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A Finite Element Study on the Effect of Bone-Implant Interfacial Conditions on Strain Distribution in Tibia Due to Total Ankle Arthroplasty

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Abstract

Total ankle replacement is the gold standard surgical treatment for major fractures and arthritic ankles. The failure of the ankle implants in the patient, however, raises major concerns about the need for revision procedures. The failure of the implant can be attributed to a variety of factors, including loosening of the talar or tibial component, dislocation, instability, misalignment, deep infection, fracture (close to the implant), flaw in the polyethylene, wear in the polyethylene bearing, etc. Revisions to total ankle arthroplasty are most performed due to aseptic loosening of the tibial component. The purpose of this investigation is to ascertain how well the tibial component is functioning and any probable reasons why it might fail. Here, we investigated the micromotion at the implant-bone contact and the strain distribution in the tibia bone because of total ankle surgery. In this study, computed tomography scan data were used to create finite element (FE) models of the natural and transplanted ankle. Investigations were conducted on the implant-bone contact in both bonded and non-bonded conditions. In contrast to bonded implant-bone interfacial conditions, it was found from this study that strain shielding was more prevalent in non-bonded implant-bone interfacial conditions. For the implant to be successful over the long term, the implant and bone interface must osseo-integrate properly.

Keywords: Total ankle replacement; Tibial component; Ankle; Finite element analysis; Aseptic loosening

Introduction

The preferred surgical treatment for ankle fracture and arthritis is total ankle replacement (TAR). The clinical outcomes of TAR have improved recently because of the development of contemporary three component prosthesis [1]. To boost the TAR's long-term stability, a number of clinical concerns still need to be resolved. There are numerous mechanisms that cause TAR to fail. One of the main causes of TAR's early failure is component loosening. One of the main causes for the loosening of the tibial and talar components is stress/strain shielding. The excessive bone density loss brought on by this stress/strain shielding leads to pathological bone remodelling, which loosens the implant [2]. There are numerous studies that assess TAR performance. The influence of implant-bone interface conditions on strain distribution in the tibia and implant-bone micromotion have not been well studied, as can be seen from past studies. This study's goal is to ascertain how implant-bone interfacial conditions affect the distribution of strain in the tibia bone and implant-bone micromotion. The current study may be useful for TAR's pre-clinical evaluation.

Materials and Method

An implanted ankle joint FE model was created. Data sets from computed tomography (CT) scans were used to accomplish this. According to previous research, each bone was divided into cortical and cancellous bone using a threshold value of 1.30g. cm^{-3} to rectify the partial volume impact [3]. The cortical bone was identified as a homogeneous, isotropic, and linearly elastic material with a Young's modulus and Poisson's ratio, respectively, of 19GPa and 0.3. Data sets from CT scans were used to distribute the cancellous bone material property, which was assigned as heterogeneous. In order to determine the heterogeneous material characteristics of cancellous bone, a linear relationship between bone density and CT grey value (expressed in terms of Hounsfield units) was implemented [4].

$$\rho = 0.022 + 0.0008456 \times HU \quad (2.1)$$

A power law between Young's modulus and density of bone was used similar to the previous study [3-4], in order to determine the Young's modulus of cancellous bone

$$E = 4778\rho^{1.99} \quad (2.2)$$

For the cancellous bone, Poisson's ratio was taken to be 0.3. Surgical recommendations (Small Bone Innovations, Inc.) were followed while selecting and positioning the Scandinavian Total Ankle Replacement (S.T.A.R@TM) prosthesis [5]. It is comprised of up of the tibial component, the meniscal bearing, and the talar component. For the tibial and talar components, Young's modulus and Poisson's ratio were chosen as 210GPa and 0.3, respectively, while for the meniscal bearing, they were chosen as 557MPa and 0.46, respectively, to be consistent with prior studies. Four parallel springs were used to represent each ligament in order to distribute the proper load transfer. This study used a total of sixteen different types of ligaments, and the corresponding stiffness and material parameters were derived from earlier studies [6]. In the current investigation, reaction forces were set in accordance with the three positions of the ankle during gait, including dorsiflexion, neutral, and plantar flexion. From earlier literature, the amplitude of response forces for three different ankle locations were taken into consideration and are shown in Table 1 [6-7]. At the farthest posterior position of the calcaneus bone, muscle force (Achilles tendon) was adjusted to 75% of the total body weight. Tibial and fibular proximal ends have been fixed in accordance with the prior studies. Figure 1 depicts a 3-D FE model of a prosthetic ankle with various bones, prosthetic parts, and ligaments. For the contact simulation, an augmented-Lagrangian contact algorithm with a contact stiffness of and a penetration factor of 0.1 was used.

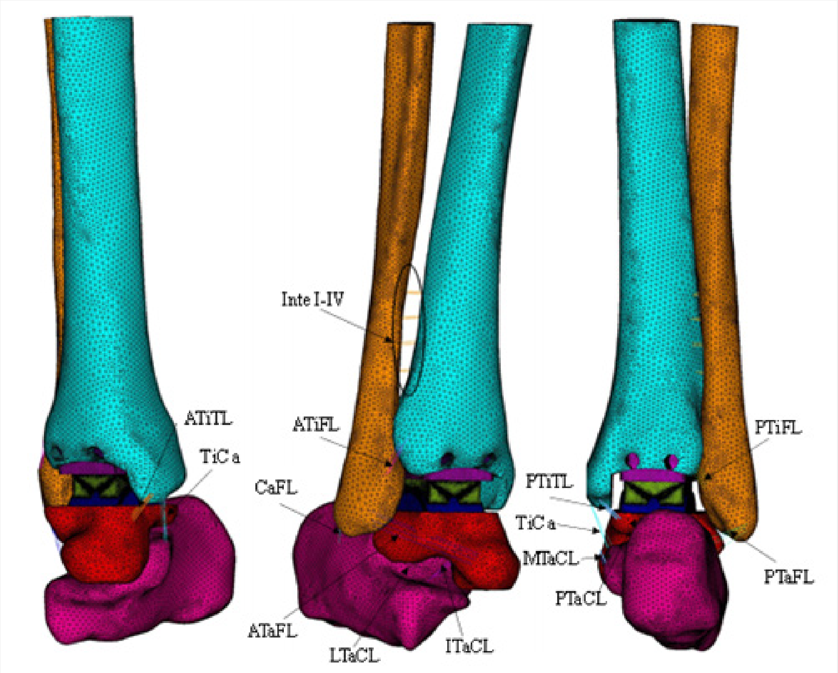

Figure 1: FE model of implanted ankle joint.

Table 1: Magnitude of reaction forces corresponding to dorsiflexion, neutral and plantar flexion positions of ankle.

Concentrated Force (N) and Moment	Position		
	Dorsiflexion (-10o)	Neutral (0o)	Plantarflexion (+15o)
Axial force (Z-component)	1600	600	400
Interior-exterior force (Y-component)	185	-150	-100
Anterior-posterior force (X-component)	-185	-280	-245

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Results and discussion

Figure 2 illustrates the equivalent strain distribution at the tibia bone for the intact and implanted model for both interface conditions. In comparison to the intact model, there was a decrease in strain after implantation for both the bonded and debonded conditions. However, in the case of the debonded condition as opposed to the bonded condition, a greater reduction in strain was seen. For all three loading positions, a considerable strain reduction was seen at the proximal wall of the cortical and cancellous bone of the tibia when considering the debonded condition. While for the condition of the bonded implant-bone interface, a reduction in strain was observed along the proximal medial wall of the cortical and cancellous bone of the tibia. However, compared to intact models, there was more strain around the implant-bone interface for prosthetic models under bonded implant-bone interfacial circumstances. In comparison to the bonded implant-bone interfacial condition, strain shielding was greater in the debonded implant-bone interfacial condition. Excessive stress or strain shielding in the bone is the root cause of bone resorption brought on by bone remodelling and the consequent loosening of implants [8]. The current study's findings indicated that proper osseo-integration between the implant and bone surfaces would be advantageous for the long-term results of the implant. The micromotion between the implant and bone was discovered to vary between 5μm to 45 μm, which is less than 50μm. Results indicated osseo-integration onto the covered surface of the implant would be possible.

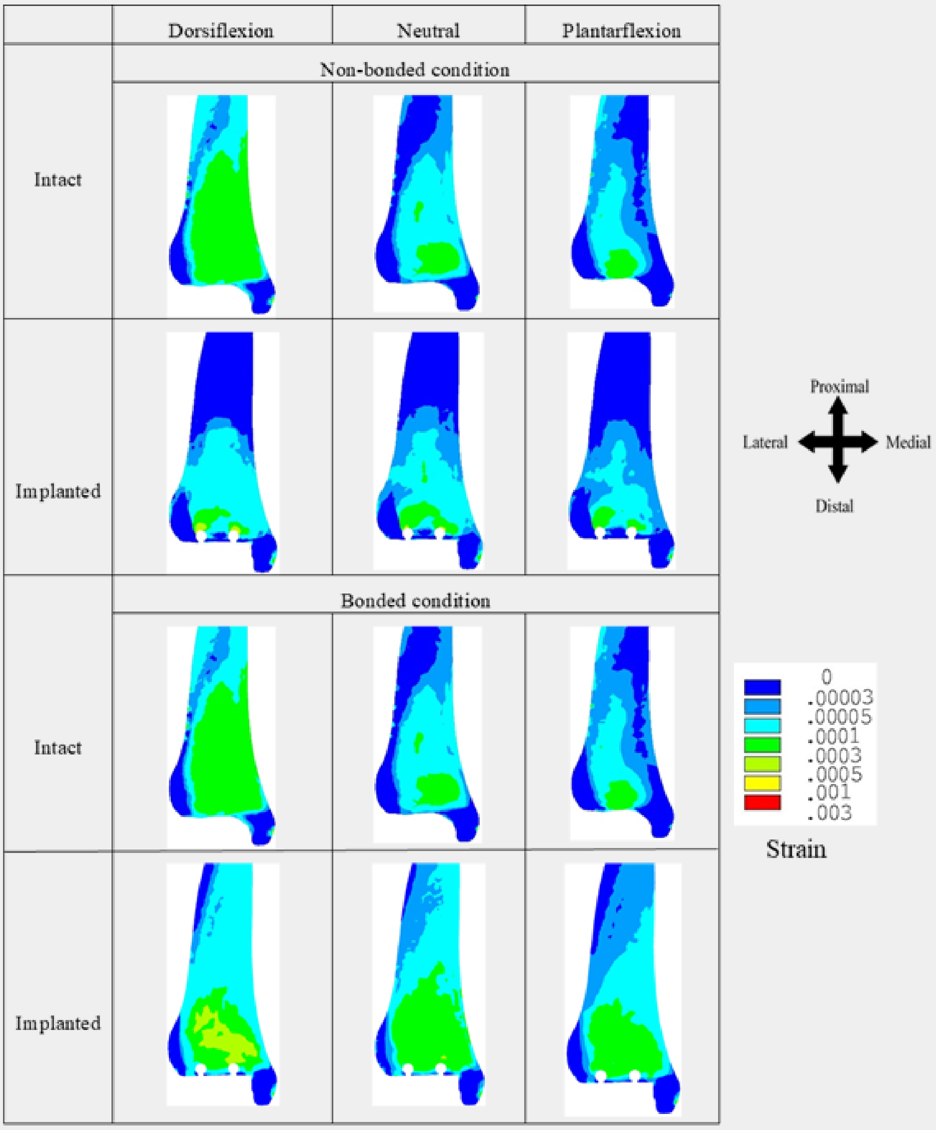

Figure 2: Equivalent strain distribution at the tibia bone for intact and implanted model for both the interface conditions.

The FE model in the current study contains a number of limitations and assumptions, which are stated below. Only ligaments and cartilages were considered soft tissues in the current FE models; other soft tissues were not well considered because their material properties are substantially different from those of bone. In accordance with past research [2,6,9], ligaments were simulated as a linear spring element. For a clearer understanding of the load transmission, a dynamics analysis of the ankle joint throughout a gait cycle might be more beneficial. For the 3D evolution of the bones, just one CT scans worth of data was used. It is true that multi-CT data from individuals of different ages and sexes may be more helpful for comprehending the effects of implantation and bone remodelling. For the formation of an intact ankle and the qualitative evaluation of load transfer and stress/strain distribution, more than one CT data set should be used. Using only CT-scan data sets, a qualitative estimation or results can be expected [10].

Conclusion

Here, using CT scan data, a realistic 3D FE model of the implanted ankle joint was built, complete with ligaments, anatomically appropriate boundary and loading conditions, regional material property distributions, and material characteristics. According to the current study's findings, appropriate bone and implant bonding will be required to reduce strain shielding. The results of this study might help to improve TAR performance.

References

1. Jyoti, Mondal S, Ghosh R (2022) Biomechanical analysis of three popular tibial designs for TAR with different implant-bone interfacial conditions and bone qualities: A finite element study. Med Eng & Phy 104: 103812.
2. Mondal S, Ghosh R (2019) Bone remodelling around the tibia due to total ankle replacement: effects of implant material and implant–bone interfacial conditions. Comp Met Biomech Biomed Eng 22(16): 1247-1257.
3. Mondal S, Ghosh R (2017) A numerical study on stress distribution across the ankle joint: Effects of material distribution of bone, muscle force and ligaments. J Ortho 14(3): 329-335.
4. Mondal S, Ghosh R (2020) Experimental and finite element investigation of total ankle replacement: A review of literature and recommendations. J Ortho 18: 41-49.
5. (2013) "STAR Surgical Technique" -Small Bone Innovations, Inc. Cited.
6. Mondal S, Ghosh R (2019) Effects of implant orientation and implant material on tibia bone strain, implant-bone micromotion, contact pressure, and wear depth due to total ankle replacement. Proc IMechE Part H J Eng in Med 233(3): 318-331.
7. Reggiani B, Leardini A, Corazza F, Taylor M (2006) Finite element analysis of a total ankle replacement during the stance phase of gait. J Biomech 39(8): 1435-1443.
8. Ghosh R, Gupta S (2014) Bone remodelling around cementless composite acetabular components: The effects of implant geometry and implant-bone interfacial conditions. J mech behavior biomed mat 32: 257-269.
9. Mondal S, Ghosh R (2020) Influence of cancellous bone material and dead zone on stress-strain, bone stimulus and bone remodelling around the tibia for total ankle replacement. Proc IMechE Part H: J Eng in Med 235(2): 185-196.
10. Mondal S, MacManus DB, Bonatti AF, Maria CD, Dalgarno K, et al. (2023) A computational analysis of a novel therapeutic approach combining an advanced medicinal therapeutic device and a fracture fixation assembly for the treatment of osteoporotic fractures: Effects of physiological loading, interface conditions, and fracture fixation materials. Med Eng Phys 114: 103967.

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