RESEARCH REVIEW JOURNALS
Volume-03
Issue-06
June-2018

ISSN: 2455-3085 (Online)
RESEARCH REVIEW International Journal of Multidisciplinary
www.rrjournals.com [UGC Listed Journal]

Computed Tomography: A Historical Perspective

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ARTICLE DETAILS

Article History
Published Online: 12 June 2018

Keywords
CT, history, generations

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ABSTRACT

Over the past decade, Computed Tomography has undergone a rapid development. Since CT is so practical and useful, undoubtedly CT technology will continue advancing biomedical and non-biomedical applications. During its more than 30-years history, the CT has made great improvements in speed, patient comfort, and resolution. The first CT scanner developed by Hounsfield took several hours to acquire the raw data for a single scan or "slice" and took days to reconstruct a single image from this raw data. Later the speed of these conventional scanners improved a lot. This article reviews the history and evolution of CT generations with advantages and disadvantages of each generation.

1. Introduction

The term "tomography" is derived from the Greek word tomos, meaning "section."[1] Computed tomography is a radiographic technique that blends the concept of thin layer radiography with computer synthesis.[2]

History of computed tomography

The early concept of 3 dimensional radiography was introduced in 1917, by Mathematician Radon, who described the basic mathematical equation which proved that the image of a three dimensional object could be calculated from an infinite number of two- dimensional projections.

Computed tomography was not the first x-ray method to produce cross-sectional images. In the late 1940s and 1980s, Takahaski in Japan published several papers describing the analog technique of transverse axial tomography. Takahashi's method was commercialized by Toshiba Inc. in the 1960s. The Toshiba product was usurped by computed tomography in the early 19?0s. William Oldendorf was a neuroscientist interested in improving the differentiation of brain tissue. In particular, he was searching for a better imaging method than pneumoencephalography for studying the brain. In 1961, Oldendorf explored the principle of CT with an apparatus using an I131 source. Shortly thereafter, Kuhl and colleagues developed emission and 241AM transmission CT imaging systems and described the application of these systems to brain imaging.[1]

In spite of these early efforts, CT remained unexploited for clinical imaging until the announcement by EMI Ltd. in the year 1972 in London of the first commercially available x-ray transmission CT unit designed exclusively for studies of the head.[1] Therefore, CT was originally known as "EMI" scan as it was developed at a research branch of EMI.[2]

The prototype for this unit had been studied since 1970 at Atkinson-Morley's Hospital in south London where the first patient, a middle aged lady with a suspected frontal lobe tumour, was scanned on 1st October 1971.[1,2] On the image obtained, it was possible to differentiate clearly between the physiological areas of the brain and the round, darker pathological area where a cyst was developing.

Its inventor, Sir Godfrey Hounsfield shared the Nobel Prize for medicine with Allen. M. Cormack, who first computed the attenuation coefficient of a slice of an object from a series of projections. Dr. Ambrose found that, by injecting iodine-based contrast agent that would localize the particular spot where the tumour was and it showed up even better.[3] Hounsfield took some of the contrast enhanced images and subtracted without contrast images to compare the blood flow on either side of the brain.[2]

In the original system the patient's head was placed in a rubber cap surrounded by water. This water bag was used to reduce the dynamic range of the detected X-rays and improve the absolute values of the attenuation figures.[4]

The basic parameters of the scanners used at that time were listed below.[8]

Table1 Basic parameters of the scanner used at that time

Scan time	about 4.5 min
Reconstruction time	20 s
Cross-section thickness	13 mm
Image matrix	80 x 80 pixels, where each pixel represented an area 3 x 3 mm

In Hounsfield first scanner, he used a reconstruction algorithm, which is known today as the algebraic reconstruction technique (ART). In the course of 1923, the time to acquire an image was reduced to 20 s. Next, the number of detectors was increased to 30; this allowed the acquisition of a reconstructed image with a resolution of 320 x 320 pixels. If we compare the first scanners with today's successors, it is striking how much progress has been made in their design and manufacture in such an extremely short time. Contemporary CT scanners can scan in a few hundred milliseconds and reconstruct an image of 2048 x 2048 pixels.[8]

2. Evolution of CT Generations

Since the introduction of the first clinical system by Hounsfield, several generations of scanners have been produced, with distinguishing tube detector configuration and scanning motion.

First Generation CT

The first generation of CT scanners used a single detector element to capture a beam of X-rays, corresponding to the integral of linear attenuation coefficients along a single line. It then translated horizontally to acquire the next line integral. After acquiring all the line integrals for a given position of the X-ray source, both the detector and source rotated one degree. a design known as the "translate-rotate" or "pencil-beam" scanner. Hounsfield's unit belonged to this generation and these first generation CT scanners were designed to scan the head only.[2]

Disadvantages

1. Long scanning time.
2. Image quality suffered due to patient motion
3. Limited use ---- to body parts such as head which can be made immobile

Second Generation CT

In 1975 a second generation of CT systems was introduced. These systems, also known as "hybrid" machines, used more than one detector and used small fan-beam, as opposed to pencil-beam, scanning. Like the first generation of CT scanners, these scanners also used a translate-rotate design, and were for the most part of head-only scanners. While the first iterations of full body CT scanners also incorporated the translate-rotate design, image quality was poor due to patient motion artifacts caused by the significant amount of time required to take the scan.

Third Generation CT

In 1976, third generation CT scanners came into sight. These scanners used a large, arc-shaped detector that acquires an entire projection without the need for translation. This rotate-only design, frequently referred to as "fan-beam", utilizes the power of the X-ray tube much more efficiently than the previous generations.

Disadvantages

1. Limited spatial resolution
2. Highly sensitive to detector performance.
3. Because of the fixed relationship of a detector to a specific part of beam, any mis-calibration or malfunction of an individual detector will appear as a ring in a final reconstructed image.

Fourth Generation CT

In 1976, fourth generation scanners followed third generation scanners. In this generation, the arc-shaped detector was replaced with an entire circle of detectors. In this design the X-ray tube rotates around the patient, while the detector stays stationary. Since these fourth generation scanners tend to be more expensive and suffer from higher levels of Compton scatter artifacts, most of the commercially available CT scanners today are third generation scanners.

Disadvantages

1. Increased scatter.
2. Very high cost due to large no. of detectors
3. Very high susceptibility to streak artifacts

Fifth Generation CT

In 1978 one of the earliest 3D volumetric scanner was the Dynamic Spatial Reconstructor (DSR) installed in the medical sciences building on the mayo clinic Rochester campus. In fifth generation scanners, an electron beam scans a circular anode surrounding the patient, producing, in effect; a moving x-ray source.6 It essentially consists of multiplex rays tubes & detectors which is primarily used to image 3D sections of the heart and reduces artifacts caused due to cardiac rhythm.

Helical or Spiral CT

By combining third and fourth generation, rotational fan-beam scanning with a continuous movement of the table in a Z-axis a helical mode scan can be performed. This type is also called as Sixth generation.

Advantages

1. Speed
2. Ability to minimize motion artifacts.
3. Decrease incidence of misregistration b/w consecutive axial slices.
4. Reduced patient dose.
5. Improved spatial resolution.
6. Enhanced multiplanar or three dimensional renderings.

Multi-row scanning/Multi slice spiral CT

In this, two parallel arcs of detectors are used to simultaneously acquire data during a single revolution of scan frame, dividing the total x-ray beam into two equal beams described by detector aperture of each row of detectors.2 Machines operating on this principle have been called seventh or multi-row scanners.

Advantages

1. Increased speed of volume coverage allows large volumes to be scanned at the optimal time following intravenous contrast administration.
2. Particularly benefitted CT angiography techniques.
3. Computer power permits increasing the post processing capabilities on workstations.

Most recent advance in medical CT imaging relies on dual-energy and improvement of travelling table system. They enable a more accurate evaluation of tissue density and brain perfusion, with a reduction of artifacts and an increase of cover thickness, retaining moderate radiation dose using suited reconstruction algorithms (ASIR).?

Today CT serve as a the major tool for clinical diagnosis in trauma, assessment of fractures, intracranial diseases, investigation of TMJ and salivary glands, staging and assessment of tumour response to treatment etc. Every day, new innovations are reported in the literature as investigations in different dental specialties discover applications of the technology. Future advances in Computed Tomography are able to come from unforeseen sources that are unknown yet, but they will come.

The summary of CT generations with different configurations and parameters are listed below. (Table 2)

Table 2 Characteristics of CT generations

Generation	Configuration	Detectors	Beam	Min scan time
First	Rotate - translate	1-2	Pencil thin	2.5 min
Second	Rotate - translate	3-52	Narrow fan	10 sec
Third	Rotate - rotate	256-1000	Wide fan	0.5 sec
Fourth	Rotate -fixed	600-4800	Wide fan	1 sec
Fifth	Electron beam	1248 detectors	Wide fan electron beam	33 ms

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