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Computed Tomography: Pioneering Work and Technical Overview

PRIOR READING ASSIGNMENT

Before attempting to answer these review questions, read the following brief summary notes on this topic.

In radiography, images are usually referred to as *planar images*. These images have the following limitations: superimposition of all structures on the image receptor (film-screen detector) and the qualitative nature of radiographic imaging. The latter simply means that it is difficult to distinguish between a homogeneous object (one tissue type) of non-uniform thickness and a heterogeneous object (bone, soft tissue, and air) of uniform thickness. Furthermore, the beam used in radiography is an open beam (wide beam), and this creates more scattered rays that reach the image and essentially destroy the image contrast.

Computed Tomography: Physics and Technology A Self Assessment Guide, Second Edition. Euclid Seeram.

Computed tomography (CT) overcomes these limitations by removing the superimposition of structures, improving image contrast, and imaging very small differences in tissue contrast, using a more sensitive detector. In particular, CT produces cross-sectional images of patient anatomy, referred to as *transverse axial images*. These sections are perpendicular to the long axis of the patient. The invention of the CT scanner is credited to two individuals: Godfrey Hounsfield (who worked at EMI [Electric and Musical Industries] in England) and Allan Cormack, who shared the Nobel Prize in Medicine in 1979 for their contributions to the development of the scanner. Both of these pioneers worked out the mathematical solutions to the problem in CT, but Hounsfield is credited with the development of the first useful clinical CT scanner.

The technical evolution of the CT scanner is marked by the development of more efficient data collection methods leading to multislice CT imaging (as opposed to single-slice CT imaging), faster image reconstruction algorithms resulting in low-dose CT scanning, and improved image postprocessing methods such as three-dimensional images.

The major components of a CT scanner include the data acquisition system, the computer system, and the image display, storage, and communications system. The data acquisition system contains imaging system components designed to collect radiation attenuation values from the patient using an x-ray tube and special detectors coupled to detector electronics. These components are housed in what is referred to as the CT *gantry*. The computer is a central and integral component in CT. The primary role of the computer is image reconstruction and image postprocessing. A graphics processing unit (GPU) is now used to reduce the processing requirements of the computer's central processing unit (CPU). Image reconstruction uses special algorithms to create the image using the attenuation values collected from the patient. Today these algorithms are iterative reconstruction algorithms and are much faster than the previous algorithm (the filtered back-projection algorithm).

CT examinations generate large amounts of data; hence large storage space on the order of gigabytes (GB) is required. Storage devices for CT include magnetic tape and disks, digital videotape, optical disks, and optical tape. Communications refer to electronic networking or connectivity by using a local area network or wide area network (LAN or WAN). *Connectivity* ensures the transfer of data and images from multivendor and multimodality equipment according to a defined standard.

A popular standard for medical images is the Digital Imaging and Communications in Medicine (DICOM) standard. CT scanners are now connected to Picture Archiving and Communications Systems (PACS).

In general, the software used in CT includes image reconstruction software, preprocessing software, and image postprocessing software. Image reconstruction software uses algorithms to build up the image from the raw data collected from the detectors. Preprocessing software performs corrections (such as correcting a bad detector reading, for example) on the data collected from the detectors before the data is sent to the computer. Image postprocessing software operates on reconstructed images displayed for viewing and interpretation and typically includes visualization and analysis software.

Self-Assessment Questions will be based on the following Keywords and Concepts

- Major differences between CT and radiography
- Godfrey Hounsfield
- Allan Cormack
- Major components of a CT scanner
- Technical evolution overview
- The imaging system
- The computer system
- Storage capacity
- Connectivity
- CT software

Challenge Questions

Answer the following questions to check your understanding of the materials studied.

True (T)/False (F)

1. CT is a planar radiographic imaging modality.
2. CT was developed by EMI.
3. Godfrey Hounsfield was awarded the Nobel Prize in Medicine for his contributions to the development of the first useful CT scanner.
4. Allan Cormack did not share the Nobel Prize in Medicine with Hounsfield.

5. Radiographic imaging produces planar images of the patient's body.
6. CT can show very small differences in tissue attenuation compared to radiography.
7. CT shows soft tissue contrast much better than radiography.
8. CT uses rendering algorithms to create three-dimensional images to enhance diagnostic interpretation.
9. Images produced by the CT scanner are generally referred to as planar images.
10. Two notable technical innovations for CT scanners are the development of multislice detectors and iterative reconstruction algorithms.
11. Data acquisition in CT refers to the process of converting attenuation data to electrical signals that are subsequently converted into digital data.
12. GPUs are now used in CT to reduce the processing requirements of the CPU.

Multiple Choice

1. Which company pioneered the development of the CT scanner?
   A. General Electric Healthcare
   B. Siemens Healthineers
   C. Philips Healthcare
   D. EMI (now called Thorn EMI)
2. Which type of image does radiography produce?
   A. Planar static image
   B. Cross-sectional image
   C. Three-dimensional image
   D. Both A and C are correct.
3. A significant difference between CT and radiography is that:
   A. CT shows very small differences in soft tissue contrast compared to radiography.
   B. CT shows better image sharpness compared to radiography.
   C. CT images show better image contrast than radiographic images.
   D. A and C are correct.
4. Which of the following problems of radiography are overcome by CT?
   1. Superimposition of all structures on the image receptor
   2. The open-beam geometry of radiography, which causes more scattered radiation to reach the image receptor

3. The qualitative nature of radiography
4. The radiographic image receptor sensitivity to radiation
   - A. 1 only
   - B. 1 and 2
   - C. 1, 2, and 3
   - D. 1, 2, 3, and 4

5. The major system component of the CT scanner responsible for image reconstruction is the:
   - A. Data acquisition components
   - B. CT detector
   - C. Computer system
   - D. Picture archiving and communication system (PACS)

6. Which of the following data sets is used by the CT image reconstruction algorithm to create CT images?
   - A. Attenuation data from the patient
   - B. Demographic data sets about the patient
   - C. Exposure factors (kV and mAs)
   - D. The computer storage capacity

7. The anatomical section that is perpendicular to the longitudinal axis of the patient is called the:
   - A. Planar section
   - B. Transverse axial section
   - C. Cross section
   - D. B and C are correct.

8. Who developed the first clinically useful CT scanner?
   - A. Dr. Euclid Seeram
   - B. Dr. Godfrey Hounsfield
   - C. Dr. Allan Cormack
   - D. B and C are correct.

9. The first CT scanner was limited to scanning only the:
   - A. Brain
   - B. Chest
   - C. Abdomen
   - D. Whole body

10. Which of the following recent technical innovations in CT are intended to improve image quality and reduce radiation dose?
    1. Multislice detectors
    2. Iterative algorithms
    3. Dose optimization tools
    4. Quality control tests

A. 1 only
B. 2 and 3
C. 3 and 4
D. 1, 2, 3, and 4

11. The purpose of the data acquisition system components in CT is to:
    1. Produce x-rays
    2. Shape and filter the x-ray beam falling upon the patient
    3. Detect the radiation passing through the patient
    4. Convert the transmitted x-ray photons into digital information
        A. 1 only
        B. 2 and 3
        C. 3 and 4
        D. 1, 2, 3, and 4
12. A term used to describe the transfer of data and images from multivendor and multimodality equipment according to a defined standard is:
    A. Digital Imaging and Communications Standard in Medicine (DICOM)
    B. Connectivity
    C. PACS
    D. Preprocessing of raw CT data

Short Answers

1. What are the basic limitations of radiography that have been overcome by CT scanning?
2. How does CT overcome the limitations of radiography?
3. What major contributions did Hounsfield and Cormack make to the development of the CT scanner?
4. What are the major advantages of CT compared to radiography?
5. What is meant by the term *transverse axial section*?
6. List the major system components of the CT scanner and briefly explain the purpose of each component.
7. Identify notable technical innovations that are intended to improve the imaging performance of the CT scanner
8. Summarize the basic elements of how a CT scanner works
9. Briefly describe what is meant by the term *data acquisition*.
10. Briefly summarize the major purpose of image preprocessing and postprocessing in CT.
11. Briefly explain the meaning of the term *communication* as used in the acronym PACS.
12. Why is a GPU now used in CT scanner technology?

Answers to Challenge Questions

True/False

1. F
2. T
3. T
4. F
5. T
6. T
7. T
8. T
9. F
10. T
11. T
12. T

Multiple Choice

1. D
2. A
3. D
4. D
5. C
6. A
7. D
8. B
9. A
10. D
11. D
12. B

Short Answer

1. The fundamental limitations of radiographic images are the superimposition of all structures on the detector (which makes it difficult and sometimes impossible to distinguish a particular detail) and the qualitative nature of radiographic imaging. The latter simply means that it is difficult to distinguish between a homogeneous object (one tissue type) of non-uniform thickness and a heterogeneous object (bone, soft tissue, and air) of uniform thickness. Finally, the beam used in radiography is an open beam (wide beam), and this creates more scattered rays that reach the image and essentially destroy the image contrast. CT overcomes these shortcomings.
2. CT removes the superimposition of structures by using very highly collimated x-ray beams, hence decreasing the amount of scattered radiation produced in the patient. Removal of scatter improves image contrast. CT also uses more sensitive electronic detectors that can discriminate very small differences in tissue contrast compared with film screen image receptors. While radiographic film can only show x-ray intensity differences between 5% and 10%, CT can detect density differences from 0.25% to 0.5%, depending on the scanner.
3. Both Hounsfield and Cormack shared the Nobel Prize in Medicine in 1979 for their contributions to the development of the scanner. Both individuals worked out the mathematics of CT. While Hounsfield's Nobel lecture was entitled "Computed Medical

Imaging," Cormack's Nobel lecture was entitled "Early Two-Dimensional Reconstruction and Recent Topics Stemming from it." Specifically, Hounsfield developed the first clinically useful CT scanner; that is, images were diagnostic and could be interpreted by a radiologist.

4. The major advantage of CT compared to radiography is that CT shows much better image contrast. While the contrast resolution (mm at 0.5%) of radiography is 10, it is 4 for CT and 1 for magnetic resonance imaging (MRI). Additionally, CT is now a three-dimensional (3D) imaging modality. Using 3D rendering algorithms, CT can transform two-dimensional transverse axial images into several types of 3D images, as illustrated in Figure 2–3 in the textbook *CT at a Glance* (Seeram 2018). These image types are intended to enhance diagnostic interpretation.
5. A transverse axial section is illustrated in Figure 1–4 in *CT at a Glance* (Seeram 2018), and it is defined as an anatomical section that is perpendicular to the long axis of the patient. Such a section removes the superimposition of structures above and below the focal plane of the volume of the patient being imaged.
6. A CT scanner has three major system components: the data acquisition system, the computer system, and the image display, storage, and communication systems. The data acquisition consists of the x-ray tube, detectors, and detector electronics, which collect transmission or attenuation data from the patient. The computer uses the attenuation data collected from points around the patient for at least 360° and special image reconstruction algorithms to create CT images. The latter system components of the CT scanner are intended to display images for viewing and interpretation on a monitor, after which they are stored for retrospective analysis using storage hardware such as optical storage disks. These images are then handled by another system component and can be sent to a different location using computer network communications technology. One popular such technology is a PACS.
7. In brief, CT has evolved from a scanner dedicated to imaging the brain only to a single-slice whole-body scanner and, today, to a multislice scanner (MSCT). Other notable technical innovations includes the development of multislice detectors, iterative reconstruction algorithms, virtual reality imaging methods, dose optimization methods, and important quality control test tools

and procedures. Currently, artificial intelligence (AI) is being applied to CT image reconstruction and other areas. These innovations are intended to improve image quality and reduce radiation dose, and they also play a role in the care and management of the patient during CT imaging.

8. The following summarizes the essential technologies (highlighted in italics) that play important roles in describing how a CT scanner works:
   - The *x-ray tube* and *sensitive electronic detectors* are coupled and rotate around the patient to collect *attenuation data* from the patient, who is positioned on the *CT table* (or *couch*, as it is sometimes called), which moves through the *gantry opening* on the CT scanner during *scanning*. This process is referred to as *data acquisition*.
   - The attenuation data is used by *special computer algorithms* to reconstruct CT images. These algorithms are called *image reconstruction algorithms*. *Image reconstruction* is the heart of the CT scanner. Without this, there will be no transverse axial CT images. The basis for image reconstruction is *mathematics*.
   - Images are *displayed* on a *monitor* for viewing and interpretation by an observer who can apply *image postprocessing* to further enhance image sharpness, brightness, and contrast. Images can be *stored* using *optical or magnetic storage devices,* and they can be sent to remote locations using *computer network technologies*, such as a *PACS*.
9. Data acquisition is the first step in the CT process. It refers to the collection of attenuation data (or x-ray transmission data) as the x-ray tube and detectors rotate around the patient, and the subsequent conversion of this data to electrical signals by the detectors. These signals are then converted to digital data by the detector electronics.
10. *Image preprocessing* and *image postprocessing* ate two categories of software used in CT. The third category *is image reconstruction* software. While the purpose of preprocessing is to perform corrections (such as correcting a bad detector reading, for example) on the data collected from the detectors before the data is sent to the computer, image postprocessing software operates on reconstructed images displayed for viewing and interpretation. Examples include visualization and analysis soft-

ware. Visualization software can provide several image types such as multiplanar reformation (MPR), maximum or minimum intensity projection (MIP), and 3D surface-shaded display.

11. *Communications,* as used in the acronym PACS, refers to electronic networking or connectivity using a local area network or wide area network (LAN or WAN). Connectivity ensures the transfer of data and images from multivendor and multimodality equipment according to a defined standard. A popular standard for medical images is the DICOM standard.
12. Presently, CT scanners use iterative reconstruction algorithms to reconstruct images. These algorithms are complex and require increased computational power. Since current CPUs cannot handle these computations, a GPU is used to reduce the processing requirements of the CPU.

IDENTIFYING AREAS TO STUDY

A. Make a list of topics and/or questions that are still not clear to you after studying this chapter.
B. See the instructor for clarification and/or consolidation of the material.