Biomechanical Analysis and Design Considerations of Tibial Component for Total Ankle Replacement

A Thesis

Submitted

by

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AFFECTIONATELY
DEDICATED
TO MY LOVING
PARENTS

Declaration by the Research Scholar

I hereby declare that the entire work embodied in this Thesis entitled "**Biomechanical Analysis and Design Considerations of Tibial Component for Total Ankle Replacement**" is the result of investigations carried out by me in the ***School of Engineering***, Indian Institute of Technology Mandi, under the supervision of ***Dr. Rajesh Ghosh***, and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgments have been made wherever the work described is based on finding of other investigators.

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Declaration by the Research Advisor

I hereby certify that the entire work in this Thesis has been carried out by ***Subrata Mondal,*** under my supervision in the ***School of Engineering,*** Indian Institute of Technology Mandi, and that no part of it has been submitted elsewhere for any Degree or Diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on finding of other investigators.

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Abstract

Aseptic loosening of the tibial component is one of the major issues of failure for total ankle replacement (TAR) and revision arthroplasty. Early loosening of the uncemented implant is caused due to excessive implant-bone micromotion, which may hamper proper initial fixation and bone ingrowth between implant and bone. Late loosening of the uncemented component is caused due to excessive bone density loss due to strain shielding and wear-induced osteolysis. The detailed relationship between the cause and effect of mechanical loosening and the extent to which mechanical factors play in the role of the process are not clearly understood yet. This study aims to investigate the load transfer, strain distribution, implant-bone micromotion, measurement of wear depth and the implant-induced bone adaption, and their relationships with the failure risk, using finite element (FE) analysis. The prime objective of this study is to develop an improved design of the tibial component of ankle prosthesis to minimize the failure rate. A realistic three dimensional (3D) FE model of the intact ankle joint with the inclusion of all musculoskeletal loading and boundary conditions, proper material property distribution was developed using computed tomography (CT) scan data set. The effect of muscle force and ligaments on load transfer and stress distribution in the tibia and talus bone was investigated. Implantation evokes abrupt changes in the load transfer through the tibia bone. The effects of implant orientation and implant-bone interfacial condition on strain energy density (SED) distribution at the tibia were investigated. Proper bonding between implant and bone would be essential to reduce implant loosening, where a decrease in SED was found to be more in the case of debonded (non-osseointegration) implant-bone interfacial condition as compared to bonded (fully osseointegration) interfacial condition. Implant orientation and implant material influence the tibial bone strain, wear depth, and implant-bone micromotion. Varus/valgus orientations of implant lead to increase the wear depth at the articulating surface, which suggests the more wear, and that might affect the loosening of the implant in the long term. Implant material combination of ceramic with carbon-fiber-reinforced polyetheretherketone (CFR-PEEK) shows the least wear depth at the articulating surface and similar bone density distribution in the tibia bone after the bone remodelling as compared with other implant material (Co-Cr-Mo alloy with ultra-high molecular weight polyethylene (UHMWPE), and ceramic with UHMWPE) combinations. Ceramic seemed to be a viable alternative to metal and CFR-PEEK as an alternative to UHMWPE, which would be beneficial for long term fixation of the implant due to its better wear resistance properties and less metal ion release. The cancellous bone material modelling has less influence on bone remodelling around the tibia due to TAR. The selection of the lazy zone has no significant impact on bone remodelling around the tibia. Variations in implant geometry affect the SED distribution, cancellous bone strain, and bone density distribution due to bone remodelling around the tibia. The ankle prosthesis having radial curvature with the round stem at the upper surface of the tibial component shows the less reduction in SED, strain, micromotion, and bone density loss than the prosthesis having a flat and concave upper surface of tibial component with two anchorage bars.

Keywords: Ankle joint, tibia, total ankle replacement, finite element analysis, implant-bone interface condition, implant orientation, implant material, strain shielding, strain energy density, wear depth, bone remodelling, dead zone, bone density, tibial component.

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