1. Introduction

Since its introduction in 1972, X-ray computed tomography (CT) has evolved into an essential diagnostic imaging tool for a continually increasing variety of clinical applications. The technology has made two major evolutionary leaps during the past decade. The first of these occurred in the early 1990s with the introduction of CT scanners with simultaneous patient translation and data acquisition. These scanners, called “spiral” or “helical,” revolutionized the use of CT, creating new applications that could not have been attempted before, such as CT angiography and virtual endoscopy. The technological advances that led to these developments were mainly slip-ring gantry designs, very high power x-ray tubes and interpolation algorithms to handle the non-coplanar projection data.

The second leap occurred mid-decade, with one vendor’s introduction of a dual-detector row spiral CT scanner. By late 1998, all major CT manufacturers launched multiple-row detector CT (MDCT) scanners capable of at least four slices per x-ray tube rotation (Fig 1). Major advantages of these scanners appear to be improved volume coverage and/or longitudinal spatial resolution.

Figure 1. Diagram shows the difference between single-row detector and multiple-row detector CT designs. The multiple-row detector array shown has elements of unequal dimension and represents that of one particular manufacturer.
Recent introduction of 16 section scanners with decreasing scan time, have yielded more thinner sections, improved z-axis spatial resolution. These scanners have led to number of new clinical applications especially in cardiac imaging. Different vendors have chosen different technological approaches to achieve their designs and, as a result, offer different sets of options to the user (Fig 2 a & b).

**Figure 2 a.** Detector array designs used in four-section MDCT scanners.
Figure 2b. Detector array designs used in 16-section MDCT scanners.
The following sections discuss key concepts, common to most multiple-row detector CT (MDCT) scanners, required to understand their functions and capabilities.

2. **Detector and Data Acquisition System (DAS)**

The MDCT detector differs from that of a single-row detector CT (SDCT) in that in addition to being divided into channels in the transaxial plane, it is further divided into multiple detector elements in the longitudinal (or slice) direction. Independent of the number of elements, scanners differ in the number of DAS channels (equivalent to the maximum number of simultaneously acquired slices) available to sample the detector. When the number of DAS channels is less than the number of detector elements, the outputs of the elements may be summed prior to sampling by the DAS. For example: on a four DAS channel scanner (commonly, but mistakenly called a 4 detector row scanner) employing a detector with 16 equal detector element dimensions (Fig. 3), sampling the inner four elements (1 element per DAS channel) results in the acquisition of four 1.25 mm (nominal) slices per rotation. Summing the elements in groups of two, three or four prior to sampling, results in four 2.5 mm slices, four 3.75 mm slices, or four 5 mm slices, respectively. Extension to scanners with 8, 16 or even more DAS channels, allowing correspondingly more slices to be collected per rotation will be discussed in the presentation.

3. **Sequential Scan Mode**

One way to scan without patient translation and to reconstruct a section from each of the DAS channel is called “Sequential multi-section scan” mode and is similar to conventional step-and-shoot CT, but with two major improvements. First, for a given section thickness, cross-sections may be acquired at up to N times the rate, where N is the number of DAS channels. Second, thicker slices may be reconstructed retrospectively using data from multiple DAS channels. For example, with the detector configured to provide four 2.5 mm channels, one can reconstruct four 2.5 mm slices, or two 5 mm slices (by summing the channels in pairs), or one 10 mm slice (by summing all four channels). These “thickened” slices, composed of data seen by “thinner” detectors, have the advantage that non-linear effects of volume averaging (such as streaks in the posterior fossa of head scans) are reduced
compared to conventional acquisitions at the same nominal slice thickness. Another way to look at this is to note that when combining adjacent DAS channels to make slices of a given thickness, the user has the possibility to reconstruct thinner slices retrospectively.

Figure 3: Four detector configurations. (a) 4 x 1.25 mm, (b) 4 x 2.5 mm, (c) 4 x 3.75 mm and (d) 4 x 5 mm channels
4. **Helical Multisection Mode**

The second way is to scan during patient translation in a manner directly analogous to helical scanning on a SDCT scanner. However, whereas in SDCT, projections for a single section are interpolated from data from the single DAS channel, data from all DAS channels contribute to each reconstructed slice in MDCT. The algorithms for this interpolation stage can be adjusted to trade off longitudinal resolution against noise and artifacts, in a manner analogous to choice of reconstruction kernel for similar trade-offs in-plane. For example, one can tailor the section profile retrospectively and select among different nominal slice width. This process, known as z-filtering, results in the new notion of slice thickness as a reconstruction parameter. With increased beam width with 16 section scanners, the cone beam artifacts become significant if conventional reconstruction methods are used. Cone beam reconstruction algorithms are been developed to accommodate cone beam geometrical issues.

5. **Helical pitch**

With single slice helical CT scanners, the concept of *pitch* is straightforward. Referring to Figure 4, with the x-ray beam width given by W (in millimeter) and the table increment per gantry rotation defined as I (in millimeter), *pitch* and more specifically the *beam pitch* is defined as:

$$\text{Beam Pitch} = \frac{I}{W}$$

With the introduction multiple-row detector CT scanners, ambiguity arises in terms of the definition of pitch, as different manufacturers used different definitions of pitch, resulting in much confusion. Consequently, beam pitch needs to be distinguished from *detector pitch*, which is defined as:

$$\text{Detector Pitch} = \frac{I}{T}$$

where, T is the width of single data acquisition system/channel (DAS) in millimeters (Fig 6). If the x-ray beam is collimated to ‘N’ DAS channels in a multiple-row detector CT scanner, the relationship between beam and detector pitch is as shown below:
Adopting the usage of beam pitch would be applicable equally to both SDCT and MDCT systems. According to the IEC agreement, consensus among all CT manufacturers is reached to commonly adopt definition of beam pitch and calling it as simply ‘pitch’. This aims to eliminate existing confusion between the relationship of radiation dose and various manufacturers defined pitch.

\[
\text{Beam Pitch} = \frac{\text{Detector Pitch}}{N} = \frac{I}{N \times T} = \text{Pitch}
\]

Figure 4. Diagram shows the concept of beam pitch and detector pitch. Beam pitch is consistent with the previous notion of pitch used in single-row detector helical CT and works well for multiple-row detector CT scanners as well. Beam pitch is simply named ‘pitch’ to maintain consistency between the single-row detector and multiple-row detector helical CT.

Single Detector Array

Multiple Detector Array

- I - Table travel (mm)/rotation
- W - Beam width (mm)
- T - Single data acquisition channel width (mm)
- N - Number of active data acquisition channels
6. **Advantages of Multiple-row detector CT:** The clinical advantages of multiple-row detector technology can be broadly divided into three categories. a) The ability to obtain large number of thin slices resulting in higher spatial resolution in both axial and longitudinal direction. This is important in terms of obtaining isotropic spatial resolution, i.e., cubic voxels, where in the images are equally sharp in any plane traversing the scanned volume. This capability is reasonably obtained with multiple sections of sub-millimeter thick. Ideally the true 3D radiograph would have cubic voxels of <1mm in size, over large volumes, acquired with very short times at least within a reasonable breath-hold. b) The speed can be utilized for fast imaging of large volume of tissue with variable slice thickness. This is particularly useful in studies with patient motion is a limiting factor. A scan volume of 1000 mm can be scanned in 30 sec with a 4-section system and 0.5 second scan time, while a 16 section scanner can cover the same region in 8 seconds. c) The other main advantage of multi-slice systems is better utilization of x-ray tube. The fast rotation times and large volume coverage with improved reconstruction technique provide images of superior quality with minimal artifact.

6. **Summary**

The advances in MDCT scanners have presented new opportunities for improved patient imaging and throughput. However, these scanners bring with them new concepts that have to be understood and new tradeoffs that have to be made. The technical considerations to be outlined and discussed in this lecture will include: discussion on different multiple-row detector designs, cardiac imaging principles with MDCT, pitch and its influence on radiation dose, image quality and section thickness, and other topics will be covered in this presentation.
7. References:


