A Topology Optimization Model to Simulate Bone Remodeling Around Hip Prostheses

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Bone adapts its structure to the mechanical environment. Changes on mechanical factors can be critical when an orthopedic implant is applied. For instance the redistribution of load on a femur after a Total Hip Arthroplasty (THA) leads to bone resorption and influences the performance of the prosthesis. Also in the case of cementless hip stems, bone-implant micromotions are an important mechanical factor that can prevent bone growing into the porous coating of the femoral component and thus precluding its proper fixation. This fact affects the stability of the prosthesis and can be a cause for implant loosening.

The development of computational tools to model the bone-implant behavior is necessary to perform pre-clinical tests and to improve prosthesis design. Lately, several authors presented numerical models to study bone remodeling after a THA (e.g. Huiskes and Rietbergen [1]), to analyze the bone ingrowth (Keaveny and Bartel [2]) and to model the bone/stem interface (Viceconti et al. [3]).

In this work we present a formulation for the simulation of bone remodeling (Fernandes et al. [4]) that considers also the changes observed in the bone-prosthesis interface conditions (ingrowth) during the remodeling process. The bone remodeling model consists on the computation of bone relative density by the solution of an optimization problem, formulated in the continuum mechanics context and assuming contact conditions for the bone/stem interface. Assuming that bone adapts to the mechanical environment to achieve the stiffest structure for the applied loads, the optimization problem consists on minimizing a linear combination of the structural compliance and the metabolic cost associated with bone tissue maintenance and/or formation. The ingrowth control at the interface is based on the relative displacements at the interface. The contact conditions are a function of the relative displacement values. If, at a certain point, contact actually happens and the bone/stem relative displacement is less than a given threshold value, the interface condition is set to be fully bonded, otherwise friction contact is considered.

The output of this model provides information about two phenomena that occurs after implant insertion. One is the bone remodeling around the stem, generally characterized by a bone resorption on the proximal femur. The second is the bone ingrowth on the stem surface. The model is valuable to analyze existing hip stems as well as to design the coating extent and location. The model is applied in a comparative study analyzing two stems with different geometries.

References

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