3-D Reconstruction in Radiology

By Reuven Shreiber, M.D.

Introduction

The majority of work performed in radiology is presented as 2-D information, from conventional x-ray images to the most advanced CT, MRI or PET-CT studies.

In the early days of radiology, when there was a need for 3-D presentation, it was performed by special stereotactic devices displaying two images, one for each eye, with a minimal change (about 5 degrees) in the view angles between the two studies.

When axial imaging began with CT and US, imaging information became available in digital form. The next step was to try and obtain volumetric information from the 2-D slices. In this paper, we will describe the types of reconstruction packages available for 3-D presentation of volumetric information and the associated diagnostic advantages.

Debut of Volumetric Data

The introduction of spiral CT created a revolution by introducing a volumetric data set that could be acquired in reasonable time. In 1993 Elscint Inc., introduced the first multi-detector row CT (MDRCT) which allowed the acquisition of two spiral slices simultaneously.

It was the only MDRCT for 5 years, then several manufacturers introduced 4 rows of detectors, which gradually evolved to 8, 16, 40 and now 64 rows of detectors. In the future, we expect that some manufacturers will be offering CT with 256 rows of detectors.

Another new approach is the introduction by Siemens (at RSNA 2005) of a CT with two separate X-ray tubes and detectors on the same gantry.

Simultaneous acquisition of more slices in one rotation reduces the number of rotations required (thus reducing the time needed) to cover the same volume when all other parameters are constant.

Another option is to reduce slice thickness (thus increasing the spatial resolution) by the same factor without increasing the time needed for the examination, or keeping the same slice thickness while increasing the volume covered by the CT in the same acquisition time.

The outcome of such systems is the availability of additional thinner slices in a shorter acquisition time—allowing the acquisition of volumetric information with the reduction of motion influence on the image quality.

Applications for Post Processing: MIP, MPR

The availability of the volumetric data set led to the next step: new applications for post processing of the CT data. The first post-processing options included Maximum Intensity Projection (MIP), Multi-Planar Reconstruction (MPR) and Surface Shaded Display (3-DSSD).

MIP is a reconstruction whereby in the view angle selected, the maximal intensity value along the line perpendicular to the view represents this line of pixels in a 2-D presentation of the reconstructed body.

In this example, the far right-hand column represents the horizontal view of the matrix, and the lower row represents the vertical view the matrix.

1	1	1	1	1	1	3	3
2	1	1	2	2	0	1	2
4	4	4	4	4	4	4	4
1	1	1	1	1	1	4	4
1	2	3	4	5	6	7	7
2	2	8	0	0	0	0	8
1	2	1	1	1	1	1	2
4	4	8	4	5	6	7	

Other angles are available in the same way.

MIP reconstruction is mainly used to show vessels with contrast material in CT Angiography (CTA) and MR Angiography (MRA), but is also used in PET examinations to provide clear views of lesions.

A variation of MIP is the Minimal Intensity Projection, added at a later stage. Here the minimal value along the view line is representing the line:

1	1	1	1	1	1	3	1
2	1	1	2	2	0	1	0
4	4	4	4	4	4	4	4
1	1	1	1	1	1	4	1
1	2	3	4	5	6	7	1
2	2	8	0	0	0	0	0
1	2	1	1	1	1	1	1
1	1	1	0	0	0	0	

This type of reconstruction is used to demonstrate organs filled with air in CT examinations, such as airways and sinuses.

Figure 1 on the next page, an example of MIP reconstruction of a CT study, shows a tip of the basilar artery aneurism.

Figure 2 on the next page is an example of Minimal MIP reconstruction of a CT study of the lung.

MPR uses the 3-D data to show other planes that were not acquired directly during the acquisition, including sagittal and coronal cross-sections reconstructed from the axial images.

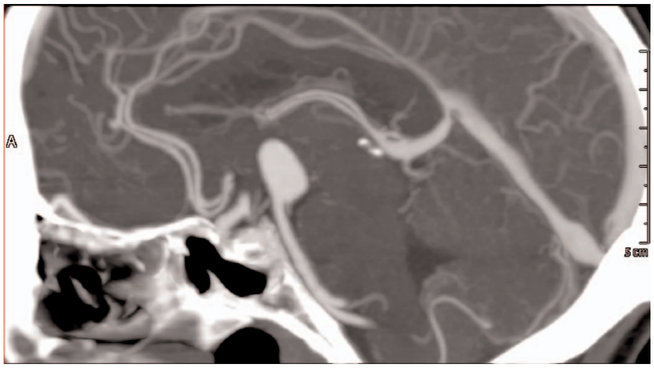


Figure 1: This example of MIP reconstruciton of a CT study shows a tip of the basilar artery aneurism.

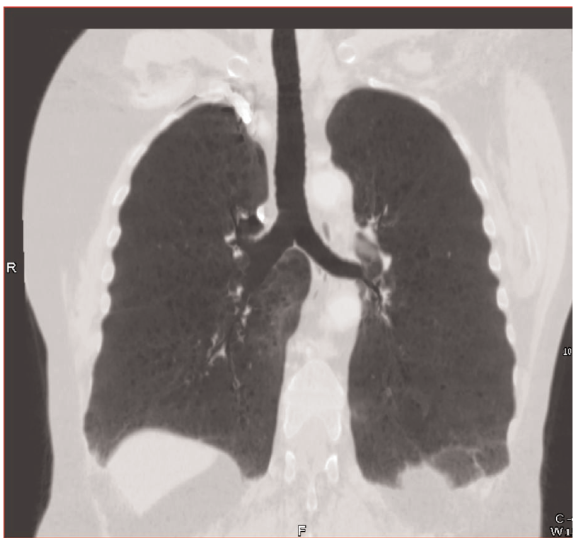


Figure 2: This is an example of Minimal MIP reconstruction of a CT study of the lung.

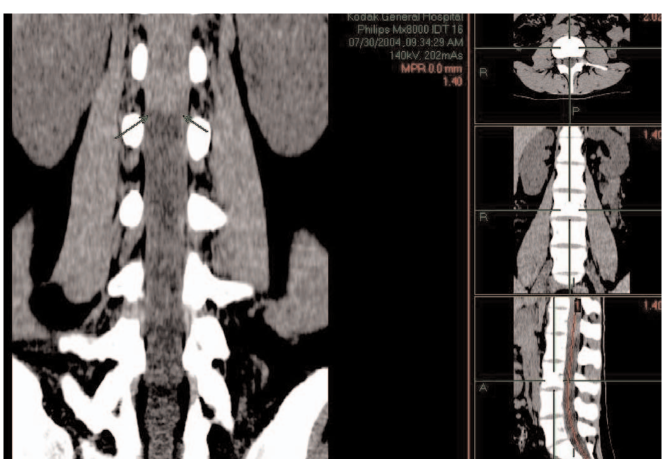


Figure 3: Curved MPR reconstruction of the spine Tumor (PNET) of the Conus medularis (arrows)

Since the entire volume data is available, it is possible to achieve any required plane and it is even possible to obtain a curved plane, parallel to any anatomical structure.

1	1	1	1	1	1	3
2	1	1	2	2	0	1
4	4	4	4	4	4	4
1	1	1	1	1	1	4
1	2	3	4	5	6	7
2	2	8	0	0	0	0
1	2	1	1	1	1	1

Curved MPR (see Figure 3) can also be used for the analysis of vessels where the plane of the cut is parallel to the vessel, thus showing the anatomical details of the vessel. When cutting perpendicular to the vessel, the real dimensions of the vessel can be measured.

Aortic vessel analyses with Curved MPR: On the lower left image of Figure 4 (opposite page), the contour of the aorta, just above the take-off of the superior mesenteric artery, is displayed with the minimal and maximal diameters of the vessel. This cut is perpendicular to the line (green) in the center of the aorta shown on the curved MPR on the right image.

MPR is the most widely used post-processing 3-D application (and in many cases it is the only one). It is used with MRI, CT and NM studies.

In Figure 5 (next page), the images were acquired on the axial plane and reconstructed using MPR to the coronal view. When the two sets are aligned, it is possible to fuse them into one image.

3-D Reconstruction

Two methods for 3-D reconstruction are available; the first is 3-D Surface Shaded Display (3-DSSD) that recognizes tissue by its density (similar to CT) or manually by drawing the contour of the organ. The view is as though one is looking from a certain point and what surface the viewer can see. This method actually shows only the surface of the organs as an opaque object. Slicing through a surfaced rendered object will not reveal internal objects. Two such examples are shown in Figure 6.

SSD is a process by which the apparent surfaces are determined within the volume of data and the resulting surface is displayed. Surface contours are usually modeled as a number of overlapping polygons derived from the boundary of the selected region of interest. A virtual light source is computed for each polygon and the object is displayed with the resulting surface shading.

Today, 3-DSSD is almost obsolete since it requires rather extensive work from the user and was replaced by volume rendering 3-D reconstruction.

3-D Volume Rendering

Volume rendering reconstruction (VR) takes the entire volume of data, calculates the contributions of each voxel (volume pixel) along a line from the viewer's eye through the data set, and displays the resulting composite for each pixel of the display.

Volume rendering involves the forming of an *RGBA volume* from the data, reconstruction of a continuous function from this discrete data set, and projecting it onto the 2-D viewing plane (the output image) from the desired point of view. An RGBA volume is a 3-D four-vector data set, where the first three components are the familiar R, G, and B color components and the last component, A, represents *opacity.*

Opacity values range from 0, which is totally transparent, to 1, which is totally opaque. An opaque background is placed behind the RGBA volume. Mapping of the data to opacity values acts as a classification of the data being examined.

Iso surfaces are displayed by mapping the corresponding data values to almost opaque values and the remainder to transparent values. The appearance of surfaces can be improved by using shading techniques to form the RGB mapping. However, opacity can also be used to see the interior of the data volume. These interiors appear as clouds with varying density and color. A big advantage of volume rendering is that this interior information is not discarded, so that it enables one to look at the 3-D data set as a whole.

Volume rendering is widely used as part of CTA and MRA, and in various applications such as cardiac imaging, orthopedic applications and others.

CT Endoscopy, Including Virtual Colonoscopy

With virtual colonoscopy (VC), internal vessels or organs are seen as if a virtual endoscope is penetrating the body and viewing the organ from a virtual viewpoint. The surface view is similar to that used in 3-DSSD with the possibility of making a virtual journey along a path in a vessel or specific organ such as the colon, small intestine or the stomach (Figure 6, next page).

A similar feature is also available with MRI 3-D data sets for visualization of sinuses, ventricles of the brain and vessels such as the aorta.

CT, MRI Perfusion Use Time As Third Dimension

Unlike other reconstruction techniques, CT and MRI perfusion use time as the third dimension. Acquisition is performed on a set of slices without contrast material. Then, at known intervals after the injection of contrast material, changes in the tissue enhancement over time are followed. This technique is mainly applied to the liver or

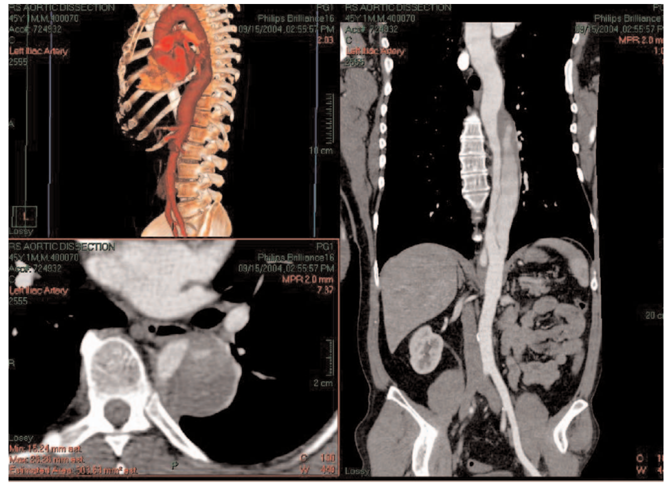
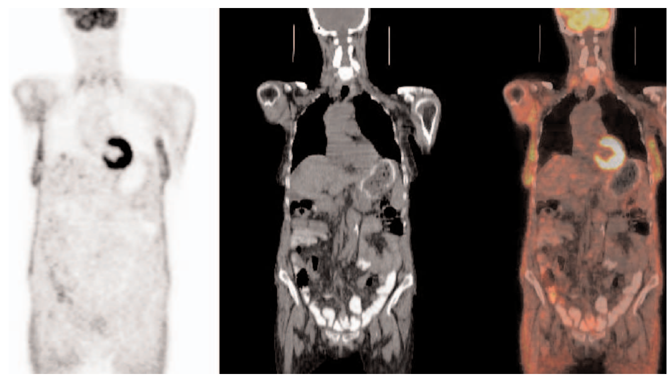


Figure 4: Aortic vessel analyses with curved MPR reconstruction along the abdominal Aorta and another plane perpendicular to the aorta at any desired level, revealing dissection of the thoracic Aorta.



PET Image *CT Image* *Fused image*
Figure 5

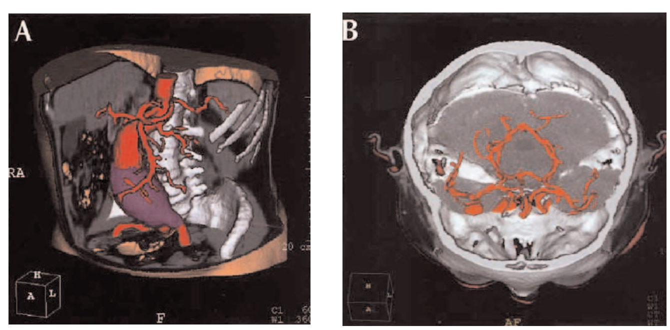


Figure 6: 3-DSSD reconstruction of Abdominal Aneurysm (left) and of Cranial (MCA) Aneurysm.

the brain to visualize brain infarcts (cerebro-vascular accident – CVA) tumors and other conditions.

The results are displayed as color maps which include blood volume in the region of interest, blood flow and time of travel of the blood through the region of interest.

Vessel Analysis

Vessel Analysis (segmentation) allows easy identification and display (panoramic and cross sectional) of vessels such as carotids, aorta and vessels of the extremities. The placement of only 4 points is necessary to acquire the reconstructed image in Figure 7.

Advantages of 3-D Reconstruction

Reconstructed 3-D data offers several advantages:

1. It enhances viewing of pathology
2. It equips radiologists to deal with the large data sets that are available with the new multi-detector CT scanners and to more easily compare current and previous exams.
3. It improves service to referring physicians, since selected 3-D images can be attached to the radiology report. These images illustrate the diagnosis and may even be shown to patients while discussing the condition and recommended treatment.

Workflow Considerations

While 3-D reconstruction provides undeniable advantages, its ability to deliver value is influenced by how it is implemented. If it is only available at a dedicated workstation, each study has to be loaded twice and manipulated twice at different workstations. This two-workstation environment consumes network bandwidth, interferes with a radiologist's reading routines and concentration and lowers overall productivity.

In an optimal work environment, advanced 3-D processing tools are embedded into the diagnostic viewing application to allow efficient reconstruction of images, simultaneous comparison of 2-D and 3-D images, and referencing of historical data. This reduces costs and creates greater productivity and enhanced diagnostic confidence.

Deploying these advanced processing capabilities in a thin-client environment, i.e. to any authorized LAN- or WAN-based workstation, provides additional benefits by equipping radiologists with more convenient access.

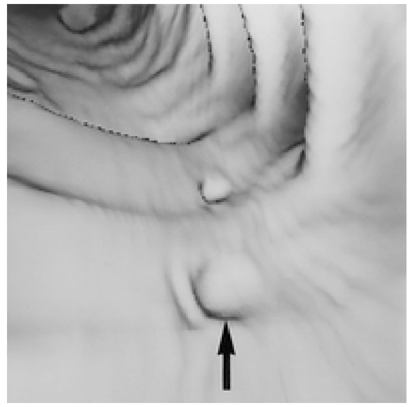


Figure 6: A small polyp in the colon detected by VC.

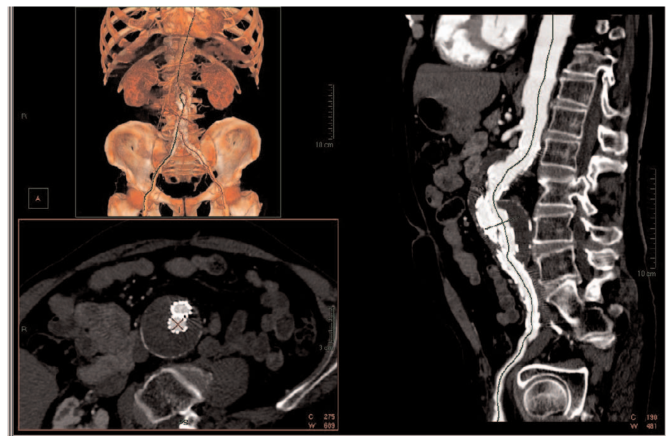


Figure 7

References:

1. *Multi-detector row CT systems and image reconstruction techniques. T.G. Flohr, S. Schaller et al. Radiology 2005; 235: 756-773.*
2. *Three-dimensional Volume Rendering of Spiral CT Data: Theory and Method P. Calhoun, B. Kuszyk et al. Radiographics. 1999;19:745-764.*

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Reuven Shreiber, M.D., is a neuroradiologist and an expert in diagnostic radiology. Dr. Shreiber received his medical degree from the Sackler School of Medicine at Tel Aviv University, and also holds a Bachelor of Science degree in Mechanical Engineering from Tel Aviv University. Dr. Shreiber previously worked at Rambam Medical Center's Department of Radiology, Haifa, Israel, and held R&D, marketing and product management positions at Elscint Inc. He is currently the Vice President for Clinical Applications at Algotec, a Kodak company.