Abstract

This doctoral research focuses on the design, development, and validation of two novel semi-powered knee prosthesis architectures aimed at enhancing the versatility of microprocessor-controlled knees (MPKs) while preserving their passive advantages. Recognizing the limitations of current prosthetic technologies in replicating healthy gait during demanding activities, two distinct approaches were proposed: Unico and Unico v2.

The first design, Unico, introduces a semi-active prosthesis that decouples the actuation system from the knee joint through a mechanical disengagement mechanism. This configuration allows the prosthesis to behave as a fully passive device during level walking, slope navigation, and sit-to-stand transitions while selectively enabling powered extension during tasks such as stair ascent. Bench and pilot clinical validations demonstrated that Unico maintained gait patterns comparable to commercial MPKs during passive-mode tasks, while significantly improving propulsion symmetry and reducing muscular effort during active-mode tasks. Participants showed improved knee flexion, increased toe clearance, and reduced metabolic costs, highlighting the potential for enhancing safety and comfort without compromising passive transparency.

Building upon the insights gained from Unico, a second design, Unico v2, was developed to overcome identified limitations. Unico v2 introduces a novel three-state speed transmission system capable of electronically switching between passive resistance, low-torque high-speed support for swing assistance, and high-torque low-speed support for powered stance extension. This design enhances the prosthesis' ability to deliver bidirectional powered assistance without sacrificing passive efficiency. The new architecture leverages a compact integrated actuation system featuring a high-torque motor and a frontal-teeth engagement mechanism, allowing fast and reliable state transitions even under load.

Overall, this research contributes to advancing prosthetic technology by bridging the gap between passive MPKs and fully powered knees. By enabling targeted active assistance while maintaining passive advantages, the proposed solutions represent a significant step toward more adaptable, energy-efficient, and user-accepted knee prostheses for individuals with transfemoral amputations.