VOLUMETRIC IMAGE PROCESSING FOR THREE-DIMENSIONAL DISPLAY OF THE SKELETAL ANATOMY OF THE SEA OTTER

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Volumetrically correct, three-dimensional color images of the sea otter, *(Enhydra lutris)*, were generated from computed tomographic (CT) data using a Sun 3/160 workstation and a Pixar Imaging Computer. These images could be displayed as static images (1024 × 768) or rotated about any axis in real-time by displaying sequential rotation sequences generated by the Pixar Imaging Computer. The images provided realistic depth of field through overshadowing and differential opacification. This was obtained through an opacification algorithm which traced rays from a selected viewing plane through colored gel volumes, and calculated absorbance percentages as a function of the transparency of the gels penetrated. Reconstructions of this type serve as alternative anatomy tutorials for species otherwise unavailable for routine dissection. They also permit topographical studies without interfering with populations of endangered animals. *Veterinary Radiology, Vol. 31, No. 3, 1990; pp 142–145.*

Key words: computed tomography, image display, anatomy, volumetric imaging, computer reconstruction, Enhydra, sea otter, endangered species.

A MAJOR PROBLEM for veterinary radiologists is development of a knowledge base of gross topographic anatomy of the many diverse nondomestic creatures requiring medical attention. Knowledge of topographic anatomy is important, not only for the correct interpretation of radiographic studies, but also for the surgeon planning surgical approaches, or the pathologist performing a necropsy. Detailed knowledge of the gross anatomy of unusual species is also of considerable value to zoologists and paleontologists studying the phylogenetic development of vertebrate species.

Volumetrically accurate, computerized reconstruction of a three dimensional image from data generated by computerized tomographic (CT) studies and other computerized imaging methods can facilitate the acquisition of detailed anatomic information. This paper presents a rapid method for developing highly informative tutorial and investigative information on the skeletal anatomy of zoological species.

Materials and Methods

As part of an anatomic study of the sea otter, (*Enhydra lutris*), volumetric images were generated from whole-body computed tomographic (CT) scans of otters found dead on northern California beaches. Two frozen otters provided by the California State Fish and Wildlife Service were imaged with CT and processed for three-dimensional reconstruction immediately after thawing and prior to traditional radiography and dissection. CT scans consisted of overlapping transaxial scans made at 3-mm intervals, scanning for 3 seconds at 230 mAs, 125 kVp with 4 mm collimation. Data from the CT scans were recorded on ½ inch tape and transferred to an imaging system consisting of a Sun 3/160 computer workstation* connected through a Unix operating system to a Pixar Imaging Computer with four concurrent

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*Motorola 68020 microprocessor; 4Mbyte RAM

†A menu based interface for computer-naive operators, written at Johns Hopkins Hospital by Derek Ney.

channel processors capable of executing 40 million instructions/second (24 Mbyte frame buffer RAM; 2048 × 48 bit picture elements/side). Program initiation and interaction with the PIC utilized the DOCTOR program.†

Three-dimensional images were rendered by processing stacks of sequential CT images as volumes, while replacing the grey scale intensity information of each pixel with gels of varying color and transparency. To create realistic depth of field through overshadowing and differential opacification, an opacification algorithm traced rays from a selected viewing plane through the colored gel volume, calculating absorbance percentages as a function of the transparency of the gels it penetrated.

Results

The three-dimensional color images obtained preserved all original CT data, not just surface boundaries, and could be displayed as static images in either a 1024 × 768 or a 640 × 488 NTSC format. Alternatively they could be rotated about any axis in real-time by displaying sequential rotation sequences generated by the Pixar imaging computer (Fig. 1). This allowed observation of angles impossible to obtain from conventional radiography in living patients including head on projections, (Fig. 2) and difficult angles in joint examinations (Fig. 3). Preprocessing control of the CT data also allowed the removal of rectangular areas of anatomy to provide unimpeded view of underlying detail in the rotating images (Fig. 4).

FIG. 2. Three-dimensional image of a whole body volumetric reconstruction of the thoracic, cervical and cranial skeleton of an adult male sea otter (*Enhydra lutris*). A. Cranial view; B. Caudal view.

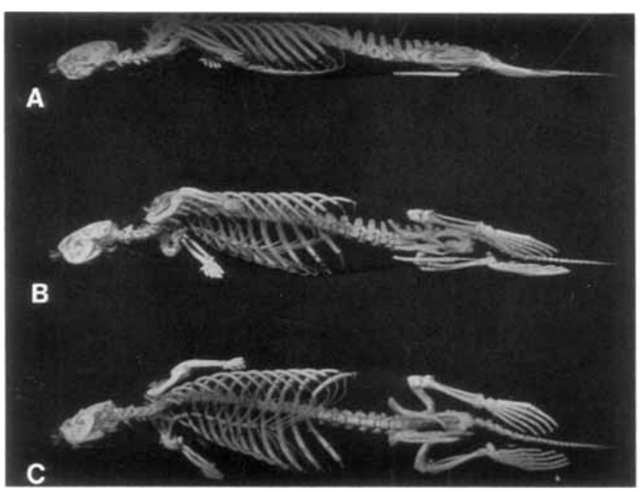

FIG. 1. Three dimensional images of a whole body volumetric reconstruction of the skeleton of an adult male sea otter (*Enhydra lutris*). A. lateral view; B. Le30V-RtDO; C. Le80V-RDO.

Discussion

Earlier three-dimensional reconstruction techniques have used surface-rendering or edge-detection algorithms which preserve only the boundaries of an object.[1–4] These techniques use only a small portion of the data available from a CT scan, limiting their ability to preserve surface detail and internal contours.[5] Volumetric reconstruction uses all information obtained in CT scans giving accurate rendering of object thickness and subtle surface details.[6] The Pixar Imaging System produces high-quality three-dimensional (3D) images which can be displayed as real-time sequences or static pictures. The high speed processing and large memory allow the system to create images which cannot be

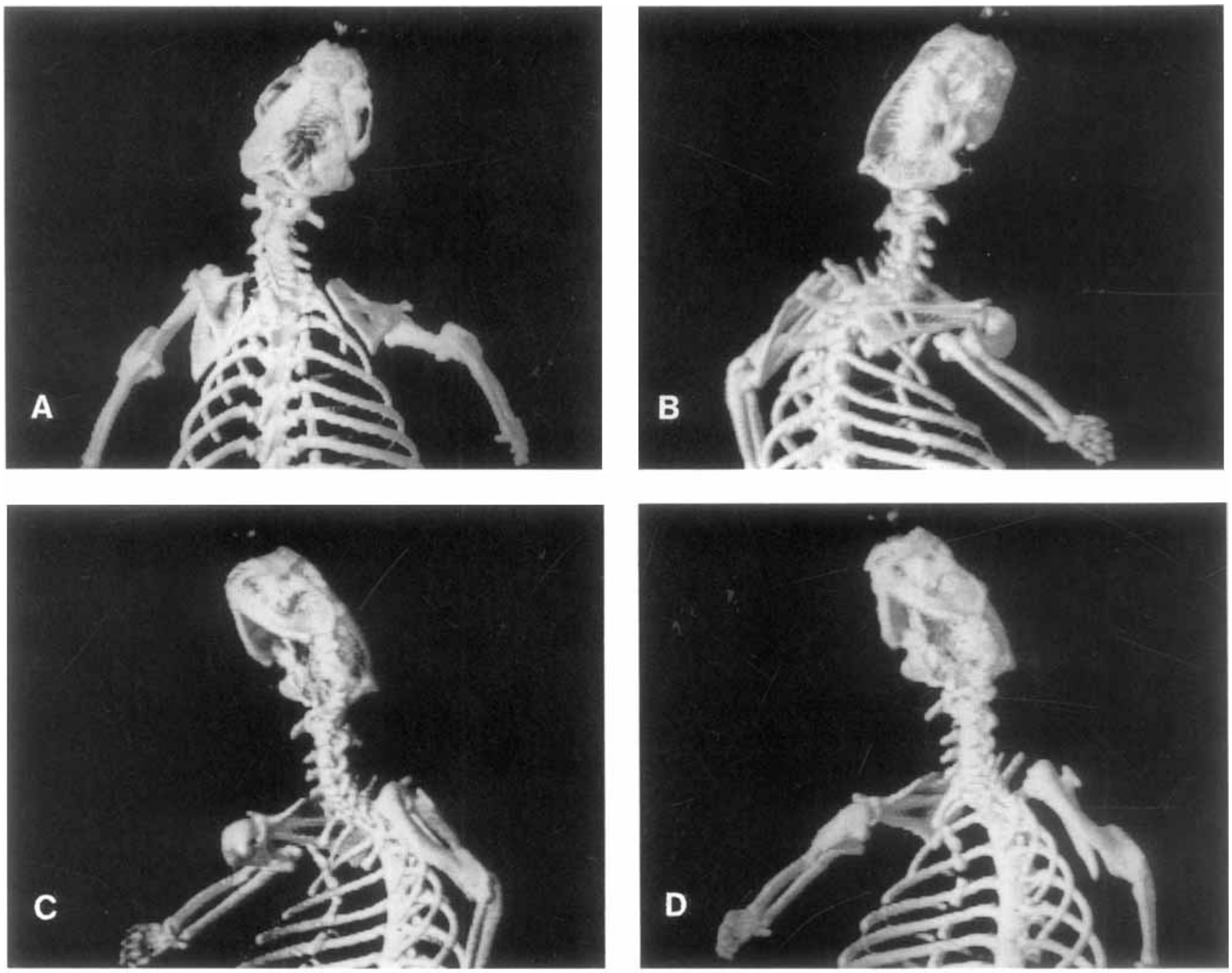

FIG. 3. Three-dimensional image of a whole body volumetric reconstruction of the thoracic, cervical and cranial skeleton of an adult male sea otter (*Enhydra lutris*) rotated along the spinal axis (A, B, C, and D).

duplicated by other available imaging systems. These images are superior to other imaging methods in clinical applications, allowing the evaluation of all possible obliquities to demonstrate optimally anatomic details.[7] Another major advantage of the technique is the ability to eliminate overlying densities that would obscure bone detail.

The rapidity of 3D volumetric reconstruction and its noninvasive nature in contrast to traditional dissection makes the detailed assessment of anatomic relationships in zoological animals practical. This capability opens up new approaches in zoological medicine, zoology and paleontology which were previously impractical or unthinkable because of restrictions in time or specimen availability. It would also be of value in diagnostic studies of domestic animals where continuous rotation of a 3D image around an axis would be superior to multiple plain view examinations.

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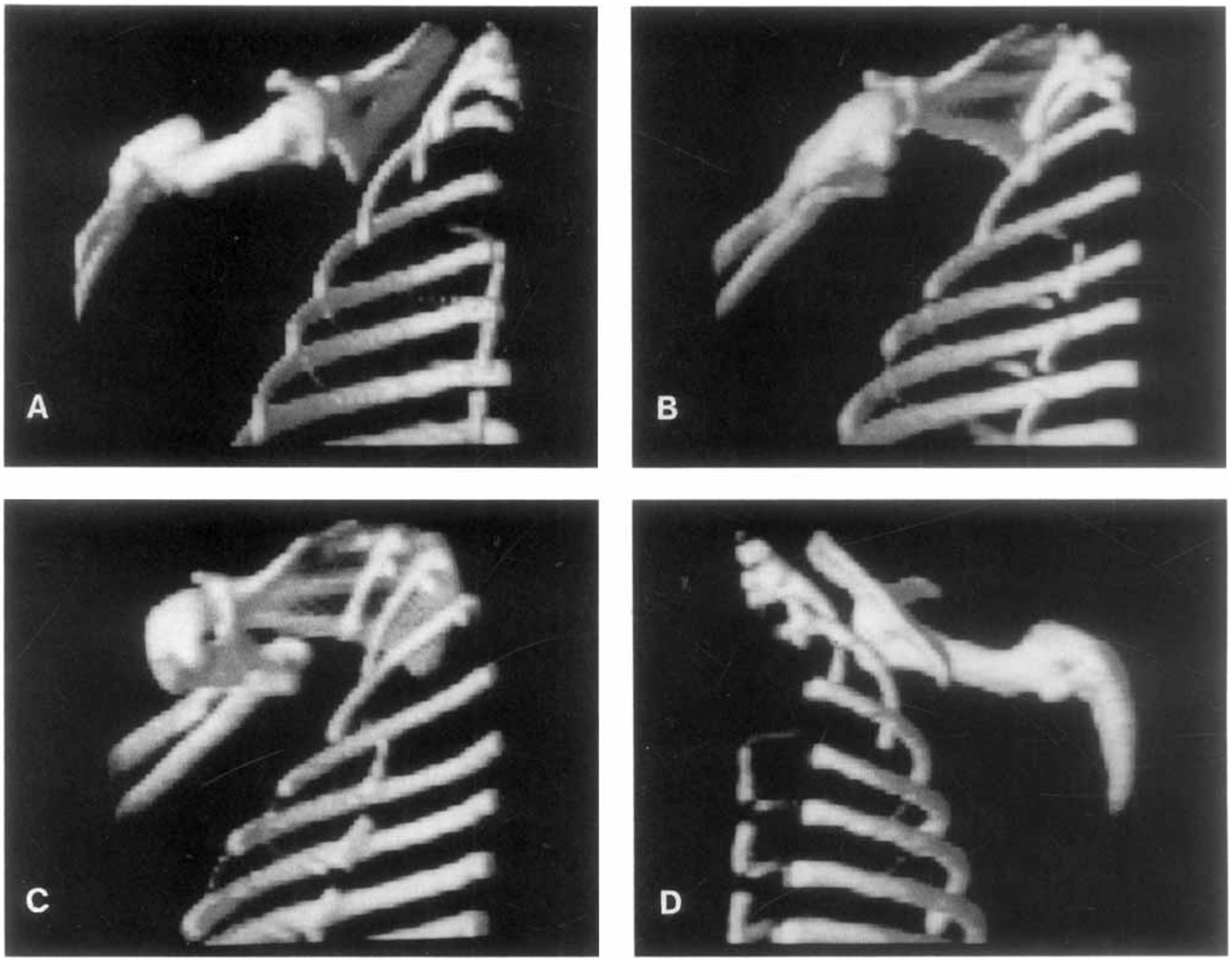

FIG. 4. Four zoomed images of an isolated three-dimensional volumetric reconstruction of the left shoulder girdle of a male sea otter (*Enhydra lutris*) shown as different projections after rotation on the spinal axis, with conflicting spinal and contralateral forelimb skeletal structures removed (A, B, C, and D).

REFERENCES

1. Altman NR, Altman DH, Wolfe SA, Morrison G. Three-dimensional CT reformation in children. AJR 1986;146:1261–7.

2. Burk DL Jr, Mears DC, Kennedy WH, Cooperstein LA, Herbert DL. Three-dimensional computed tomography of acetabular fractures. Radiology 1985;155:183–6.

3. Marsh JL, Vannier MV. Surface imaging from computerized tomographic scans. Surgery 1983;94(2):159–65.

4. Totty WG, Vannier MW. Complex musculoskeletal anatomy: analysis using three-dimensional surface reconstruction. Radiology 1984;150:173–7.

5. Pate D, Resnick D, Andre M, et al. Perspective: three-dimensional imaging of the musculoskeletal system. AJR 1986;147:541–5.

6. Fishman EK, Drebin B, Magid D, et al. Volumetric Rendering Techniques: Applications for Three-dimensional Imaging of the Hip. Radiology 1987;163:737–8.

7. Scott WW, Fishman EK, Magid D. Acetabular Fractures: Optimal Imaging. Radiology 1987;165:537–9.