A unifying algorithm for bone remodeling for total joint replacement surgery – development and validation with clinical osteodensitometry datasets

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Total joint replacement surgery is one of the major surgical advances in the last century, with an average success rate of more than 90% ten years and more after surgery. However, it is still far from being perfect as some unfortunate patients have to suffer from the debilitating consequences of implant failure and repeated revision surgeries. One reason for such painful failure is bone remodeling and loosening of the prosthesis or bone fracture due to the change in biomechanical environment of the joint after the insertion of implants. The aim of this project is to develop an algorithm that is capable of predicting bone remodeling pattern after total hip and knee replacement surgery.

There have been a number of attempts to develop such algorithms (Beaupre, et al. 1990; Huiskes et al. 1987, Jacobs, et al. 1997). However they are mainly a theoretical model with arbitrary loading conditions. As such it is difficult to apply them to patient-specific cases under physiological loading conditions. Moreover, a prohibitive amount of labor required in model generation and the high computational cost make them almost impossible to use it with clinical data sets. As a result their performance have only been qualitatively checked against some clinical data (e.g. DEXA).

Two requirements should be met if a realistic and accurate bone remodeling algorithm for total joint replacement is to be developed. Firstly, one needs a validated FE model of the hip and knee joint that will be able to reflect physiological loading conditions of daily routines. Such models, therefore, should accurately represent the joint structures and also include major soft tissues in the joint. A number of authors have identified that having soft tissues in the model is vital for achieving accurate and realistic results (Phillips, et al. 2007) (Li, et al. 2006). Secondly, the algorithm needs to be validated against clinical data. This is possible when one has access to clinical CT data from follow-up studies. Moreover, an automated and efficient mesh generation algorithm is required to use the clinical data sets which are often incomplete or sparse. The FE mesh generation method developed previously will be very beneficial in this regard because it is capable of using such data sets (Shim, et al. 2007).

We are in an excellent position to meet these requirements; 1) we have access to clinical quantitative CT based osteodensitometry data for five years post total knee replacement and 7 years post total hip replace; 2) we have a validated FE model of the hip (Shim, et al. 2008) and knee (Shim, et al. 2010) which can be customized to patient specific FE models of the joint; 3) we are in the process of building a gait database which contains muscle forces and hip and knee joint forces during gait for subjects across different age groups. This database will provide physiologically based accurate boundary conditions required for realistic mechanical simulations.

Therefore we propose to develop a unifying algorithm for total joint replacement surgery that can predict bone remodeling patterns after the insertion of implant. The following steps will be taken.

1. Extend the current mesh development and mechanical simulation framework for hip and knee to be able to handle vast amount of clinical data sets.
    a. Automate image processing and model customization processes as much as possible.
    b. Streamline all the processes involved in model generation and mechanical simulation so that non expert users can use it.
2. Process the clinical osteodensitometry data of TKR and THR patients and perform patient-specific mechanical simulation to characterize stress transfer pattern changes after surgery.
3. Develop a bone remodeling algorithm that can predict bone density change patterns using the initial stress pattern from the post-op CT scans.
4. Generalize the framework so that different types and designs of implants can also be tested.

Project outputs

We will aim to publish three conference papers and three journal articles.

Personnel involved

One PhD student will be supervised by Dr. Vickie Shim, Dr. Iain Anderson and Professor Rocco Pitto.

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