Model-driven electrical stimulation therapy design improves walking gait in individuals with limb amputations

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Summary

Previous studies have highlighted musculoskeletal system adaptations following limb loss, which may increase the risk of knee osteoarthritis in the intact limb and lead to muscle atrophy and osteoporosis in the residual limb. Our hypothesis is the use of functional electrical stimulation, can promote better gait function and long-term musculoskeletal health. We used muscle-driven gait simulations with a patient-specific cost function to optimize the gait performance. Once a beneficial effect is demonstrated in the in-silico simulation, we conducted physical experiments to confirm the findings.

Introduction

Amputation is a life-changing experience, resulting in impaired mobility and numerous musculoskeletal complications: within two years post-amputation, over 85% of patients develop chronic pain [1]; within five years post-amputation, more than 50% are diagnosed with osteoporosis and osteopenia [2], further limiting their quality of life. While prosthetics remain the standard of care, they do not effectively manage pain or prevent musculoskeletal deterioration. Innovative healthcare interventions are urgently needed to enhance patient outcomes and overall well-being.

Functional electrical stimulation (FES) uses electrical pulses to stimulate sensory nerves, creating sensation. When the stimulation intensity increases, motor nerves are excited, leading to muscle contractions. This combination helps manage pain and improve mobility. While FES is commonly used for neurological and musculoskeletal conditions, it has not yet been applied to people with limb amputations.

Methods

Utilizing advanced musculoskeletal modelling techniques, we designed FES therapy for people with unilateral transtibial amputations. To mitigate adverse post-amputation adaptations, we proposed cost terms (Fig.1. including minimizing the energy expenditure rate and joint contact forces in the intact limb). When the costs were satisfied, the gait simulation predicted the need to stimulate residual vastus muscles during stance.

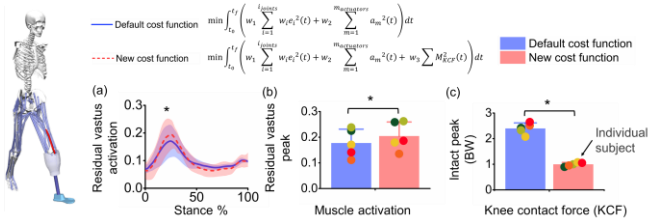

Figure 1: Predictive changes in vastus activation patterns and knee contact forces in level walking from five individuals with unilateral transtibial amputations.

Results and Discussion

The effect of the model-driven FES therapy was evaluated in the laboratory on five individuals with unilateral transtibial amputations (N=5, age=52±9years, body mass=74±14kg, height=177±13 cm, Figure. 2). The residual vastus muscle was stimulated using an FES stimulator (ODFS Pace, Odstock Medical Limited, UK), triggered by a wired footswitch (Odstock Medical Limited, UK) placed under the insole. The stimulator parameters, configured by the clinician, included an asymmetric biphasic waveform, a 40 Hz frequency, a 180 us pulse width, a rising ramp of 200 ms, a falling ramp of 300 ms, and a 2.5 s time-out period. The current intensity was adjusted individually, beginning at a low level and gradually increasing to the comfort threshold. Positive effects of FES gait include increased muscle forces in the residual limb and reduced knee contact forces in the intact limb, indicating the mitigation of musculoskeletal conditions (osteoporosis at the residual limb and osteoarthritis in the intact limb) in the long term.

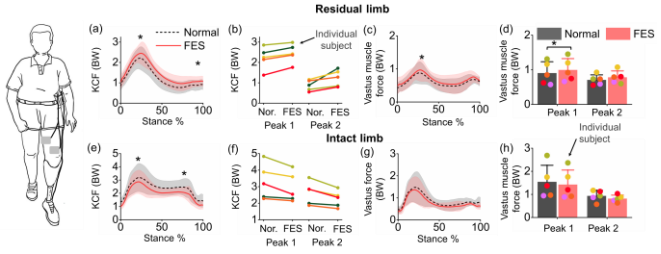

Figure 2: Changes in the musculoskeletal dynamics between normal walking and FES walking with stimulation on the residual vastus muscle.

Conclusions

Our computational design of FES therapy showed great potential to mitigate the onset of musculoskeletal conditions. To clinical adoption, the treatment effect of the FES therapy needs to investigate in a longer period of time.

Acknowledgments

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References

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