Changes in Thigh Soft Tissue Stress According to Attachment Conditions in Hip-Assist Walking Robots

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Summary

We tested three different strap widths and assist modes in a hip-assist robot to evaluate thigh soft tissue stress. Overall, stress levels stayed below discomfort thresholds, suggesting that, under typical usage, skin injury risk is minimal.

Introduction

Wearable walking assist robots must be secured tightly, potentially causing significant skin pressure [1]. Fluctuating strap tension during gait can lead to discomfort if stress surpasses certain thresholds [2], and prolonged excessive stress can pose risks for soft tissue damage [3]. However, many previous studies have only considered static postures or relied on simplified models, limiting their ability to capture the dynamic nature of gait. This study therefore investigates how different hip-assist robot modes and strap widths influence thigh tissue loading under realistic walking conditions. By quantifying both normal and shear stresses over a full gait cycle, we aim to provide a more comprehensive assessment of user safety.

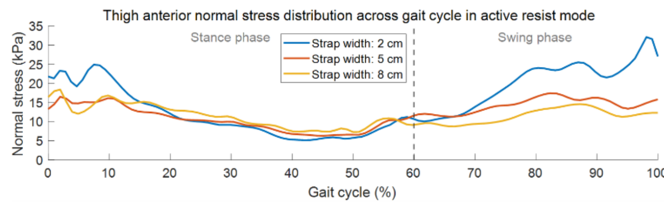
Methods

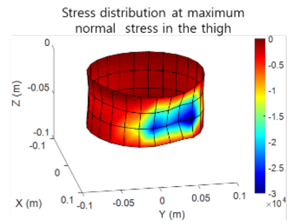
Figure 1: Simulation model.

A forward dynamics simulation was conducted using custom code made with the RaiSim dynamics solver and a 25-degree-of-freedom skeletal model wearing the 6-degree-of-freedom GEMS hip-assist robot [4]. We developed a multi-layer mass-spring mesh with physiological Young's modulus and damping properties of the thigh soft tissue [5], linking the skeletal system to GEMS. Compared with finite element analysis, this approach provided faster computation, enabling multiple gait cycles to be evaluated in different conditions. A gait controller for forward dynamics simulation was trained to generate normal walking motion via reinforcement learning [6]. The gait controller was used to provide joint torques to a skeletal model with GEMS hip-assist robot. The GEMS operated in unpowered, active assist (Delayed Output Feedback Control), and active resist (inverted DOFC) modes [4]. Normal and shear stresses on the thigh were recorded over a complete gait cycle (0–100%) for each strap width and mode. The resulting stress values were compared with known discomfort thresholds and tissue-injury criteria [1, 3].

Results and Discussion

As shown in Figure 2, the resist mode typically produced the highest normal stress values, particularly when using the narrowest strap (2 cm). This finding aligns with the expectation that restricting gait leads to stronger interaction forces between the limb and the robot interface. Wider straps (5 cm and 8 cm) dispersed load over a broader region, thereby moderating peak stress.





Maximum normal (shear) stress in the thigh

Maximum normal (shear) stress (kPa)		Unpowered mode	Active assist mode	Active resist mode
Strap width	2 cm	18.8 (7.4)	25.6 (10.3)	32.1 (8.8)
	5 cm	20.2 (9.7)	25.4 (11.6)	22.8 (9.4)
	8 cm	21.9 (10.2)	26.5 (11.5)	19.5 (9.1)

Figure 2: Thigh Stress Analysis During Gait.

According to [1], 50 kPa is commonly cited as the boundary above which pain becomes likely. In the resist mode with a 2 cm strap, peak normal stress reached 32.1 kPa, indicating that while users might experience mild discomfort, it remains below the threshold for severe pain. In contrast, other modes and wider straps exhibited substantially lower peak normal stresses, suggesting a more comfortable fit in those conditions. Shear stress was also measured and evaluated against tissue-injury criteria [3]. Even under extended usage scenarios, observed shear levels did not approach values known to cause significant skin or soft tissue damage, indicating minimal injury risk for most users.

Conclusions

Normal stress peaked in resist mode with a 2 cm strap but remained below levels associated with severe pain. Shear stress also stayed within safe margins across all configurations, indicating a generally low risk of injury under typical usage.

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