PROSTHETIC KNEE STABILITY DURING THE PUSH-OFF PHASE OF WALKING - EXPERIMENTAL FINDINGS

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ABSTRACT

Most of the energy needed for ambulation is generated during the double support phase of walking. Knee flexion during push-off is crucial to maintain the walking velocity. Since users of an above-knee prosthesis have to stabilize the knee with the hip muscles, and regular knee mechanisms are not stable during flexion, this may cost a large effort.

This paper deals with experimental findings of walking with different types of knees. The results indicate that for walking with a more stable knee, the symmetry increases and the net hip moments of force, required to stabilize the knee, reduce. The mechanical work however, performed at the hip joint at the prosthetic side, remains about equal.

INTRODUCTION

With the present knee-hinges, there is no or only a very limited possibility to make a stable knee flexion during the stance phase. None of the knee mechanisms allow for a functional knee flexion during push-off. Since no muscles cross the knee in an above knee prosthesis, the prosthetic user has to stabilize the knee with the hip musculature, which may cost a large effort.

The knee flexion during push-off is crucial to maintain the walking velocity. The knee instability is one of the reasons that users of an above-knee prosthesis in general walk at a lower speed and with a smaller time duration of the prosthetic stance phase [1].

Numerical simulations of walking revealed that an implicitly more stable construction of the knee would yield a larger walking velocity and an increased symmetry. This resulted in the design of the UTKnee, a four-bar knee mechanism with an inverted (as compared to the regular knees) trajectory of momentary points of rotation (figure 1).

The purpose of this paper is to compare the effect of different knee designs on prosthetic gait, especially the effect on the work performed at the hip joint to stabilize the knees.

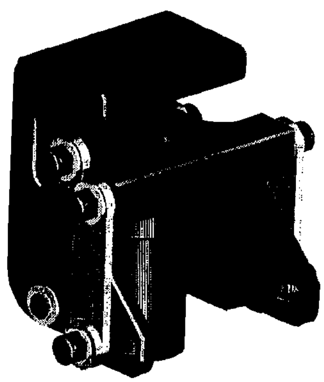

Figure 1: Prototype of the UTKnee, posterior view.

METHODS

Three different knees were tested on a single healthy subject (male, 26 years, 83 kg, 1.83 m) with an above-knee prosthesis. Analysis of the kinematic and dynamic gait parameters has been done by measurements with a Vicon video system. An average cycle was calculated in each session from 10 walking trials at a comfortable speed.

In each session, a different type of knee was fitted in the prosthesis. With the exception of the knee, the prosthesis remained identical. Three knee-types were used: A single axis knee with an adaptable (in anterior-posterior direction) center of rotation, a regular four-axial knee which the subject normally used and a UTKnee with adaptable polar curves varying from setting 1 (largest polar curve) to setting 4 (smallest polar curve).

The average cycle for each session was analyzed using an inverse dynamics method and a segments model containing 8 segments: Pelvis, upper legs, lower legs, feet and a HAT segment for head, arms and trunk [2].

RESULTS

One of the most significant parameters is the push-off time with the prosthetic leg. Normally this double support time is shorter for the prosthetic leg than for the sound leg. This is also the case for the measurement with the normal prosthesis of the subject (figure 2).

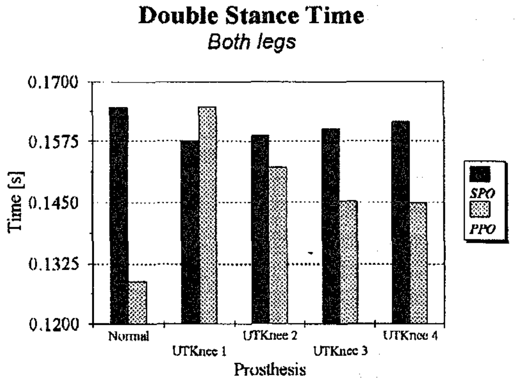

Figure 2: Push-off times (prosthetic and sound leg) for different knees.

In this figure the time duration of the double support phase with the push-off of the sound leg (SPO = Sound Push-Off) is considerably larger than the time duration of the other double support phase (PPO = Prosthetic Push-Off). For all different settings of the UTKnee (1 indicates the largest polar curve, 4 the smallest) the prosthetic push-off time increases significantly, whereas the sound push-off time remains the same.

The results for the single axis knee are not shown in figure 2; these can be summarized with the conclusion that the prosthetic push-off time increases (towards the normal push-off time) when the knee center is placed more backwards.

An interesting dynamic parameter is the hip moment of force on the prosthetic side. Figure 3 shows these moments for the normal four-axial prosthetic knee and the different adjustments of the UTKnee as a function of time during one cycle. The averaged cycle starts with prosthetic heel contact. Except for setting 1, the moments needed to flex the knee (or to stabilize the knee) during push-off are smaller for the UTKnee than for the normal prosthesis.

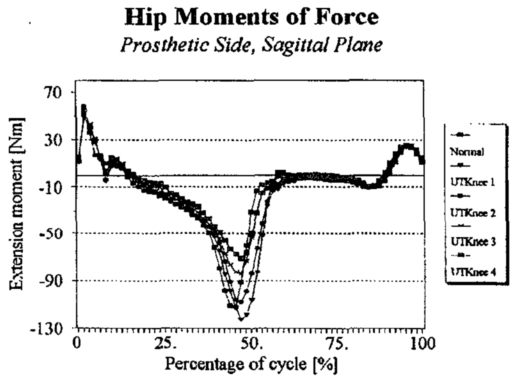

Figure 3: Sagittal hip moments of force on the prosthetic side to stabilize the knee.

Although the hip moments of force are less, the total mechanical work done at the hip joint during the push-off time remains about equal.

DISCUSSION and CONCLUSIONS

The results show that the inherent stability of a prosthetic knee has a large effect on the walking pattern. A knee which is stable during the initial part of knee flexion, such as the UTKnee, allows for an improved symmetry of gait. The stability of the prosthetic knee directly relates to the effort needed to walk: Although the mechanical work output at the hip joint during push-off is about the same, the net joint moment of force is less for a more stable knee. This indicates that the muscular effort will be less as well.

REFERENCES

[1] James, U and Öberg, K: Prosthetic gait pattern in unilateral above-knee amputees. Scan. J. Rehab. Med. 5:35-50, 1973

[2] Koopman, B, Grootenboer, HJ and de Jongh, HJ: An inverse dynamics model for the analysis, reconstruction and prediction af bipedal walking. J. Biomechanics 28-11: 1369-1376, 1995