UTILISING A 3D FE MODEL TO ASSESS THE EFFECTS OF ANATOMY ON STRESS/STRAIN DISTRIBUTION IN OSSEOINTEGRATED IMPLANTS

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Introduction

Osseointegrated prostheses (OIP) for transfemoral amputees represent a solution to the array of complications caused by sockets. Bypassing the soft-tissues, loads are transferred directly through the musculoskeletal (MSK) system. Mechanical complications such as bone fracture, loosening, and implant failure represent a barrier to OIP success [1]; it is important to identify how the human anatomy affects the biomechanical profile of these OIPs so that clinicians can feel confident in their recommendations. The aim of the study is to assess the effects of gender and amputation length on stress/strain distribution across the bone-implant interface through utilisation of a 3D finite element (FE) model. The overarching goal is to improve patient outcomes by producing hypotheses on biomechanical failure to inform surgical intervention and implant design.

Methods

Four healthy adult CT scans (2 female) were used to generate 12 femur models of different lengths. Each bone was amputated at 30, 40 and 50% of the original lengths and the surgical procedure of implantation simulated to create bone-implant assemblies. The assemblies were meshed (minimum element size of 3mm) and material properties applied (using grey scale values for bone) forming 3D FE models. The femurs were subdivided into seven Gruen Zones (GZ) and fixed proximally. Representative loads [2] were applied to the distal face of the device in a static structural analysis with assumed full osseointegration contact. Data were cleaned and statistical analyses ($p < 0.05$) performed using non-parametric tests to understand the effects of anatomy on stress and strain distribution across the system.

Results

Median stresses and strains in the system were found to be similar amongst the different bone lengths (Table 1).

		Amputated Length		
		30%	40%	50%
Bone	EES	.00306	.00412	.00332
	EVM	5.92	4.15	2.76
Implant	EES	.00004	.00005	.00003
	EVM	4.72	5.67	5.40
Adapter	EES	.00248	.00179	.00140
	EVM	2.70	2.63	2.62

Table 1: Summary data for median Equivalent Elastic Strain (EES) and Equivalent von Mises Stress (EVM) (MPa) for different amputation levels.

More detailed bone analysis, however, showed there were significantly different strains experienced in GZ3&5 (p = 0.022 and p = 0.029) and stresses in GZ4 (p = 0.018) (Figure 1). As femur length decreases, the implant is located higher up the medullary canal, closer to the increased proportion of trabecular bone that is less dense and more fragile than cortical bone.
The results also showed a statistical difference (p = 0.004) between genders, with female bones experiencing higher strains (F:0.0068 and M:0.0002).

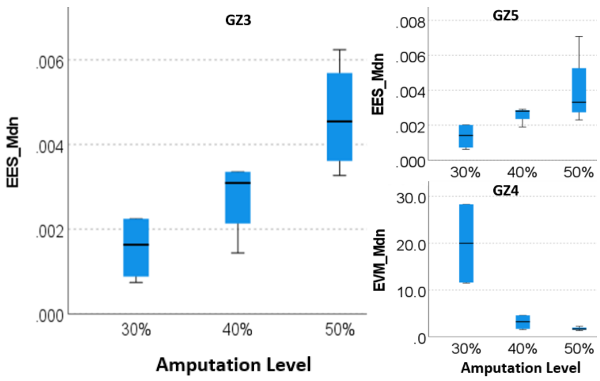

Figure 1: Volume of stress and strain due to level of amputation

Discussion

This model facilitates quantification of stress and strain distribution, allowing predictio ns of mechanical complications associated with anatomical differences. Results indicate the importance of prescribed implant geometric specification in directing load transmission through the MSK system to optimise this stress/strain distribution and improve the probability of implant success.

References

1. Hagberg et al, JOT, 38:56-64, 2023.
2. Niswander et al, Med Eng Phys, 84:56-64, 2020.

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