Analysis, imaging and visualization technologies are being applied increasingly in medical applications, particularly in evaluating different approaches to surgery and determining the best ways to proceed in the operation. In this growing field, one of the primary focuses of our work applies finite element analysis to orthopedic surgery: specifically, the specialized area of osteotomy, where bones are surgically segmented and repositioned to correct various deformities. We chose ANSYS for this work because of the reliability and flexibility of the software in handling the irregular geometries and nonlinear properties inherent in these materials.

Medical imaging technologies such as CT, MRI, PET or SPECT deliver slice or projection images of internal areas of the human body. These tools are generally used to visualize configurations of bones, organs and tissue, but they also have the ability to export image data and additional information in commonly known medical file formats like DICOM.

These files then can be processed by third-party computer programs for assessing and diagnosing the condition of the patient and planning surgical intervention, that is, how the surgical procedure will be performed. Other very promising fields include telesurgery, virtual environments in medical school education and prototype modeling of artificial joints.

The goal of the research is to develop computer applications in the field of orthopedic surgery, especially osteotomy intervention procedures based on CT images. The team at the Institute of Informatics uses this simulation technology to examine theories underlying new types of surgeries as well as to aid doctors in treating individual patients undergoing hip joint correction. These two approaches have many common tasks: extracting image data from diverse medical image exchange format files, enhancing images, choosing the appropriate segmentation techniques, CAD-oriented volume reconstruction, data exchange with FEM/FEA tools, and geometric description of virtual surgery.

**ANSYS for Virtual Surgery**

FEA is a valuable tool that aids doctors in orthopedic operations.

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Building Orthopedic Models

CT data files. The first step in building an orthopedic model is extracting an image file from medical data exchange formats. As CT images represent the X-ray absorption of a given cross-section, the intensity values of their pixels represent this 12-bit absorption rate, rather than common color ranges. Since the slice density is usually reduced to a minimum for in-vivo scanning, considerable information often is lost, especially in complex regions of the human body. For visualization purposes, this deficiency can be compensated with interpolation techniques, but no lost anatomical data can be recovered in this way. Using these files for FEA work thus often requires further enhancement.

Image enhancement and segmentation. As given tissue structures have their own absorption rate intervals, a windowing technique might be sufficient for a simple visualization. However, because these intervals can overlap, other tissue parts that differ from our VOI (Volume Of Interest) remain in the image, after applying the intensity window. Some conventional procedures like morphological or spectral-space filtering must be applied, as well as specific techniques for CT segmentation. We found that other methods, such as region growing and gradient-based segmentation, achieved excellent results for bone structures.

Volume reconstruction. The final goal of the project is to develop an application to be used in surgery planning on a routine basis by medical staff without experience in using CAD-related software. We wanted this application to be able to transfer structural data into a finite element modeling and analysis software. Thus, volumetric information must be represented in a geometrically appropriate way. There is a difference between simple surface rendering and geometrical volume reconstruction in CAD systems. Volumetric data has to be represented using solid modeling primitives, and reconstructed using related concepts: keypoints, parametric splines, line loops, ruled and planar surfaces, volumes and solids.

When extracting contour points of ROIs (Regions Of Interest), we need to reduce the number of points to approximately 10-15% by keeping only points with rapidly changing surroundings. These points then can be interpolated with splines, splines assembled to surfaces and surfaces to solids. The major difficulty is that CAD-related systems are designed to work with regular-shaped objects, and bone structures are not like that. However, to be able to execute FEA, it is necessary to use this approach. Moreover, virtual surgery interventions have to be carried out on this representation, or in such a way that proper geometrical representation of the modified bone structure remains easy to regain. As is often the case, conversion problems may occur when exchanging data between CAD systems, so we perform the above volume reconstruction procedure directly in the FEM software using built-in tools provided in the package. After testing many FEM programs, we chose ANSYS software for this task. Figure 1 illustrates how they
reconstructed in ANSYS an 8-inch part of a femur (pipe-like bone) using the mentioned procedure. The entire reconstruction procedure was implemented in a simple ANSYS script file.

A natural extension of this method seems to be suitable also for bones containing more parts, holes, etc. In this case, Boolean operations between solids provided by ANSYS gives us a powerful tool. Another challenging problem currently being investigated is the reconstruction of those parts of the bones where the CT slices contain varying topology (e.g., when reaching a junction in some special bones).

Approaches to Virtual Surgery

Planar approach. There are some cases when information from 2-D slices is sufficient for performing virtual surgery instead of 3-D solids. For example, the first subject of our project – human femur lengthening using helical incision – provided a good opportunity for experimenting with 3-D interventions performed in 2-D. By taking the intersection (dark section on Figure 2) of the theoretical cutting tool path (Figure 2 left) with the planes of the individual CT slices, we subtracted these profiles from the bone section profile (Figure 3).

After the volume reconstruction using this technique, we obtained the modified bone structure without the need for further intervention. Another possibility is to use ANSYS to build up the geometric model of the bone and the cutting tool from their boundary lines, then to remove the solid defined by the path of the cutting tool. The team wrote an ANSYS script to obtain fast and automatic model creation.

In the case of the hip joint correction, some intervention also might be simulated in 2-D, but designating and registering ROIs on the slice set is more difficult. However, handling volumes as a set of unsorted 3-D points with additional attributes serves as an intermediate solution.

Three-dimensional approach. In the first subject, the 3-D approach adopted by us was the combination of the volume reconstruction technique and conventional CAD modeling. We reconstructed the middle part (diaphysis) of the human femur, and, in the same coordinate system, using the axis of the actual bone, we constructed the solid object representing the path of the cutting tool. This was achieved by applying helical extrusion along this axis on a rectangle, using the parameters of the actual osteotomy. By subtracting these solids from each other, they
obtained the wanted solid object (Figure 4). This Boolean subtraction was also executed by ANSYS.

As previously mentioned, they also work on pre-operative analysis and comparison of hip joint osteotomy. The 3-D reconstruction of this region is more difficult because of the information loss during the CT scanning procedure. There are many consecutive slice pairs with large differences. In this case, interpolation gives no satisfying results, and we specialize in general methods to reduce the level of user action required.

Our interface for virtual surgery is GLUT-based, containing I/O tools for importing existing meshes and exporting the model into a FEM/FEA environment. Besides using similar scripts for building up the geometry as described above, we also take advantage of the mesh generator and manager capabilities of ANSYS in data exchange. That way, we can import a tetrahedron mesh used in OpenGL technology into ANSYS for FEA analysis, for example, and ANSYS geometry also can be exported as a tetrahedron mesh for visualizing purposes. Figure 5 shows an example of a tetrahedron mesh visualization in OpenGL.

**FEM/FEA results.** Using the volume reconstruction approach, we needed only to translate our internal representation to the scripting language. Material types and parameters also can be defined using scripts. The bone material model we used is a linear isotropic one. After applying constraints and forces on the nodes of the solids, they have tested stress and displacement of the bone structure. Using the obtained results, a comparison can be made for the known osteotomy interventions of a certain type. For femur lengthening, our experience indicated that the highest stress values occurred around the starting and ending boreholes of the cut, so we also considered the usability of different borehole types and helix with variable pitches, as shown in Figure 6.

**Web Links to More Information**

- [http://graphics.stanford.edu/data/3-Dscanrep/](http://graphics.stanford.edu/data/3-Dscanrep/)
- [http://image.soongsil.ac.kr/software.html](http://image.soongsil.ac.kr/software.html)
- [http://medical.nema.org](http://medical.nema.org)
- [http://www.ablesw.com/3-D-doctor/](http://www.ablesw.com/3-D-doctor/)
- [http://www.kanazawa-it.ac.jp/ael/imaging/synapse](http://www.kanazawa-it.ac.jp/ael/imaging/synapse)
- [http://www.materialise.com](http://www.materialise.com)
- [http://www.nist.gov/iges](http://www.nist.gov/iges)