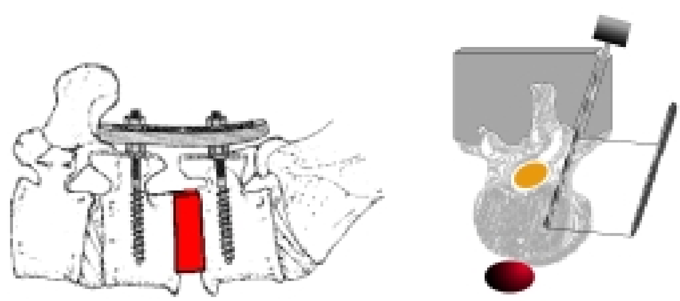
Template Guided Intervention: Interactive Visualization and Design for Medical Fused Deposition Models

T.S. Yoo[1], J. Morris[2], D.T. Chen[1], A.C. Richardson[3]

[1]National Library of Medicine, National Institutes of Health, Bethesda, MD, 20894, USA
{yoo | dave}@nlm.nih.gov
[2]Department of Internal Medicine, Washington Hospital Center, Washington, DC, 20010, USA
morris@nlm.nih.gov
[3]Department of Radiology, National Naval Medical Center, Bethesda, MD, 20889, USA
acr@rad.navy.mil

Extended Abstract: We are combining surgical planning techniques with computer aided manufacturing systems to create custom surgical aids for orthopedic surgery. Our first application area is planning and controlling the trajectories of pedicle screws for spine surgery. The goal is to manufacture a physical jig that conforms to the contours of the patient's vertebrae. The jig is constructed with holes that correspond to the trajectories of the pedicle screws. These holes guide the drill placement and depth, increasing the accuracy and precision of screw placement (Figure 1). These devices are created for each individual patient, one per segment, and improve accuracy without the introduction of navigation tools or increased fluoroscopic radiation dose. The intent is to use a jig to transfer the surgical plan directly to the operating room without introducing additional technology. Difficulties of computer - assisted surgery remain in the laboratory without intruding into the operating room.

We briefly describe our work in rapid prototyping for computer-assisted surgery. In this paper we address the design issues for the surgical planning and template design workstation. Our prototype is an interactive modified texture-based volume rendering program [2] augmented with physical user interface devices, 3D stereo viewing, polygonal primitives, and tools for constructive solid geometry (CSG) to serve as the computer aided design foundation for modeling templates.



1a. 1b.

Figure 1. We are working on techniques for the precise placement of pedicle screws, required for many spine procedures. Figure 1a: lumbar plate secured with pedicle screws. Figure 1b: Our goal – a proposed template, guiding the drill path and depth. Structures such as the spinal cord, nerve roots, and the aorta must be avoided.

Background and Related Work

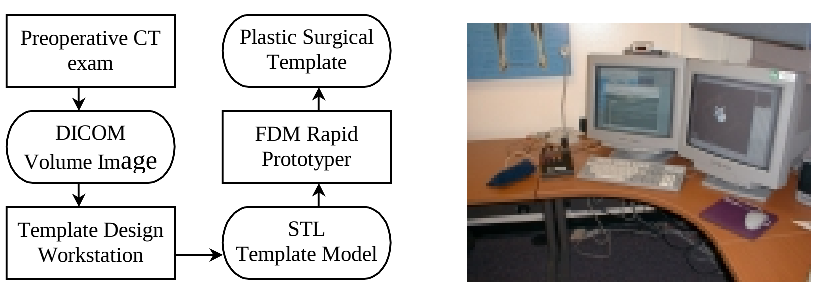
Figure 1a shows the basic problem faced in spine procedures. Appliances such as plates and rods require fixation through narrow channels called pedicles. Trajectories through these narrow isthmuses of bone have optimal placement and limited tolerances [5]. Complications can arise when the screws accidentally enter epidural or spinal spaces and transect the spinal cord, constrict the emerging nerve roots arising from the ganglion, drift through a disc, or by emerging out the anterior surface and cutting the aorta [3].

Figure 1b shows the goal of our project, the creation of custom drill guides designed to mate closely with individual vertebrae that limit depth and provide for precise control of the screw path. Other groups have pursued templates for pedicle screw placement. Radermacher and Birnbaum have reported favorable results using numerically controlled (NC) machine tools to create plastic templates [1,4].

Our approach differs from theirs in our use of Fused Deposition Modeling (FDM), an alternate technology for creating the templates. Many affordable NC machines are limited to three axes of control. This prevents many NC machines from supporting the complex geometries required to create custom templates. By contrast, FDM is the successor to stereolithography in rapid prototyping technology. It is flexible and accurate, capable of creating a wide variety of geometries, well beyond those needed in pedicle screw placement procedures. Stratasys, a manufacturer of these rapid prototyping devices, has secured U.S. FDA approval for the generation of 3D models for diagnostic purposes. The requirements of high fidelity reproduction necessary for diagnosis are equally important in intervention. They also supply a production material that can be sterilized for use in medical procedures.

Design and Software Tools for Template Planning Workstation

We built our surgical planning workstation around an interactive volume rendering system. Recent trends in graphics workstations have led to the emergence of 3D transparent textures, enabling interactive volume rendering using conventional graphics primitives [2]. Figure 2 shows the process and the console.



2a. 2b.

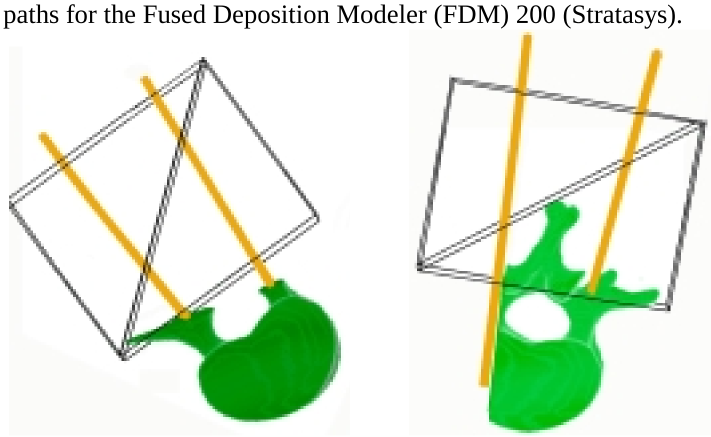
Figure 2. Procedure and console. Fig. 2a: The pipeline from exam to template. Fig. 2b: This paper describes the template design workstation: Joysticks, stereo viewing glasses, pushbuttons, and physical sliders provide more natural human interfaces than overloaded mouse controls.

To augment the interactive visualization of the vertebrae and the placement of tool paths, the workstation has recently been augmented with physical I/O devices including a 3D joystick, supplementing the overloaded mouse controls. A mouse is by definition a 2D input device, limiting its use for viewpoint control. Tactile coherence can be improved by the use of physical input devices.

Volren 6.1, a texture-based volume rendering system running on a dual 250 MHz CPU Onyx2 with dual Reality Graphics™ raster managers was modified into a surgical planning workstation enabling the modeling of objects through constructive solid geometry (CSG). Texture based volume rendering naturally combines clipping planes and polygonal objects in a simplified volume rendering pipeline. The hardware accelerated graphics systems necessary to support these methods are available in PC cards today. Clip planes, polygonal models, and volume rendering combine to make a natural graphical interface for planning screw placement.

Results, Discussion, and Future Work

As a test of the technology and its precision, we selected a dry, dissected lumbar vertebrae and created a surgical plan for pedicle screw placement. Thin section CT scans (1mm apart and 1mm thick) of 5 individual dry lumbar vertebrae were obtained on a GE Genesis High Speed RP Scanner. A block was modeled to fit tightly to the posterior surface of the vertebrae. Cylinders, that would ultimately be the drill guides, were then modeled through the block. The positioning of the cylinders, or trajectory planning, was accomplished with the aid of clipping planes and interactive control of the volume rendering transfer functions. This assured the authors that the planned trajectory was through the isthmus and along the axis of the pedicle, as shown in Figure 3. The 3-D drill guide block with trajectories was then divided into 2-D slices and converted to DICOM files. The 2-D slices were imported into Mimics v.6.3 (Materialise) and converted to .STL files. The .STL files were then used to generate the tool paths for the Fused Deposition Modeler (FDM) 200 (Stratasys).



3a. 3b.

Figure 3. The template design, taken from the texture-based volume rendering based surgical planning workstation. Clipping planes, polygonal primitives, and volume data are easily combined using advanced graphics.

We have achieved frame rates on the order of 10 frames per second for interactive template design including rendering the medical volume. Drawing from experience with molecular modeling systems, physical I/O tools such as joysticks were added improving the intuitive feel of the workstation. Some overloading of the input devices still occurs, leading to occasional confusion. Stereo viewing does not appear to speed template design. The use of Open GL as a programming base significantly reduced software development costs and permitted the fast integration of CSG.

A drill guide was produced by the FDM 200 with approximately 125.06 cm^3 of non-medical ABS plastic at a slice interval of 0.2540 cm. The block, as designed, had an intricate area reserved for the posterior elements of the chosen lumbar vertebra. This first attempt was flipped in the x-axis due to an image format discrepancy. A second template was produced, correcting the defect, and pedicle pilot holes were drilled into the dry vertebrae. A CT scan was conducted to verify the placement of the pilot holes (Figure 5). At the time of this writing, a second project to test the insertion of screws into a cadaver subject on four vertebral segments is underway. Physical templates transfer the power of surgical planning workstations to the operating room without the need for complex technology. Confidence in the path planning will increase accuracy, speed procedures and reduce patient radiation dose by decreasing fluoroscopic verification.

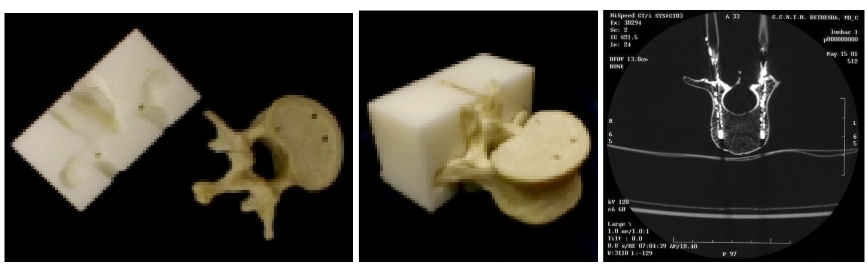


Figure 5. The prototype template and the dry spine test with a validating CT exam. (The pinholes in the top of the vertebrae are incidental, and leftover from the string connecting multiple vertebrae for its former use as an anatomy teaching tool.).

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