Longitudinal analysis of lumbar loading in an amputee using musculoskeletal simulation and direct collocation

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Summary
OpenSim MOCO software was used to analyse a lower limb amputee’s gait for 12 months after amputation, across 5 time points. Increases in intervertebral lumbar load were seen over time, although these appear to be caused by increases in body mass and walking speed rather than muscle activity changes.

Introduction
Regaining mobility after a lower limb amputation is key to an amputee's quality of life. Previous research has found 52-89% of amputees go on to develop lower back pain (LBP) in comparison to 12-45% in the non-amputee population [1]. Despite this, very few studies have made use of the latest biomechanical analysis tools to understand if there are any early mechanical indications that an amputee may go on to develop LBP based on their gait patterns.

Methods
A 67 year old unilateral male transtibial amputee underwent gait analysis 3 months post amputation and then every ~3 months after that for a period of 12 months. Before biomechanical analysis, participants completed questionnaires on their catastrophizing pain experience [3]. Full body kinematics were captured with an eight camera marker based motion capture system and kinetics were capture with a single force plate during repeated walking trials with their fitted prosthetic and at their preferred speed. A musculoskeletal model in OpenSim 4.5 was first scaled to match the anthropometrics of the participant and inverse kinematics was performed to retrieve model joint angles, including 3D lumbar vertebrae angles. The Opensim MOCO tool was used to solve an optimal control problem using direct collocation methodology. Whereby the full body kinematics were prescribed, the measured ground reaction forces were applied and an optimization was performed to minimize muscle activity and maintain dynamic consistency.

This process was repeated for three foot contacts on the prosthetic side and across the five longitudinal sessions. Within this study the biomechanical analysis focused on the mean vertical force between each lumbar vertebrae and model estimated muscle activation patterns across the sessions.

Results and Discussion
Results output from OpenSim MOCO showed that the total compressive force in the lumbar spine did increase slightly in each session from 3 months post amputation through to 12 months (Figure 1). In line with values identified in this work, previous studies [2] have found peak compressive loads ranging from ~600-900 N during walking at each L1-L5 vertebrae.

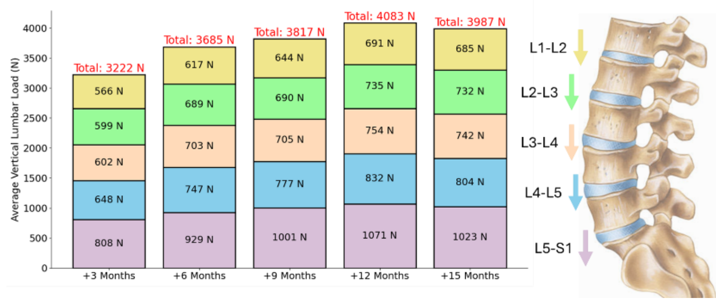

Figure 1: Compressive force output from OpenSim, averaged over analyzed duration and across the three contacts within each session.

Additional results suggest that the increases in compressive force across sessions may be predominantly explained by increases in walking speed and therefore external forces, rather than changes in estimated muscle activation patterns (Table 1). The largest increase in compressive forces from 3-6 months also coincided with the largest body mass increase from 70.5 to 75.5 kg. Apart from the elevated catastrophizing pain score within the first session, common at this stage, the self-reported pain remained low in the following sessions. Future research should look to evaluate these same biomechanical parameters amongst other amputees that experience LBP to see if they elicit more pronounced changes in biomechanics.

Conclusions
The musculoskeletal simulation methods used in this study allowed for an in-depth analysis of the lumbar loading patterns in the 15 months following amputation. The results suggest that this participant did not show large changes in their muscle activation patterns or reported pain after 3 months. The increase in compressive lumbar load may therefore have been largely due to increases in body mass and walking speed

References
[1] Highsmith et al. (2019). *Spine J*, **19**: 552-563.
[2] Mousavi et al. (2021). *Front. bioeng. biotechnol.*, **9**
[3] Sullivan et al. (1995). *Psychol. Assess.*, **7:** 524-532.

Table 1: Mean left and right Erectus Spinae muscle activation output from OpenSim, alongside the self-reported pain within each session

	3 months	6 months	9 months	12 months	15 months
Mean estimated External Oblique activation (%)	1.9	2.5	3.5	3.4	2.9
Mean estimated Erectus Spinae activation (%)	3.2	3.6	3.3	3.4	3.7
Mean walking speed (m/s)	0.55	0.82	0.94	0.78	0.81
Pain Catastrophising Scale (out of 52)	23	1	0	0	0