Bone Material Treatment Influences Finite Element Predicted Tibia-Implant Micromotions in Total Ankle Replacement

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Summary

We evaluated how bone material behavior assumption influences finite element analysis (FEA) predicted tibia-implant interfacial micromotion, a key variable used to evaluate initial implant stability in cementless total ankle replacement (TAR). Five tibia geometries and corresponding density distributions were acquired from CT scans of TAR patients, each then virtually implanted with two tibial implant designs. FEA-predicted peak micromotions and von Mises stress differences were compared for each patient-implant configuration, when incorporating nonlinear (elastic-plastic) versus only linear elastic bone material behavior. Our data suggest that when bone is assumed to behave only as a linear elastic material, there is an associated underestimation of tibia-implant interfacial micromotions.

Introduction

Initial implant stability is important for successful outcome after cementless TAR. Tibia-implant interfacial micromotion is a key variable used to evaluate initial implant stability using FEA, though many studies only model the elastic region of bone material behavior for simplicity. Here, we evaluated how bone material behavior assumption influences FEA-predicted tibia-implant interfacial micromotions in cementless TAR.

Methods

Five tibia geometries and bone density distributions were acquired from CT scans of 5 TAR patients. Each were then virtually implanted with two tibial implant designs (spikes, stemmed). 20 model configurations were analyzed (5 tibias × 2 implant designs × 2 tibia material behaviors).

All geometries were meshed using quadratic tetrahedral elements. Tibia elements were assigned isotropic ($\nu = 0.3$), inhomogeneous, CT density-based material properties. Nonlinear bone material behavior was modeled as bilinear elastic-plastic with post-yield modulus reduced to 5% of the pre-yield value [1]. Bone yield was simulated using the von Mises yield criterion [2]. Loadings from the stance phase of gait [3] were simulated with line-to-line implantation.

FEA predictions of peak micromotions and von Mises stress differences were compared across each patient-implant configuration, when incorporating nonlinear (elastic-plastic) versus only linear elastic bone material behavior.

Results and Discussion

Predictions of peak micromotions trended substantially larger when nonlinear bone material behavior was incorporated. The largest differences (as large as 69%) occurred when the micromotions from simulations incorporating only linear elastic bone material exceeded 100 µm. These findings imply that comparisons of TAR tibial implant configurations incorporating only linear elastic bone behavior should be interpreted with caution when larger micromotions are observed, as these are likely conservative. Peak micromotions from simulations incorporating nonlinear versus linear elastic bone material behavior were strongly correlated ($r = 0.98$, $p < 0.001$), which means that discrepancies in micromotion predictions from simulations incorporating only linear elastic bone material behavior could potentially be estimated. Larger differences in peak micromotions could be expected with larger differences in peak interfacial von Mises stresses between simulations incorporating nonlinear versus linear elastic bone material behavior (Figure 1A; $r = -0.73$, $p < 0.001$). The larger peak micromotions when nonlinear bone material behavior was incorporated were strongly associated with the amount of interfacial bone that underwent plastic deformation (Figure 1B; $r = 0.92$, $p < 0.001$).

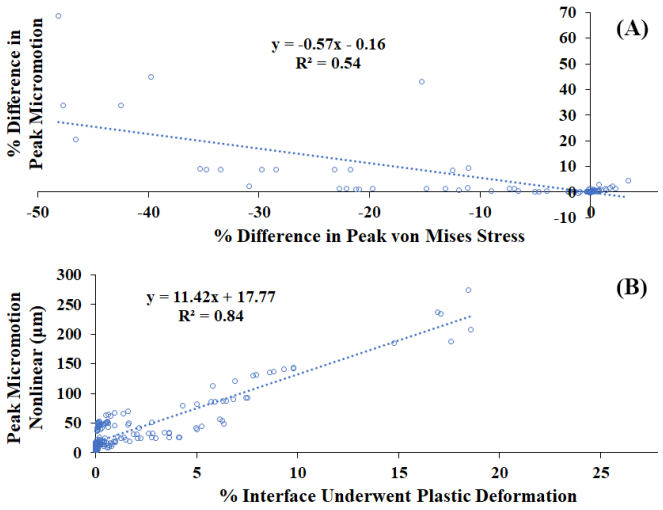

Figure 1: Peak micromotion relationships.

Conclusions

FEA-predicted TAR tibia-implant interfacial micromotions may be underestimated when bone is assumed to behave only as a linear elastic material, and these model results should be interpreted with caution as they are likely conservative.

Acknowledgments

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References

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