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DEVELOPMENT OF A SHOCK-ABSORBING 3D-PRINTED LINER FOR LOWER LIMB PROSTHESES

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ABSTRACT

The current situation in Ukraine, exacerbated by ongoing military operations and a significant increase in amputations among both military personnel and civilians, requires urgent solutions in the field of prosthetics. A personalized approach to the production of high-quality and comfortable lower limb prostheses has become especially relevant. Custom design, taking into account the anatomical features of each patient's residual limb, enables the creation of inserts with optimal shape and density. This minimizes pain, reduces the risk of irritation, inflammation, or swelling, and accelerates adaptation to a new way of movement. The use of 3D printing technology makes this process more accessible and cost-effective, as it allows for the rapid creation of personalized products without the need for expensive equipment or complex, multi-level production chains. In addition to improving patient comfort, this approach stimulates the development of Ukrainian engineers and biomedical specialists, fostering collaboration between research institutions and manufacturers and laying the foundation for a competitive high-tech industry. Ultimately, this has a positive impact on the socio-economic situation: the faster reintegration of amputees into active life reduces state spending on long-term treatment and rehabilitation while increasing employment rates and labor productivity. Therefore, the combination of high quality, personalization, and efficient resource use makes the implementation of modern 3D printing methods in lower limb prosthetics one of the most effective responses to the urgent needs of both veterans and civilians.

Keywords: 3D Printing, clinical integration of new drugs, prostheses.

1. THE AIM OF THE STUDY

The aim of this study is to develop and thoroughly substantiate a shock-absorbing 3D-printed liner for lower limb prostheses, designed to enhance both comfort and functionality while minimizing the risk of stump irritation and associated complications. The primary focus lies in combining a personalized approach to product design with the application of modern additive manufacturing technologies, all within a cost-effective framework.

The study explores the technological aspects of fabricating such a liner, including the analysis of optimal materials and printing parameters that ensure the required shock-absorbing properties, sufficient flexibility, and long-term durability. Particular attention is given to adapting the liner to the patient's individual anatomical characteristics, as a precise fit and uniform pressure distribution between the stump and the inner surface of the prosthetic socket are critical for preventing chafing, irritation, and inflammation. To achieve this, the use of specialized geometric structures and materials is proposed—those capable of effectively absorbing microvibrations and reducing excessive friction, both of which are common causes of skin damage, pain, and overall discomfort. The effectiveness of the developed 3D-printed liner will be evaluated through a series of biomechanical tests (including shock load and pressure distribution assessments) as well as clinical trials, aimed at demonstrating improved comfort and reduced pain compared to conventional liners.

2. MATERIALS AND RESEARCH RESULTS

Modern research in the fields of additive manufacturing and prosthetics highlights an active search for solutions to ensure effective shock absorption in lower limb prostheses through the use of highly flexible yet durable materials. Thermoplastic polyurethanes (TPU) and thermoplastic elastomers (TPE) have gained significant popularity due to their high wear resistance, elasticity, and the ability to fine-tune their mechanical properties by adjusting 3D printing parameters or modifying the internal geometry of the product. One promising direction is the development of antibacterial TPU composites, as demonstrated by the findings of Chang, Zhu, and Liu [1]. Specifically, the authors detailed the integration of silver nanoparticles directly into the composition of the filament used to print medical devices. The conducted tests

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showed a pronounced inhibitory effect of silver-containing TPU on the growth of pathogenic microorganisms such as Staphylococcus aureus and Escherichia coli. This is particularly relevant for prosthetic components that remain in prolonged contact with the skin and are susceptible to irritation, infection, and unpleasant odors. This approach not only enhances the hygienic characteristics of the product but also preserves its functional performance, as TPU maintains the required flexibility and sufficient tensile strength. In parallel, Kwon, Seo, and Lee [2] focused on optimizing the production of elastic liners using fused deposition modeling (FDM). During their experiments, they evaluated several types of TPU with varying Shore hardness levels, with special emphasis on the impact of extrusion temperature and printing speed on the final mechanical properties of the printed inserts. The authors concluded that properly selected printing parameters can produce more elastic components with improved stump conformity compared to traditional silicone liners.

High precision of fit significantly reduces the risk of pressure sores and skin irritation, as confirmed by preliminary field tests conducted with a group of volunteers. In terms of the internal structure of 3D-printed components, lattice architectures have garnered considerable interest due to their ability to selectively vary stiffness across different regions of a product. Huang et al. [3] investigated how modifications in lattice parameters—such as cell size, shape, and orientation—affect the mechanical properties of TPU components fabricated using selective laser sintering (SLS). Their findings demonstrated that a gradient in lattice density can significantly reduce peak loads and enhance elastic deformation during both cyclic and impact testing. This enables a more even distribution of pressure across the stump surface, thereby reducing material fatigue and improving patient comfort during ambulation.

Another innovative approach was proposed by Bickel, Matusik et al. [4], who emphasized software-based control of material elasticity. By employing advanced topological optimization algorithms, they developed a method for precisely tuning the spatial distribution of material density according to user-specific requirements. This enabled the fabrication of "zoned" components—for instance, a central section with increased rigidity to provide structural support, surrounded by peripheral zones with higher elasticity for cushioning and pressure redistribution. Such customization is particularly beneficial for individuals with irregular stump geometries or heightened tissue sensitivity. A key area in current research is the assessment of functional and clinical performance indicators of new prosthetic solutions. For example, Choi, Ogle, and Shin [5] conducted a comparative study between 3D-printed prosthetic sleeves and conventional ones, involving users with various types of lower limb amputations. Their results indicated that a well-matched geometric fit of the flexible sleeve to the stump significantly reduces friction and the likelihood of edema, while also improving stability and walking comfort. However, the study also highlighted persistent challenges, including ensuring adequate joint strength between the flexible sleeve and the rigid prosthesis components, as well as validating the material's performance under extreme fluctuations in temperature and humidity. These factors must be thoroughly considered when implementing flexible 3D-printed elements into prosthetic devices [6].

CONCLUSIONS

The study showed that FDM 3D printing technology using TPU is an effective means of manufacturing shock-absorbing inserts for lower limb prostheses. This approach has a number of important advantages that make it extremely promising for medical applications, especially in the context of individualized prosthetics. First, 3D printing allows for high-precision adjustment of the liner to the shape of the stump, which is critical for uniform load distribution and prevention of painful pressure points. Second, the use of flexible TPU polymer in combination with an optimized lattice structure provides effective absorption of shocks and vibrations without loss of the supporting capacity of the structure. This significantly increases patient comfort and reduces the risk of skin and soft tissue damage during prolonged use of the prosthesis. Third, the use of additive technologies makes it possible to quickly manufacture individualized inserts at a moderate cost, which is especially important for accelerating rehabilitation and reducing prosthetic costs. Further development of the research is seen in improving the materials and technology for manufacturing inserts. In particular, the use of other 3D printing methods (SLS, MJF) to improve the uniformity of the structure and accuracy of products is promising, as well as the introduction of antibacterial additives to TPU to improve the hygiene of long-term use. Additional long-term clinical trials will allow assessing the wear resistance and effectiveness of the inserts in real operating conditions, providing full confidence in their reliability. Overall, the results of the work confirm the high effectiveness of using modern 3D printing technologies to create personalized prosthetic components, opening up new opportunities for increasing the comfort and safety of prosthesis users.

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