyfarth et al. [3]. Bogert describes that passive structures crossing multiple joints can reduce the energy cost in legged locomotion. Seyfarth et al. shows that biarticular structures crossing the knee and the ankle joint can support push-off in Robots. Under these approaches, a lower leg prosthesis (Fig. 2) was developed, in which the biarticular M. gastrocnemius is substituted by a spring. Also for the monoarticular M. soleus and M. tibialis springs were included. The aim of the study was to investigate whether the integrated set of springs and the coupling of the ankle and the knee joint can improve the push-off. Furthermore, we tested the effects of varying spring stiffness values on the foot function during walking.

METHODS

During treadmill walking (0.8m/s to 1.7m/s), joint kinematics (Qualisys Pro-Reflex camera system) and kinetics were measured. The initially used spring-stiffness was derived from kinematic and force data collected during treadmill walking of healthy subjects. In a second setup about 50% of this stiffness was used for the tibialis-, the soleus- and the gastrocnemius-springs. In some trials, the soleus- and the gastrocnemius-springs were completely omitted. For one setup, we also tested variations of the rest-length of the gastrocnemius-spring.

The OPAK prosthesis (Fig. 2) was adjusted to a 45-year old below knee amputee. Trials with the everyday-prosthesis of the subject and data of the natural gait pattern of healthy subjects were used for comparison.

RESULTS AND DISCUSSION

It is shown that the phase-specific activity of the muscles during walking can be partially reproduced by the OPAK (Fig. 1). The fixed attachment of the springs to the prosthesis and linear elastic

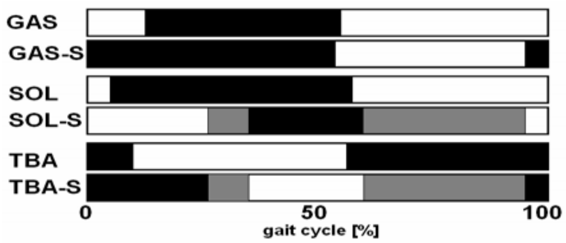

Fig. 1: phases of muscle- (1,5m/s, S. Lipfert unpublished) and spring-activation (1,7m/s, for one selected spring setup) during the gait cycle in walking (black = on / grey = equilibrium state SOL-S and TBA-S / white = off)

behaviour is different to a Hill-type muscle behaviour. We measured insufficient knee extension during Mid- and Terminal Stance avoiding an improved push-off as aimed with the gastrocnemius-spring. Possible solutions to this could be to use non-linear springs or to engage the springs in different phases of the gait cycle. Also, an adaptation of the lever arms of the springs could improve the function of OPAK.

Fig 2: OPAK (Ortho-Prosthesis-Ankle-Knee)

REFERENCES

1. Schaarschmidt, M. *Biomechanik des Prothesenlaufens – Von der Analyse zur Intervention*. Diploma thesis, *Friedrich Schiller Universität Jena*, 2007.
2. van den Bogert, A.J. Exotendons for assistance of human locomotion. *BioMedical Engineering OnLine*, **2,** 17, 1-8, 2003.
3. Seyfarth, A. et al. Towards Bipedal Jogging as a Natural Result of Optimizing Walking Speed for Passively Compliant Three-Segmented Legs. *The International Journal of Robotics Research*, **28**, 2, 257-265, 2009.