- **Helical/spiral CT Scanners: Requirements for Volume Scanning:**
  - Slip-ring technology

▶ ***Sixth Generation (Helical or spiral CT)***

In conventional CT (the 3rd and 4th generation CT scanners), the patient was scanned one slice at a time. The x-ray tube and detectors rotate for 360 degrees or less to scan one slice while the table and patient remain stationary. This slice-by-slice scanning is time-consuming. On the other hand, cables are spooled onto a drum, released during rotation and respooled during reversal. Scanning, braking and reversal required at least 8-10 sec of which only 1-2 sec were spent for data acquisition. The result was a poor temporal resolution and long procedure time.

Therefore, efforts were made to increase the scanning of larger volumes in less time. This notion led to the development of a technique in which a volume of tissue is scanned by moving the patient continuously through the gantry of the scanner while the x-ray tube and detectors rotate continuously for several rotations. As a result, the x-ray beam traces a path around the patient.

The development of helical or spiral CT was a truly revolutionary advancement in CT scanning that finally allowed true 3D image acquisition within a single breath hold technique. For more clarification, when the examination begins, the x-ray tube rotates continuously while the couch moves the patient through the plane of the rotating x-ray beam, (the table smoothly moves through the rotating gantry). This means that the X-ray tube and detector perform a ‘spiral’ or ‘helical’ movement with respect to the patient, generally at a rate of one revolution per second.

In this technique the data are continuously acquired or collected without pausing while the patient is simultaneously transported at a constant speed through the gantry. For this reason the duty cycle of the helical scan is improved to nearly 100% and the volume coverage speed performance can be substantially improved. This technique allows fast and continuous acquisition of the data from a complete volume.

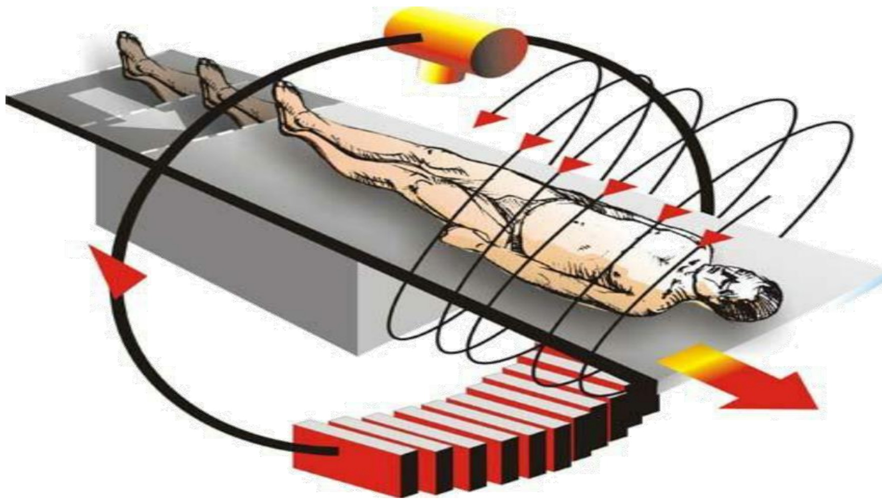


Fig. (1): Helical CT

Three technological developments were required:

- Slip ring technology
- high power x-ray tubes
- Interpolation algorithms

Slip ring technology

All generations of CT scanners (**except 4th gen.)** required winding and unwinding of connection cables causing inter-scan delays. Slip ring was designed to **eliminate** this. A **slip ring** is a drum with grooves along which electrical contactor brushes slide. Data are transmitted from detectors via various high capacity wireless technologies, thus allowing continuous rotation. Eliminating interscan delays made possible by slip ring technique. A slip ring passes electrical power to the rotating components without fixed connections.

It allows the complete elimination of interscan delays except for the time required to move the table to next slice position. For eg : if scanning and moving the table each take 1s, only 50% of the time is spent acquiring the data.

Slip rings *are* electromechanical devices consisting of circular electrical conductive rings and brushes that transmit electrical energy across a moving interface. All power and control signals from the stationary parts of the scanner system are communicated to the rotating frame through the slip ring.

The slip-ring design consists of sets of parallel conductive rings concentric to the gantry axis that connect to the tube, detectors, and control circuits by sliding contactors (Fig. 2, 3). These sliding contactors allow the scan frame to rotate continuously with no need to stop between rotations to rewind system cables. This engineering advancement resulted initially from a desire to reduce interscan delay and improve throughput.

However, reduced interscan delay increased the thermal demands on the x-ray tube; hence, tubes with much higher thermal capacities were required to withstand continuous operation over multiple rotations.

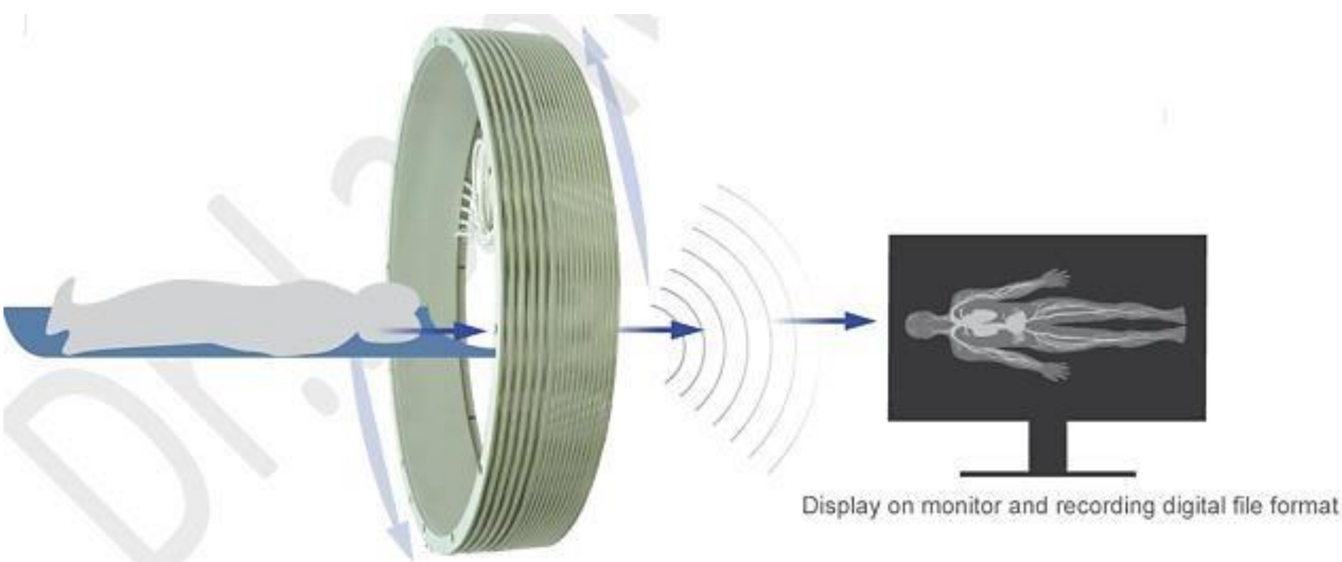


Fig. (2): Slip ring technology

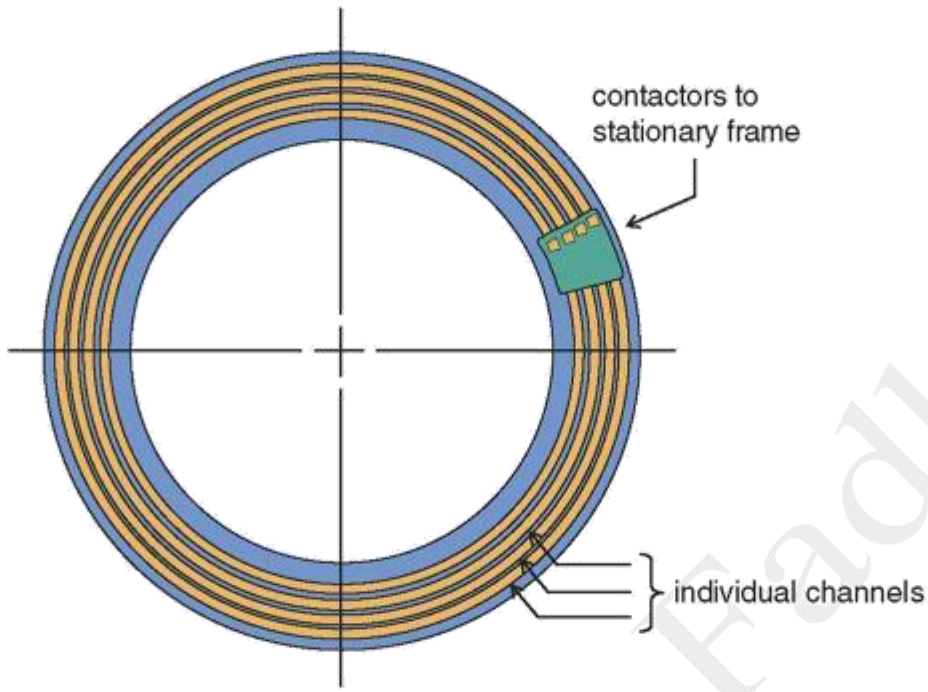


Fig. (3): To convey power onto the rotating gantry from the stationary frame, as well as to conduct signal data from the rotating gantry to the stationary frame, a slipring is used. A slipring uses gliding contacts to allow communication and power transfer between the stationary and rotating frames without the use of wires, and this enables the gantry to rotate continuously in a single direction. Sliprings have enabled gantry rotation periods to move from 3.0 s (when cables were used) to modern CT rotation periods of as little as 0.25 s.

High power x-ray tubes

X-ray tubes are subjected to far higher thermal loads in CT than in any other diagnostic x-ray application. In early CT scanners, the power level was low. Since long scan times allowed heat dissipation. Shorter scan times in later versions of CT scanners required high-power x-ray tubes and use of oil cooled rotating anodes for efficient thermal dissipation.

The introduction of helical CT with continuous scanner rotation placed new demands on x-ray tubes. Several technical advances in component design have been made to achieve these power levels and deal with the problems of the target temperature, heat storage, and heat dissipation. For example, the tube envelope, cathode assembly, and anode assemblies including anode rotation and target design have been redesigned.

As scan times have decreased, anode heat capacities have increased by as much as a factor of five, preventing the need for cooling delays during most clinical procedures, and tubes with capacities of 5–8 million heat units are available. In addition, improvement

in the heat dissipation rate (kilo–heat units per minute) has increased the heat storage capacity of modern x-ray tubes.

The large heat capacities are achieved with thick graphite backing of target disks, anode diameters of 200 mm or more, improved high-temperature rotor bearings, and metal housings with ceramic insulators (Fig. 4).

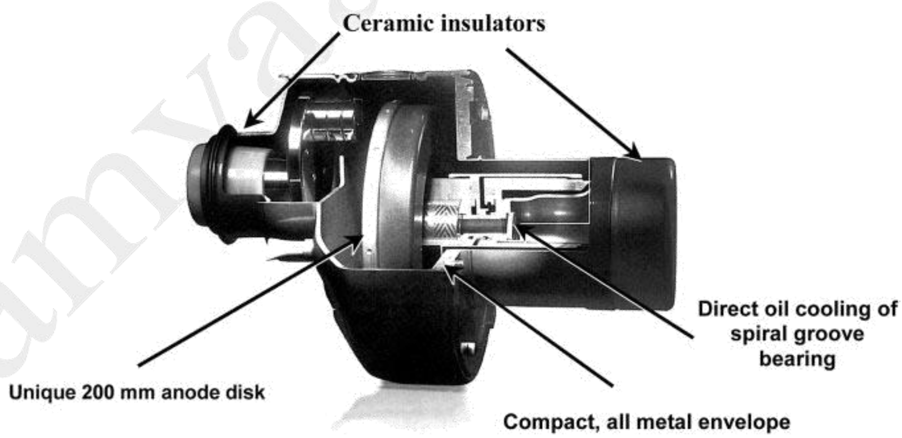


Fig. (4): CT x-ray tube.

Among other factors. The working life of tubes used to date ranges from 10,000 to 40,000 hours, compared with the 1,000 hours typical of conventional CT tubes. Because many of the engineering changes increased the mass of the tube, much of the design effort was also dedicated to reducing the mass to better withstand increasing gantry rotational rates required by ever faster scan times.

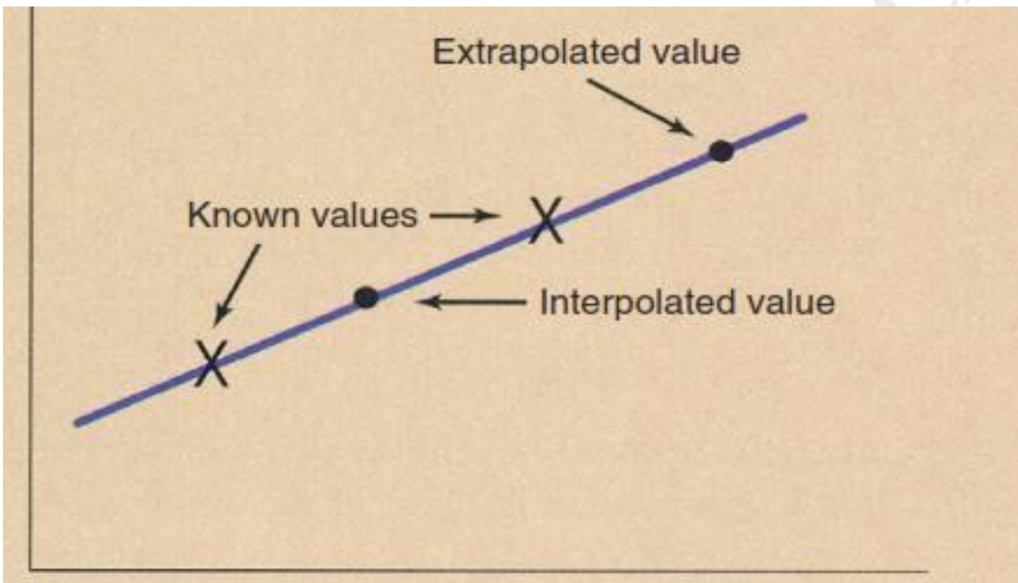
In summary:

Shorter scan time required high power of x-ray tubes and use of oil cooled rotating anodes for efficient thermal dissipation. Largest heat capacities are achieved with:

- Thick graphite backing of target disks
- Anode diameters of 200mm or more
- Metal housing with ceramic insulator.
- The working life of tubes ranges from 10,000 – 40,000 hours

Interpolation Algorithms

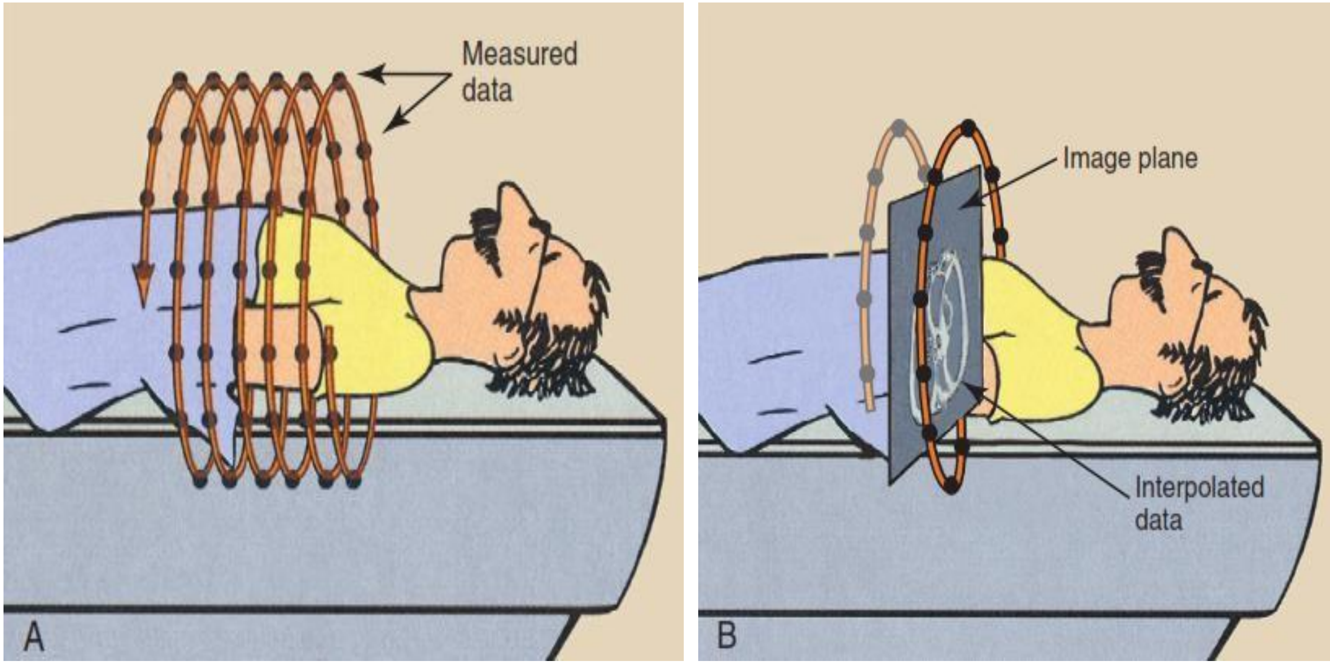
Reconstruction of an image at any z-axis position is possible because of a mathematical process called **interpolation**. Figure (1) presents a graphic representation of **interpolation** and **extrapolation**. If one wishes to estimate a value between known values, that is an interpolation; if one wishes to estimate a value beyond the range of known values, that is an extrapolation.



Fig(1): Interpolation estimates a value between two known values. Extrapolation estimates a value beyond known values.

During helical CT, image data are received continuously, as shown by the data points in Figure 2*A*. When an image is reconstructed, as in Figure 2,*B*, the plane of the image does not contain enough data for reconstruction.

The data in that plane must be estimated by interpolation. Data interpolation is performed by a special computer program called an ***interpolation algorithm***.



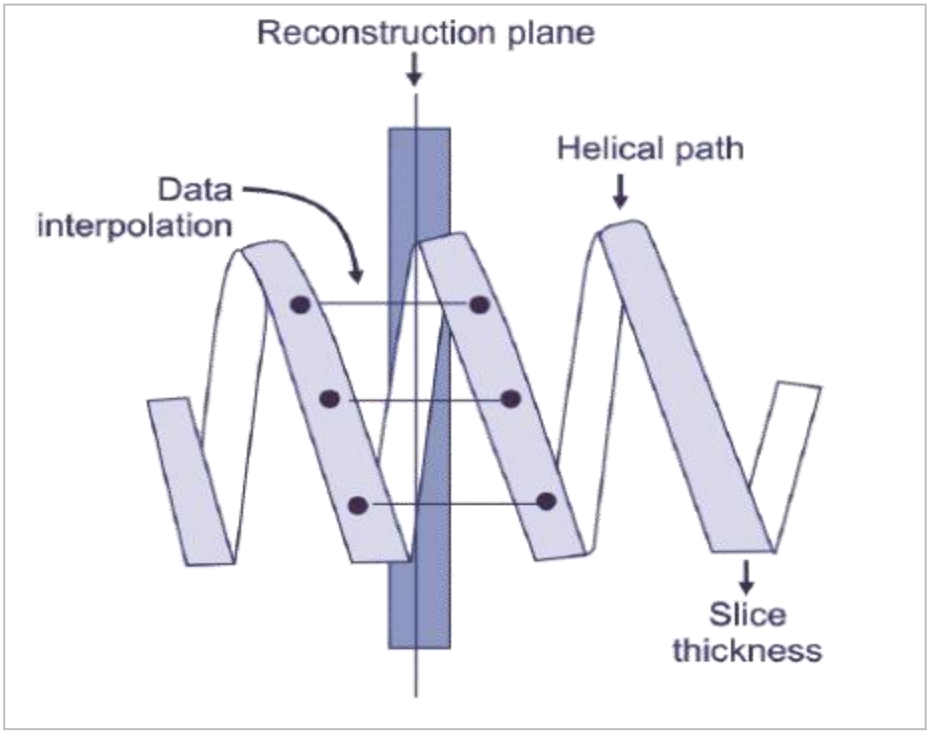
Figs.(2): A, During multislice helical computed tomography, image data are continuously sampled. B, Interpolation of data is performed to reconstruct the image in any transverse plane.

Image interpolation creates a number of new slices between known slices in order to obtain an isotropic volume image.

The problem with continuous tube and table motion was that

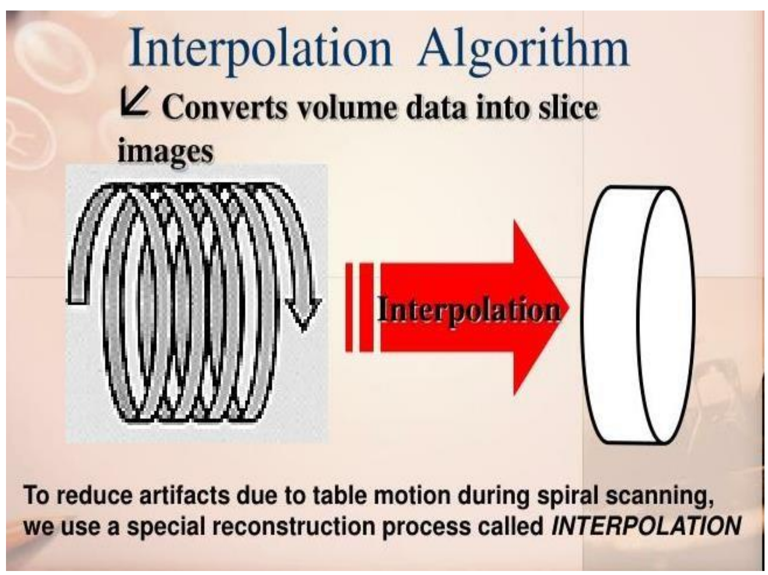
1- projections precessed in a helical motion around the patient
2- did not lie in a single plane. This meant that conventional reconstruction algorithms could not work.

Helical CT scanning produces a data set in which the x-ray source has travelled in helical trajectory around the patient, (the data are acquired in a helical path around the patient). Present day CT reconstruction algorithms assume that the x-ray source has negotiated a circular not a helical path around the patient. To compensate for these differences in the acquisition geometry, before the actual CT reconstruction the helical data set is interpolated into a series of planar image data sets (the reconstruction plane of interest). Interpolation is essentially a weighted average of the data from either side of the reconstruction plane, with slightly different weighting factors used for each projection angle.



Figs.(3): Data interpolation

In summary: *Interpolation Algorithms are the mathematical process required to reconstruct axial images from the spiral volume data set.*



Pitch

During helical scans, the table motion causes displacement of the fan beam projections along the z axis; the relative displacement is a function of the table speed and the beam width. The ratio of table displacement per 360° rotation to section thickness is termed *pitch.*

Pitch is the table movement per rotation divided by beam width.

$$\textit{pitch} = \textit{table travel} / \textit{beam width}$$

- pitch = 1 - coils of the helix are in contact
- pitch < 1 - coils of the helix overlap
- pitch > 1 - coils of the helix are separated

For example

↳ If beam width is 10cm, the table moves 10cm during one tube rotation, then pitch is 1, so, x-ray beam associated with consecutive helical loops are contiguous.

↳ If beam width is 10cm and table moves 15cm per tube rotation, then pitch is 1.5 So, a gap exists between the x-ray beam edge of consecutive loop.

↳ If beam width is 10cm and table moves 7.5cm then pitch is 0.75, so, beams and consecutive loops overlap by 2.5 (doubly irradiating the underlying tissues).

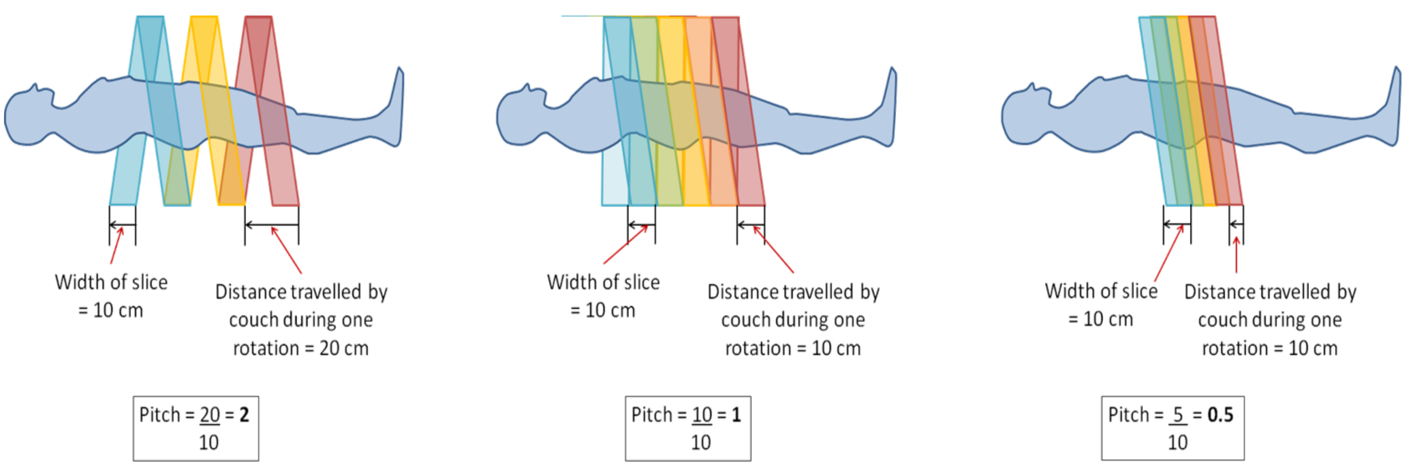


Fig (4): Illustration of pitch concepts

The relationship between the volume of tissue imaged and pitch is given as follows:

VOLUME IMAGING

$$\text{Tissue imaged} = \frac{\text{Beam width} \times \text{Pitch} \times \text{Imaging time}}{\text{Gantry rotation time}}$$

Advantages of helical CT scanner

- ✓ Fast scan times and large volume of data collected.
- ✓ Minimizes motion artifacts.
- ✓ Less mis-registration between consecutive slices.
- ✓ Reduced patient dose.
- ✓ Improved spatial resolution.
- ✓ Enhanced multiplaner or 3D renderings.
- ✓ Improved temporal resolution