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Physics of Computed Tomography

Lecture (3)

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Physics of Computed Tomography

Data Acquisition

Basic concepts for data acquisition

Radiography reduces a three-dimensional (3D) body part to a two-dimensional (2D) image with limited contrast, because structures that lie on top of one another are projected onto a single image. The contrast can be improved by using exogenous agents to enhance certain structures or by taking extra projections from different angles to separate the structures in the image plane, but there are limits to how well this can work. The advantage of CT is the improvement in image *contrast* that comes from using a 2D image to show an almost-2D section of the patient without the effect of overlapping structures.

The CT image is a cross-sectional view of the patient rather than an x-ray shadow of the beam passing through the body part (Fig. 1). An x-ray beam is used to collect information about the tissues, but the image is not an ordinary projection view from the perspective of the x-ray tube looking toward the film or detector. The image is a cross-sectional map of the x-ray attenuation of different tissues within the patient. The typical CT scan generates a transaxial image oriented in the anatomic plane of the transverse dimension of the anatomy. Reconstruction of the final image can be reformatted to provide sagittal or coronal images; these are viewed from the same perspective as a digital radiograph, but they show thin slices of tissue rather than superimposed tissues and structures. The pixel values show how strongly the tissue attenuates the scanner's x-ray beam compared to the attenuation of the same x-ray beam by water.

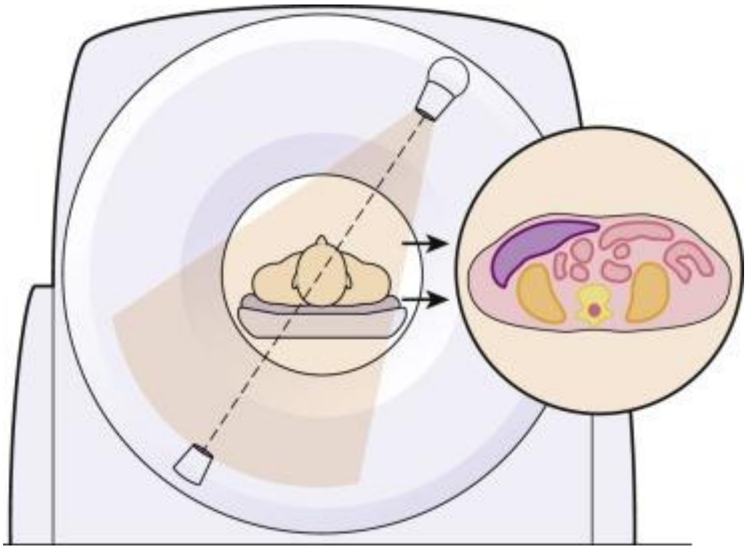


FIG 1

A CT image represents a cross section of the imaged subject rather than the x-ray shadow of the anatomy, as in a conventional radiograph.

The CT image is produced by the process of *reconstruction:* digitally combining information from x-ray projections through the patient from many different angles to produce the cross-sectional image. Because the image is digital, it is made up of a group of ***pixels*** (shortened from "picture elements"). Each pixel has a grayscale value that is displayed to the viewer. The image is 2D, but it represents a 3D volume of tissue with a finite thickness (usually a very small thickness compared to the field-of-view (FOV) size [≈2-5 mm]). Each pixel is the projection, or 2D representation, of the x-ray attenuation of a ***voxel*** (shortened from “volume element”) of physical tissue. The size of the pixels and the thickness of the voxels relate to some important image quality features, such as detail, noise, contrast, accuracy of the attenuation measurement (CT number value), and artifacts.

CT Acquisition Overview

The basic process of collecting data in CT is illustrated in Figure 2. **In a CT of a single section of tissue using a single detector**, the x-ray beam is collimated to the desired image thickness. The detector array has a number of individual detector elements that each record the intensity of the beam passing through the tissue along the path from the x-ray tube to the element. The system captures a simple projection x-ray through the patient, consisting of a thin strip or row of pixels. It can be thought of as a one-dimensional (1D) radiograph. The scanner then rotates the source and detector to capture additional 1D “strip x-rays” through the same section of the patient, viewed from a number of angles. Each strip radiograph *(projection)* is stored in the computer memory for later reconstruction.

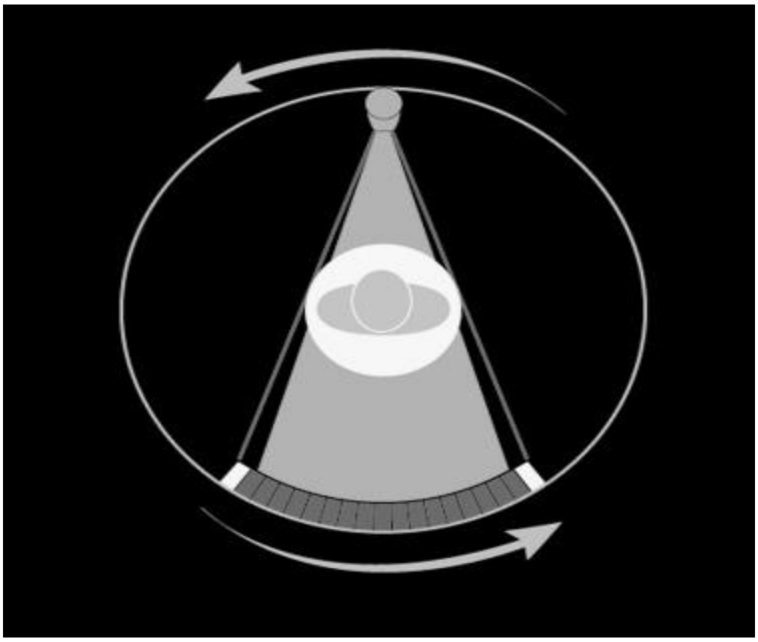


FIG 2

A simple CT scan produces a one-dimensional strip radiograph for each projection through the patient.

In ***multislice CT*** (Fig. 3) this operation is performed simultaneously for many arrays of detectors stacked side by side along the z-axis (long axis) of the patient. The x-ray beam collimators can be opened so that a wider section of the patient is irradiated, and each row of detectors can measure a separate transmission signal for the tissue section that lies between the detector row and the tube. The width of tissue that is sampled by each detector row is determined by the physical width of the detector elements along the z-axis.

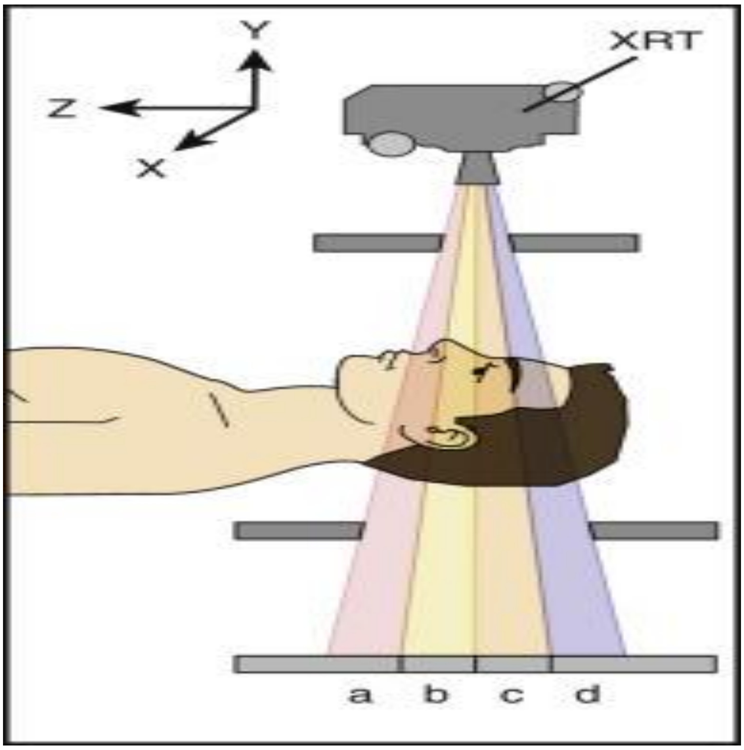


FIG 3

In multislice CT, several independent detectors arranged side by side sample data from unique locations within the x-ray beam.

CT images and individual rotations of the scanner gantry are often called *slices* because a single data acquisition and reconstruction produces an x-ray map of a thin section of the patient's body. The tissue displayed in the image represents the same tissue as if a thin slice or section of the patient's body were cut in a plane perpendicular to the long axis (superior-inferior) of the patient's body and fixed for viewing

Image Reconstruction

- The projections acquired by each detector during CT are stored in computer memory.
- The image is reconstructed from these projections by a process called **filtered back projection**.
- The term **filter** refers to a mathematical function rather than to a metal filter for the x-ray beam. This process is much too complicated to be discussed here, but a simple example helps to explain how it works.

Imagine a box with two holes cut into each side

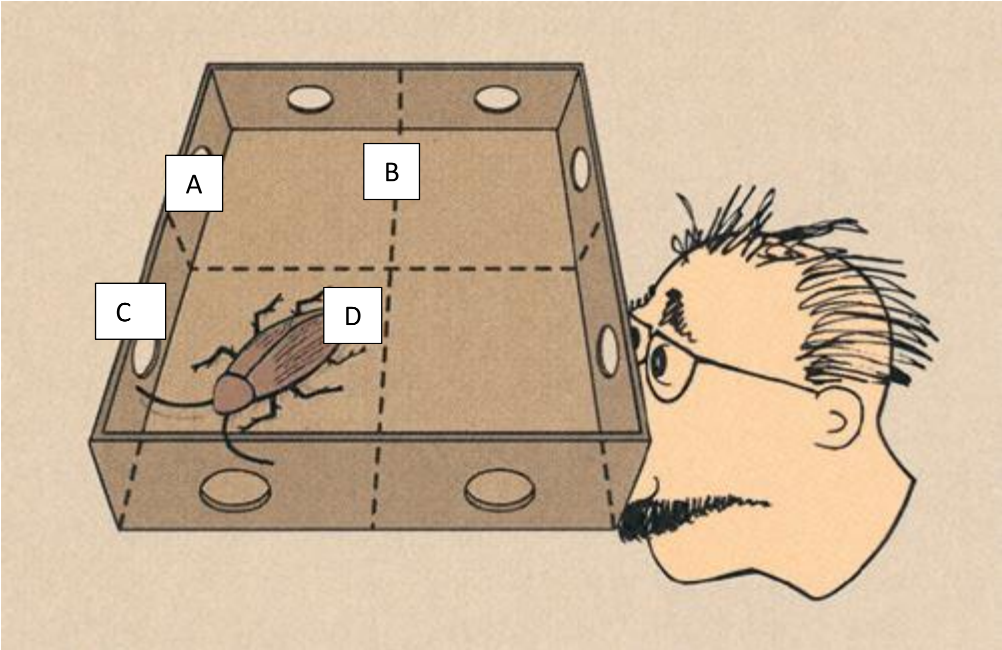
Imagine a box with two holes cut into each side (Figure 4). The box is divided into four cells labeled *a*, *b*, *c*, and *d*, and a Texas-sized cockroach is found in cell *c*. If we now cover the box and look through the four sets of holes, we can devise a way of determining precisely in which section the cockroach resides.
Let "1" represent the presence of the cockroach for each viewing. If one can see through a hole two empty cells and the opposite hole, then obviously, the cockroach is not there. We indicate the absence of the **cockroach** with "0." The path that is being viewed in Figure 4 can be represented symbolically as $c + d = 1$. Examination of all possible paths shows the following:

$$a + b = \mathbf{0}$$

$$c + d = \mathbf{1}$$

$$a + c = \mathbf{1}$$

$$b + d = \mathbf{0}$$



Figure(4)

The result is four equations for which, if solved simultaneously, the solution is
c = 1 and *a*, *b*, and *d* = 0.
In CT, we would have not four cells (pixels) but rather more than 250,000. Consequently, CT image reconstruction requires the solution of more than 250,000 equations simultaneously. Recently, a more robust reconstruction algorithm, **iterative reconstruction**, has been introduced. Iterative reconstruction requires more computer capacity but can result in improved contrast resolution at lower patient radiation dose.

Multiplanar Reformation

- Multislice helical CT excels in three-dimensional **multiplanar reformation (MPR)**.
- Transverse images are stacked to form a three-dimensional data set, which can be rendered as an image in several ways.
- Three 3-dimensional MPR algorithms are used most frequently: **maximum intensity projection (MIP)**, **shaded surface display (SSD)**, and **shaded volume display (SVD)**.
- MIP reconstructs an image by selecting the highest value pixels along any arbitrary line through the data set and exhibiting only those pixels (Figure 5).
- MIP images are widely used in CTA because they can be reconstructed very quickly.

Only approximately 10% of the three-dimensional data points are used. The result can be a very highcontrast three-dimensional image of contrast-filled vessels (Figure 5).

- A maximum intensity projection (MIP) reconstruction creates a three-dimensional image from multislice twodimensional data sets. The result is a computed tomographic angiogram.

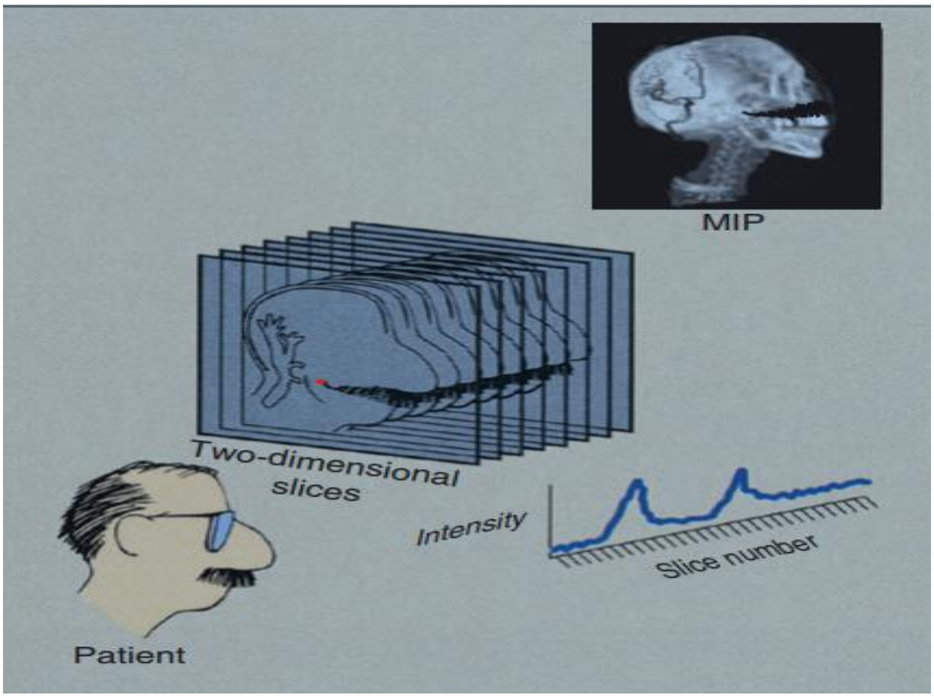


Figure (5)

MIP is the simplest form of three-dimensional imaging. It provides excellent differentiation of the vasculature from surrounding tissue but lacks vessel depth because superimposed vessels are not displayed