Study of Biomechanical Model for Smart Sensor Based Prosthetic Socket Design System

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Abstract : Prosthetic socket is a component that connects the residual limb of an amputee with an artificial prosthesis. It is widely recognized as the most critical component that determines the comfort of a patient when wearing the prosthesis in his/her daily activities. Through the socket, the body weight and its associated dynamic load are distributed and transmitted to the prosthesis during walking, running or climbing. In order to achieve a good-fit socket for an individual amputee, it is essential to obtain the biomechanical properties of the residual limb. In current clinical practices, this is achieved by a touch-and-feel approach which is highly subjective. Although there have been significant advancements in prosthetic technologies such as microprocessor controlled knee and ankle joints in the last decade, the progress in designing a comfortable socket has been rather limited. This means that the current process of socket design is still very time-consuming, and highly dependent on the expertise of the prosthetist. Supported by the state-of-the-art sensor technologies and numerical simulations, a new socket design system is being developed to help prosthetists achieve rapid design of comfortable sockets for above knee amputees. This paper reports the research work related to establishing biomechanical models for socket design. Through numerical simulation using finite element method, comprehensive relationships between pressure on residual limb and socket geometry were established. This allowed local topological adjustment for the socket so as to optimize the pressure distributions across the residual limb. When the full body weight of a patient is exerted on the residual limb, high pressures and shear forces between the residual limb and the socket occur. During numerical simulations, various hyperplastic models, namely Ogden, Yeoh and Mooney-Rivlin, were used, and their effectiveness in representing the biomechanical properties of soft tissues of the residual limb was evaluated. This also involved reverse engineering, which resulted in an optimal representative model under compression test. To validate the simulation results, a range of silicone models were fabricated. They were tested by an indentation device which yielded the force-displacement relationships. Comparisons of results obtained from FEA simulations and experimental tests showed that the Ogden model did not fit well the soft tissue material indentation data, while the Yeoh model gave the best representation of the soft tissue mechanical behavior under indentation. Compared with hyperplastic model, the result showed that elastic model also had significant errors. In addition, normal and shear stress distributions on the surface of the soft tissue model were obtained. The effect of friction in compression testing and the influence of soft tissue stiffness and testing boundary conditions were also analyzed. All these have contributed to the overall goal of designing a good-fit socket for individual above knee amputees.

Keywords : above knee amputee, finite element simulation, hyperplastic model, prosthetic socket
Conference Title : ICSRD 2020 : International Conference on Scientific Research and Development
Conference Location : Chicago, United States
Conference Dates : December 12-13, 2020