Design and evaluation of a novel bioinspired prosthetic foot for running applications in lower limb amputees

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ABSTRACT

With the rise in transtibial and transfemoral amputations, the number of athletic amputees has steadily increased. This study aims to develop an alternative prosthetic foot for the lower limb to address the limitations of conventional prosthetic designs and better meet user requirements. The proposed prosthetic foot offers a promising solution by incorporating cost-effective materials and mechanisms. The primary objective is to create a prosthetic device suitable for sports activities – particularly running – allowing lower limb amputees to participate in endurance sports using mechanically enhanced limbs that closely mimic the function and characteristics of natural biological limbs. The mechanical and miscibility properties of the prosthetic foot were evaluated through experimental, theoretical, and numerical approaches. Polyester matrix laminates reinforced with both natural and synthetic fibers were fabricated using a vacuum-assisted system and subjected to tensile, hardness, bending, fatigue, and Fourier transform infrared (FTIR) spectroscopy tests. To assess loading behavior and user comfort, force plate measurements during the gait cycle provided insight into ground reaction forces, moments, and abutment interface pressures, supplemented by F-Socket testing. Finite element analysis was used to determine the distribution of safety factors, strain energy, total deformation, and equivalent von Mises stress and strain. Laminates reinforced with hybrid glass, carbon, and linen fibers demonstrated optimal tensile strength, bending resistance, fatigue performance, and hardness. FTIR spectroscopy analysis further indicated significant interaction between the fibers and the resin. Gait cycle analysis revealed that the prosthesis made from composites reinforced with carbon, glass, and linen fibers exhibited superior comfort, with a maximum applied force of 610 N and acceptable interface pressure values – making it suitable for prosthetic applications. In conclusion, the selected materials meet established safety standards, confirming their suitability for prosthetic foot design. This study underscores the orthopedic potential of biodegradable materials and highlights advancements in biomedical engineering through enhanced biocompatibility and durability.

Keywords:
Amputation; Biomaterials; Finite element methodology; Foot; Sport prosthetics

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1. Introduction

Running has become one of the most prominent events in the Paralympic Games. The use of artificial carbon blade prostheses in sprinting and long jump has reached remarkable performance levels, sparking debates about the fairness of these mechanical advantages compared to able-bodied athletes.[1] Nevertheless, increased participation in adaptive sports has not only heightened public interest but also fostered greater awareness and inclusivity for individuals with amputations. Advancements in prosthetic components for daily use have steadily expanded the functional capabilities available to athletic amputees. Over the past two decades, prosthetic components and designs have undergone continuous advancements for professional