STRESS RESULTANTS IN PROXIMAL FEMUR OF TRANSFEMORAL AMPUTEES DURING DIFFERENT CASES OF FALLING: A MULTI-BODY SIMULATION

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SUMMARY
The clinical application of osseointegrated exoprosthesis sockets is under current development. Therefore we investigate loading conditions of the prosthesis/implant interface in risk situations such as falling scenarios and present results from a multi-body simulation.

INTRODUCTION
Conventionally, above knee amputees are fitted with shaft prosthesis. In order to improve the quality of life of such patients, where the conventional treatment evokes difficulties, skeletal integration of an exoprosthesis was developed [1,2,3]. The TExoPro cooperative was founded in order to deal with the persistent issues of microbiological infection in the percutaneous passage and possible bone/implant interface overloading. In the context of the TExoPro cooperative, the loads in the region of the exoprosthesis are investigated in activities of daily living and risk situations.

Recent studies illustrated the danger of skeletal and implant fractures of osseointegrated prosthetic interfaces [4]. Therefore the development of a safety element for daily use is planned. It is designed to protect the bone/implant interface from overloading, similar to a ski binding mechanism. As direct measurement is not possible for practical and ethical reasons, the loads acting on the interface are investigated with a multi-body simulation in different cases of falling. The aim of the study is to provide an upper bound of loading conditions serving as design parameters for the safety element.

METHODS
A multi-body model is developed for the evaluation and analysis of loads acting on the implant interface during different cases of falling, using the commercial software The AnyBody Modeling System™ (Version 4.2.0, AnyBody Technology A/S, Denmark) (Figure 1) [5]. The model has been validated in a previous study regarding calculated forces and moments against a strain gauge based measurement device at six over-knee amputees during normal gait [6]. Maximum error in axial direction is 8.5%.

Figure 1: A) Multi-body model with a treatment consisting of an implant, an artificial knee and foot prosthesis on the left side. B) Position and orientation of the 0 DOF joint above the implant, determining loads.

Figure 2: Single sided, self-induced fall from gait with impact on the left knee: the falling scenario with the highest loading conditions.
The essential data of movement as well as ground reaction forces for driving and loading the model are acquired with motion capturing technology in the Gait Laboratory (PlugIn-Gait marker set [7], 8 cameras Vicon MX-20/MX-40, 2 force plates AMTI).

Different cases of falling of transfemoral amputees with a conventional shaft prosthetic are developed and analyzed. Patients are safely fastened with a harness to prevent injuries. With analysis of video sequences five particular scenarios of falling (Table 1) were selected for discussion. These scenarios are repeated by a healthy subject (185cm, 75kg) without the harness. The subject is protected with hockey pads to prevent injury. The study design has been approved by the local ethics committee.

The multi-body model divides the femur into two parts, which are connected by a 0 DOF joint at the location of the implant interface, where loads can be determined.

### Table 1: Overview of falling scenarios for maximum stress in the femur. No. 4 has additional ground contact with the second foot to balance the fall. No. 5 induces stress via maximum knee flexion.

<table>
<thead>
<tr>
<th>No.</th>
<th>Direction</th>
<th>Stance/Gait</th>
<th>Ground Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>forwards</td>
<td>stance</td>
<td>both knees</td>
</tr>
<tr>
<td>2</td>
<td>forwards</td>
<td>stance</td>
<td>one knee</td>
</tr>
<tr>
<td>3</td>
<td>forwards</td>
<td>gait</td>
<td>one knee</td>
</tr>
<tr>
<td>4</td>
<td>forwards</td>
<td>gait</td>
<td>one knee and foot</td>
</tr>
<tr>
<td>5</td>
<td>backwards</td>
<td>gait</td>
<td>hands</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

For brevity only the results of the one sided fall from gait onto the left knee are presented (Figure 2). It is the case with the highest loads. Over a short time (ca. 80 ms) a resultant force of 3.390 N as well as a resultant moment of 697 Nm acted on the implant interface (Figure 3). The largest component of the resultant force is directed axially along the bone. Due to the angle of the femur with respect to a vertical axis, the large force causes considerable moments.

The results of the multi-body simulation indicate a possible fracture at the implant interface in every investigated scenario. Biomechanical testing on human and artificial bones determined a maximum moment of 190 Nm, considerably lower than results in every falling scenario.

### CONCLUSIONS

With consideration of a safety factor, the obtained results from the multi-body simulation pose an upper bound for the loads the safety element has to deal with. The determination of lower bounds calls for further investigation on activities of daily living. These investigations are currently conducted at the MHH.

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### REFERENCES