Designing Total Joint Arthroplasty of Metatarsophalangeal Joint and Performing Finite Element Analysis

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Athletes' performance can be hindered by several pathologies associated with the first metatarsophalangeal joint. Arthrodesis is described as the most successful 'gold standard' surgical procedure for treating the first metatarsophalangeal joint injuries. However, there is a growing consensus that the ability to total metatarsophalangeal joint replacements outperforms arthrodesis. Therefore, there are several evolutionary stages and complications to be addressed in the current first metatarsophalangeal joint prosthesis. In this study, based on the clinical requirements and anthropometrical data found from the literature, a 3-dimensional model of the total joint arthroplasty was designed using AutoCAD software. Next, the material properties were defined for each component, including the cartilage, metatarsal head and phalangeal base, and insertion screws considering biocompatibility and mechanical properties. Finally, finite element analysis was performed using Solid Works software to compare the mechanical strength and stress concentrations on the first metatarsophalangeal joint arthroplasty under different loading conditions. Loading condition representative of the forces experienced during daily activities was applied and static modal including stress distribution, and strain deformation within the implant and the surrounding bone were analyzed. The model consisted of 34012 nodes, 21086 elements and the degree of freedom was 75120. A physiological loading force of 600N was applied and the maximum von Mises stress observed in the static modal stress model is 9.245X107 N/m2, less than the yield strength of 1.200X108N/m2. Therefore, it is evident that the maximum stress does not exceed the ultimate tensile stress of the material. The first metatarsophalangeal total joint arthroplasty design used in this study is durable for the given force. This research as a preliminary approach would greatly reduce the number of engineering hours to scale up this design for a prosthetic design using more sophisticated technologies.

Keywords: 3D Modelling, Finite Element Analysis, Arthroplasty, Engineering