

Patient-Specific Hexahedral Mesh Generation for Orthopaedic Surgical Planning

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INTRODUCTION

Modern imaging methods such as CT and MR have become the basis for geometrically precise 3D display of anatomical structures. This has provided an impetus for computer assisted surgical planning and simulations of surgical procedures. Moreover, imaging data provides the foundation for finite element (FE) model development of such anatomic structures. Oftentimes, the FE method is used to predict the response of the host bone to an implant, or the resulting stresses throughout the implant itself. Due to demands placed on generating such models, studies often rely on an 'average' baseline model. The goal of this study was to develop techniques aimed at easing the model development process with hopes of making patient-specific surgical modeling a reality. As a proof of concept, preoperative planning techniques are introduced to simulate a PIP joint arthroplasty procedure.

METHODS

Our procedure for FE mesh generation initiates with a source image set (i.e. CT and /or MR) and involves a series of interdependent steps initiating with image processing/segmentation, surface generation and identification, followed by finite element mesh generation based on a multi-block approach (IA-FEMesh).

Once the bony surface had been created, the surgical procedures were carried out in Paraview as follows. First an osteotomy cut of the middle phalanx bone was simulated by creating a plane in 3D space that could be moved interactively around the bone and positioned precisely to 'cut' the surface. The bony surface was then clipped with the cutting plane. Since the surface of the bone is hollow, Delaunay triangulation was used to patch the cut so that the resulting surface was closed as shown in Figure 1a. The next step was to 'broach' the bone, thereby creating a surface replicating the implant so that the bone could accommodate the device. This was accomplished by clipping an stl surface representation of the implant's stem with a cutting plane and appending the resulting surface to the post-osteotomy surface of the finger as shown in Figure 1b. The proximal phalanx bone followed a similar procedure with the exception that two osteotomy cuts (vertical and oblique) were required (Figure 1d). Thereafter building block definitions offered by IA-FEMesh were used to create a hexahedral mesh with the desired mesh seeding. Further optimization based smoothing techniques were used to improve the overall quality of the meshes (Figures 1c and 1f).

RESULTS

Figures 2a and 2b show the final hexahedral mesh of the middle and proximal phalanx bones with the implant generated using the surfaces shown in Figures 1b and 1e. These models provide the engineer and surgeon a wide range of modeling tools for surgical planning.

SUMMARY AND CONCLUSIONS

We have developed methods to create hexahedral finite element meshes that can be used for pre-surgical planning and post-surgical outcome studies. This work is an extension of our previous study (Tadepalli, 2007) which addressed the introduction of cylindrical holes at both the levels of the surface and the mesh definitions. The methods presented can be extended to other implants as well as other anatomic regions for patient specific analysis. In conclusion this method appears to be a feasible tool which can be used for planning orthopaedic procedures.

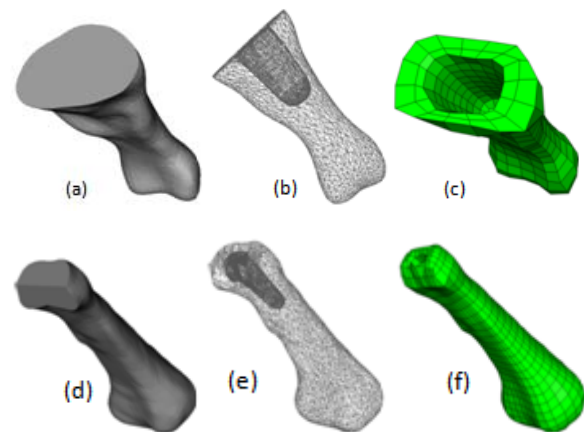


Figure 1: (a) Surface of the middle phalanx bone after the osteotomy; (b) Wireframe representation of the bone with the 'broached' surface appended to it; (c) Meshed model of the middle phalanx bone; (d) Surface of the proximal phalanx bone; (e) Wireframe representation of the bone with 'broached' surface appended to it; and the (f) Meshed model of the proximal phalanx bone.

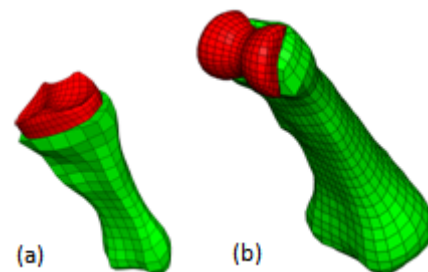


Figure 2: The resulting implanted mesh definitions for the (a) middle and (b) proximal phalanx bones.

REFERENCES

Tadepalli S., *et al.* Patient Specific Orthopaedic surgical Planning, ASB 2007.