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COMPUTER ASSISTED PLANNING FOR KNEE SURGERY: A PATIENT SPECIFIC APPROACH

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INTRODUCTION.

Current medical imaging technology provides orthopaedic surgeons with powerful tools to diagnose knee joint disorders. However, after having planned a corrective procedure, surgeons are confronted with the problem of transposing a pre-operative protocol based on medical images to the patient. Furthermore, this planning all to often bears an inherent qualitative character resulting from the current impossibility to fully appreciate the complexity of the joint's biomechanics.

With recent progresses in virtual reality technology applied to medicine, a growing number of researchers are designing computer codes to predict the effects of reconstructive surgery on human joint biomechanics in "real time" (*e.g.*, DiGioia *et al.*, 1995). All these projects demonstrate how computer-assisted surgery can help orthopaedic surgeons to better appreciate the outcome of a given procedure. However, the computational speed required to run these virtual models can only be achieved to the detriment of more advanced mechanical analyses of the joint.

The purpose of this contribution is to describe a set of computational tools capable to produce realistic patient-specific models of the knee joint from both anatomical and biomechanical points of view. An interactive 3D visualizer is used to generate and visualize the anatomical model of the joint in real time. High-level mathematical modeling capabilities are included to predict the joint's biomechanics (kinematics, contact pressure and stresses in the joint) under the action of forces generated by muscles. A surgical intervention can then be simulated on this patient specific model, and its outcome analyzed from a biomechanical point of view.

MATERIAL AND METHOD.

The program includes six components as depicted in Figure 1:

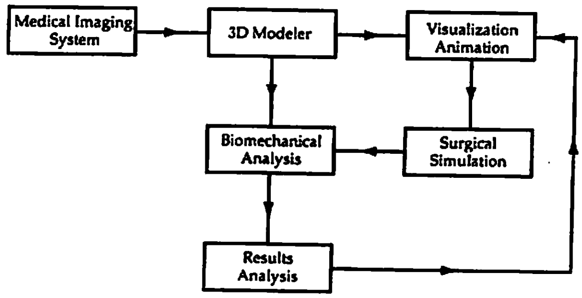

Figure 1: Block diagram for the surgery computer assisted planning program

The main function of the 3D Modeler is to provide an interface between medical imaging devices and the computer-aided planning program. Input to this module consist of 2D raw images (CT or MRI slices) representing the joint geometry. Each image is semi-automatically segmented into regions of interest including bone, cartilage, ligaments and tendons. These planar regions are finally assembled into 3D CAD surfaces (NURBS) prior to further processing like finite element mesh generation.

The Visualization and Animation module is constructed using efficient graphical libraries (OpenGL and Inventor, Silicon Graphics Inc., Mountain View, CA). This module represents the main interface between the user and both Biomechanical Analysis and Results Analysis modules. The various segments can be visualized and rendered in real time allowing also to animate the predicted kinematics of the of the joint during its motion.

The Biomechanical Analysis module represents the heart of the simulation program. The input to this module include the 3D model representing the joint geometry and a set of initial and boundary conditions specified in the Visualization module. The following methods are used to solve the mechanical problems:

- a variational formulation (Gibbs-Appel equations) for rigid multi-body dynamics.
- the finite element method (FEM) to solve field equations like stresses in the joint during its motion (Heegaard *et al.*, 1995).
- unilateral contact algorithms to account for the interactions between the various segments in the joint.

In its current version, the Surgical Simulation module enables the user to simulate Total Knee Replacement (TKR) using a Total Condylar type implant. The natural surfaces of the knee joint are replaced with those of the prosthetic components (as illustrated on Figure 2 for the patellar component). The influence of component positioning on the joint's biomechanics can then be analyzed and visualized.

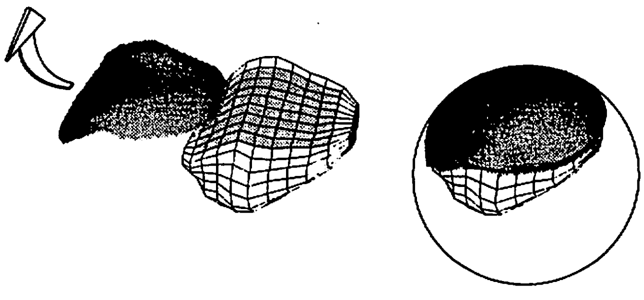

Figure 2: Patellar surface replacement

RESULTS.

The motion of the various segments of the knee were predicted and expressed in terms of quasi-rigid body kinematics variables (3 translations and 3 rotations). Validation with experimental results (Heegaard *et al.*, 1994) indicated very high accuracy of the biomechanical model (less than 1% relative error on kinematical parameters). Comparison of knee kinematics before and after TKR have highlighted the sensitivity of patellar tracking to the positioning of the femoral component, with a possible threat for patellar subluxation under external rotation of the femoral component.

DISCUSSION.

This project describes a set of computational tools to build a patient specific diarthrodial joint model. Such a model is then used to simulate, evaluate and plan a surgical procedure (TKR in the present case). Various parameters of the surgical procedure are under the user's control and their effects on the joint's biomechanics can be comprehensively analyzed.

Future work will include better segmentation of the raw medical images (further automation and improved reliability) and more realistic definition of the forces applied to the joint by the various muscles Integration of EMG data in the present model could represent a possible solution.

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