CAN TRANSIENT SIMULATIONS IMPROVE LOWER LIMB-PROSTHESIS INTERACTION ANALYSIS?

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Introduction

Human gait is a highly dynamic process; however, most numerical analyses to simulate a lower limb prosthesis wearer are still performed using an implicit static method [1]. To account for the dynamic effects, a transient numerical simulation was performed in this study, simulating a gait cycle of a lower limb-prosthesis system. Donning of the socket followed by heel strike and push-off conditions of the gait were analyzed using a recently developed generic transtibial limb model representing an average male amputee [2]. The static results previously obtained were compared with the transient simulation and the results in terms of contact pressure, stresses, strains, and the global deformation were evaluated. The numerical results show a significant difference between the transient and static numerical simulations due to the inertia effect incorporated in the dynamic analysis, indicating a more realistic gait simulation.

Methods

Well-established Finite Elements Method (FEM) was used to analyze the interaction between the below-knee amputated residual limb and the associated prosthetic socket and liner. In contrast to the previously commonly used implicit static method, a transient dynamic method was used to simulate the gait cycle, including the inertial effect of the residual limb-prosthesis system. The main difference between the static and dynamic analysis is that in the static analysis, only the stiffness matrix K is included in the calculation (1). Whereas in the dynamic case, the mass matrix M and the damping matrix C are taken into account, forming a second-order differential equation that can be solved by both implicit and explicit methods (2). This study used the implicit method to simulate donning of the socket (quasi-static) and the explicit method to simulate the gait cycle according to ISO 10328.

$$[K]\{u\} = f(t) \quad (1)$$

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{f(t)\} \quad (2)$$

Results

The results regarding the contact pressure at the limb-liner interface, as well as the stress-strain results of the socket, were analyzed with a dynamic FEM and compared to the static results to evaluate the applicability of the new transient approach. The relative comparison between the static and dynamic simulations shows that the former overestimates the results during the gait condition. Although the socket and the liner deform similarly, a significant difference in the magnitude of the results can be observed.

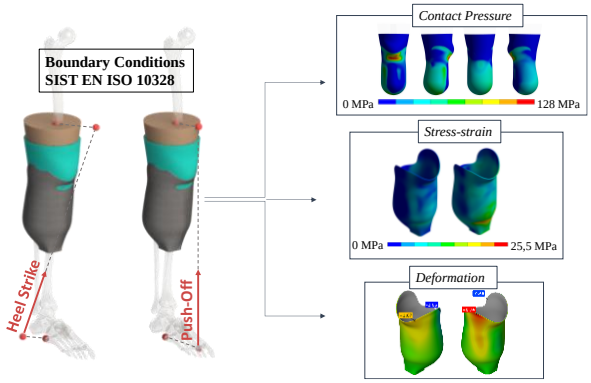

Figure 1: Left: Heel strike and push-off loading conditions according to the ISO 10328. Right: Numerical results in terms of contact pressure, stress-strain, and global deformation.

Discussion

This study took the novel approach of analyzing the socket donning and the gait of the transtibial amputee using a transient implicit and explicit method, hence creating more realistic loading conditions. Most researchers have used static simulations that exclude inertial and damping phenomena, which, as the analysis show, significantly affect the numerical results. The newly developed simulation can effectively incorporate dynamic effects and therefore allows for a more accurate assessment that supports the development of lower limb prostheses and the exploration of new manufacturing techniques, such as 3D printing of prosthetic sockets and liners.

References

1. Dickinson et. al, Med Eng Phys, 43:1-18, 2017.
2. Plesec et al, WCB 2022 Taipei, 2022.

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