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Volumetric Rendering Techniques: Applications for Three-dimensional Imaging of the Hip[1]

Volumetric rendering is a new approach to three-dimensional (3D) imaging that overcomes many of the drawbacks of currently available surface-rendering systems. Its application on the Pixar Imaging System in two cases of acetabular fracture was assessed to illustrate the features of the technique. The fast-computing architecture and large memory of this system allow rapid generation of a series of high-quality 3D images in each plane of rotation (x or spinal axis, z or somersaulting axis) that can be viewed as independent static images or as an animated real-time video loop. Editing to remove the normal contralateral hemipelvis enhances appreciation of acetabular abnormalities. Every pixel of computed tomographic data is preserved, allowing representation of both soft tissue and bone as translucent overlap. The presentation of data also allows detection of subtle abnormalities and features and minimizes the artifact generation common in surface-rendered images.

Index terms: Acetabulum, fractures, 442.41 • Computed tomography (CT), data processing • Computed tomography (CT), image display and recording • Computers, examination control • Hip, CT, 442.1211 • Pelvis, CT, 441.1211

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THE fine anatomic detail generated by computed tomography (CT) scanning is of use only if one can understand the normal anatomy and abnormalities present. Transaxial CT provides a sequence of images that must be integrated by the physician into a three-dimensional (3D) picture. Radiologists, because of their extensive training in image analysis, are better than most physicians at performing this task. Even radiologists, however, may find complex anatomic areas difficult to conceptualize. To overcome this difficulty, display of the data in coronal and sagittal planes was attempted (1-3). This was successful, and all major CT manufacturers now provide computer software for generating these images.

It soon became apparent that a simulated 3D model of CT data would prove to be of more use to both the radiologist and nonradiologist. However, the earlier programs produced images of limited quality, and the programs were limited in scope (4-7). Independent companies developed free-standing 3D systems, but they were expensive (over $200,000) and the image quality was fair at best (8, 9). Physician acceptance of these images was mixed.

The need for development of high-quality 3D images led us to the use of the Pixar (San Rafael, Calif.) Imaging Computer. The system, designed at Lucasfilm (San Rafael, Calif.) in 1985, was originally designed for use in computer animation. However, because of its incredible speed (40,000,000 instructions per second) and its production of high-quality images, we thought it might provide images acceptable to the medical community as well. This report summarizes our initial experience with this imaging system.

MATERIALS AND METHODS

Two representative cases of acetabular trauma were selected from among 40 tapes of patients with acetabular fractures. The cases were chosen to show the spectrum of acetabular trauma and included both a minimally displaced fracture (Fig. 1) and a T-shaped fracture (Fig. 2). All studies were performed on a commercially available CT scanner with use of the technique we previously described for multiplanar reconstruction (3). Briefly, the examination consisted of 35-45 overlapping transaxial scans obtained at 3-mm intervals through the area of interest. To minimize radiation dose, the scanning parameters were 3-second scan time, 230 mAs, 125 kVp, and 4-mm collimation.

The transaxial image data were transferred to the Pixar Imaging System on ½-inch magnetic tape. The volume of data was then stored in the Pixar's picture memory. The Pixar Imaging System consists of a host computer; the Sun Microsystems (Mountain View, Calif.) 3/160

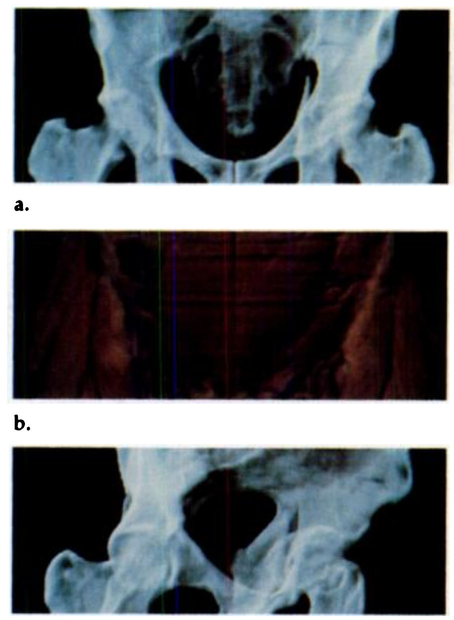

Figure 1. Forty-nine-year-old man with left acetabular fracture following auto accident. **(a)** X-axis view demonstrating fracture of left acetabulum. **(b)** Same view as **a** with muscle reconstruction program. **(c)** Additional x-axis view with bone reconstruction algorithm.

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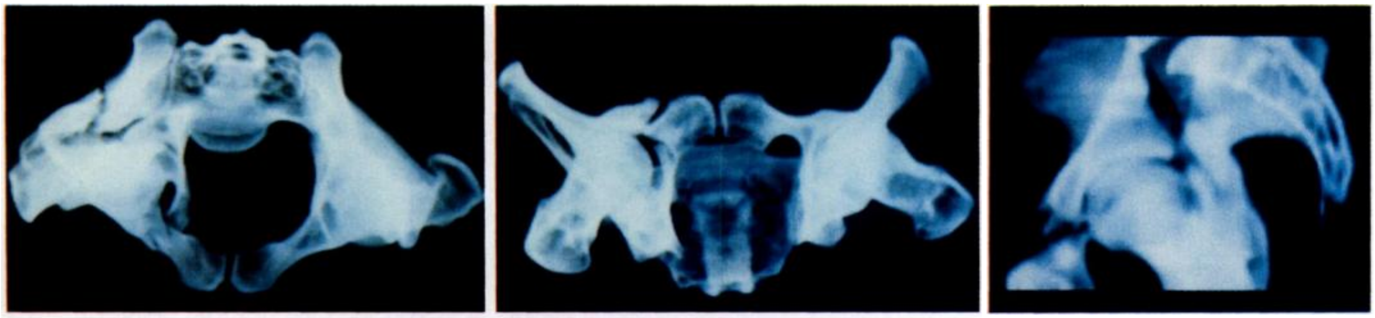

a. b. c.

Figure 2. Forty-two-year-old man with T-type fracture of left acetabulum following auto accident. Pelvic inlet and outlet views demonstrate extent of right acetabular fracture.

workstation, which has 4 million bytes of random access memory (RAM) and can process up to 5 million instructions per second; and the Pixar Imaging Computer. The Pixar Image Computer programming and all program initiation is through the Sun workstation. The Pixar has 20 million bytes of RAM and can handle up to 40 million instructions per second. This is accomplished through four concurrent channel processors, each performing 10 million instructions per second. Images are displayed on a high-resolution 1,024 × 768 Barco (Holland) monitor.

The 3D CT program (volumetric rendering technique) creates up to 84 views of the pelvis that can be displayed on the monitor. Typically, four views are displayed at once to create a satisfactory-sized image. All image reconstructions are performed with the volumetric rendering technique as developed by the Computer Graphics group at Pixar. The volumetric rendering technique processes "stacks" of sequential CT images as a volume. The gray-scale intensity information in each pixel in this volume is replaced with gels of varying color and transparency. The technique allows for definition of object thickness, a critical factor in creating quality 3D images. The images are then rotated in real time in any plane desired. Typically, we use the rotation around the x- and z-axes. (Figs. 1, 2).

These data can be viewed on the monitor or put on VHS or Beta tape for later viewing. With use of a "mouse-driven" program (DOCTOR program), an average study can be done in 25–40 minutes with only minimal user interaction.

RESULTS

The studies were reviewed by two radiologists (E.K.F., D.M.) and two orthopedic surgeons (A.F.B., J.A.S.V.). Images generated on the Pixar were compared with initial transaxial CT scans, multiplanar reconstruction, and, in two cases, 3D images obtained on a Cemax-1000 (Cemax, Santa Clara, Calif.). There was unanimous agreement that (*a*) the Pixar images clearly displayed the full extent of the fractures and/or dislocations; (*b*) there was no discernible computer-generated noise or artifact, as is commonly seen with other 3D techniques (i.e., Cemax-1000); and (*c*) the ability to create and review a "real-time" model of the pelvis allowed better understanding of the extent of abnormality. The surgeons believed this added information would help in determining the type of surgery needed and in planning the surgical approach.

DISCUSSION

One of the major disadvantages of all the previously described 3D techniques was their use of surface-rendering or edge-detection programs (5). These programs preserve only the boundaries of a given object and in effect, present only a subset of available data. Volumetric rendering differs from surface rendering in that all the information from the CT scans is preserved, not just surface boundaries. Object thickness and internal contours can be seen in 3D projection. In addition, unlike surface rendering, volume rendering can preserve the subtle surface details such as nondisplaced fractures that can be less than 1 pixel wide.

The Pixar Imaging System provides high-quality 3D images that can be displayed as either real-time sequences or static pictures. Because of its high-speed processing power and large memory, it is able to create images that cannot be duplicated by any other available imaging system. At present, we are both retrospectively and prospectively evaluating a series of patients with acetabular trauma, congenital hip disease, avascular necrosis, and arthritis to determine the larger clinical implications of this new imaging system. ■

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