Computed tomography scan (CT scan)

Previously we discussed the conventional method of x-ray to take images of the interior of our body so we can use this conventional x- ray imaging technique to detect things like bone fracture, cancerous tumour and lung diseases. Conventional x-ray imaging has its limitations, for one thing, the entire thickness of the body is actually projected onto the photographic film and this means that all the tissues, organ and structures overlap and are placed onto a single film and this makes it very difficult to read and distinguish between the different tissues, organs and structures.

In 1970s a second type of technique that also uses x-rays was developed and become known as computed tomography (CT scan). Tomo means a cross section or slice and graphing means to form an image. So what CT scan does it takes cross sectional images or slices of the organ and then we can use these two dimensional slices and put them on top of one another and build three dimensional image of the entire organ that we are examining so unlike conventional x-ray, CT scan are able to create images in which organs and tissues are not all superimposed on top of one another onto a single photographic screen so CT scans allow physicians to visualize and examine the specific details of the structures and organs.

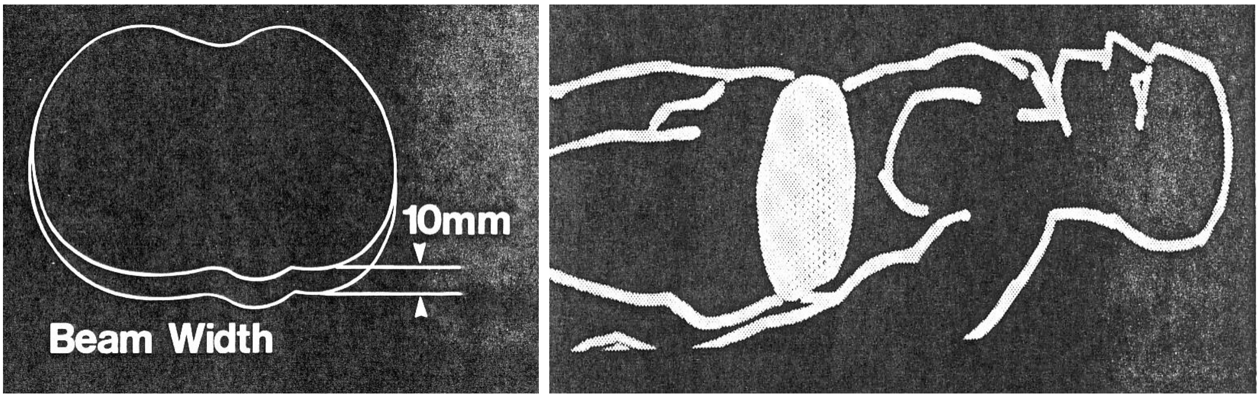

Fig. (1) shows single slice (cross sectional)

Fig. (2)   Computed Tomography Instrumentation

Data Acquisition Systems

Whatever the differences in design of the different generations of scanners, the main elements remain the same.

The main components of the scanner design are:

• The gantry with a central opening, into which the patient is moved during the examination. This is the most recognizable element of the CT scanner;

• The X-ray tube, the source of the X-rays that pass through the body situated in the gantry and carry the information about the structure of the body to the detectors. The information is in the form of a series of projections;

• The detector array converts the projection values, in the form of radiation intensities, into electrical quantities. Usually, the whole detector array rotates synchronously with the X-ray tube around the test object;

• The table allows the patient to be manoeuvred easily into position. The table can be controlled manually before the actual scan begins, but it moves automatically during the scan. The table can be moved into or out of the gantry along the axis of the patient's body, as well as up and down. This allows the patient to be appropriately positioned depending on which part of the body is being examined.

First-Generation Scanners

First-generation scanners, sometimes called pencil beam or translation/rotation single detector scanners, belong to the class of device that uses a parallel-beam projection system. Figure (3) shows how a single projection is carried out in this type of system.

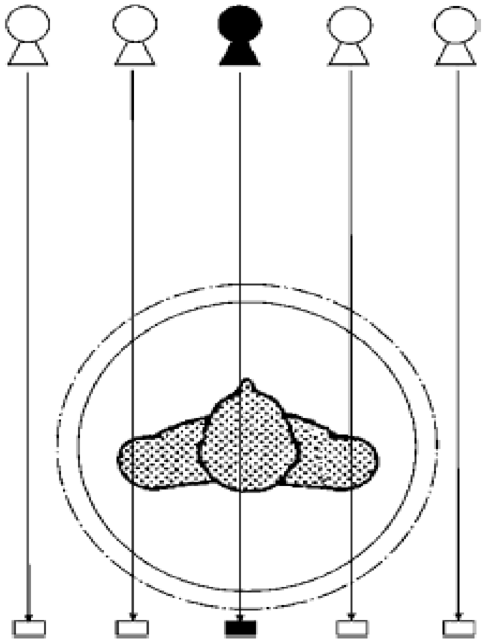

Fig. (3) A parallel beam projection system

In this type of scanner, there are two components to the movement of the rigidly coupled tube-detector system: a lateral movement to make a single projection and a circular movement about the central opening in the gantry to gather all the projections necessary to reconstruct the image.

The acquisition of the individual projections can be either continuous or discrete, but each of these projections is obtained only at a discrete angle of rotation of the projection system. It is easy to see how this method of scanning is not fast enough (it takes approximately 5 min); both the single detector and the X-ray tube must travel a distance equal to the diameter of the gantry opening, twice during each projection. A sequence of two projections for this type of scanner is shown in more detail in Fig. (4).

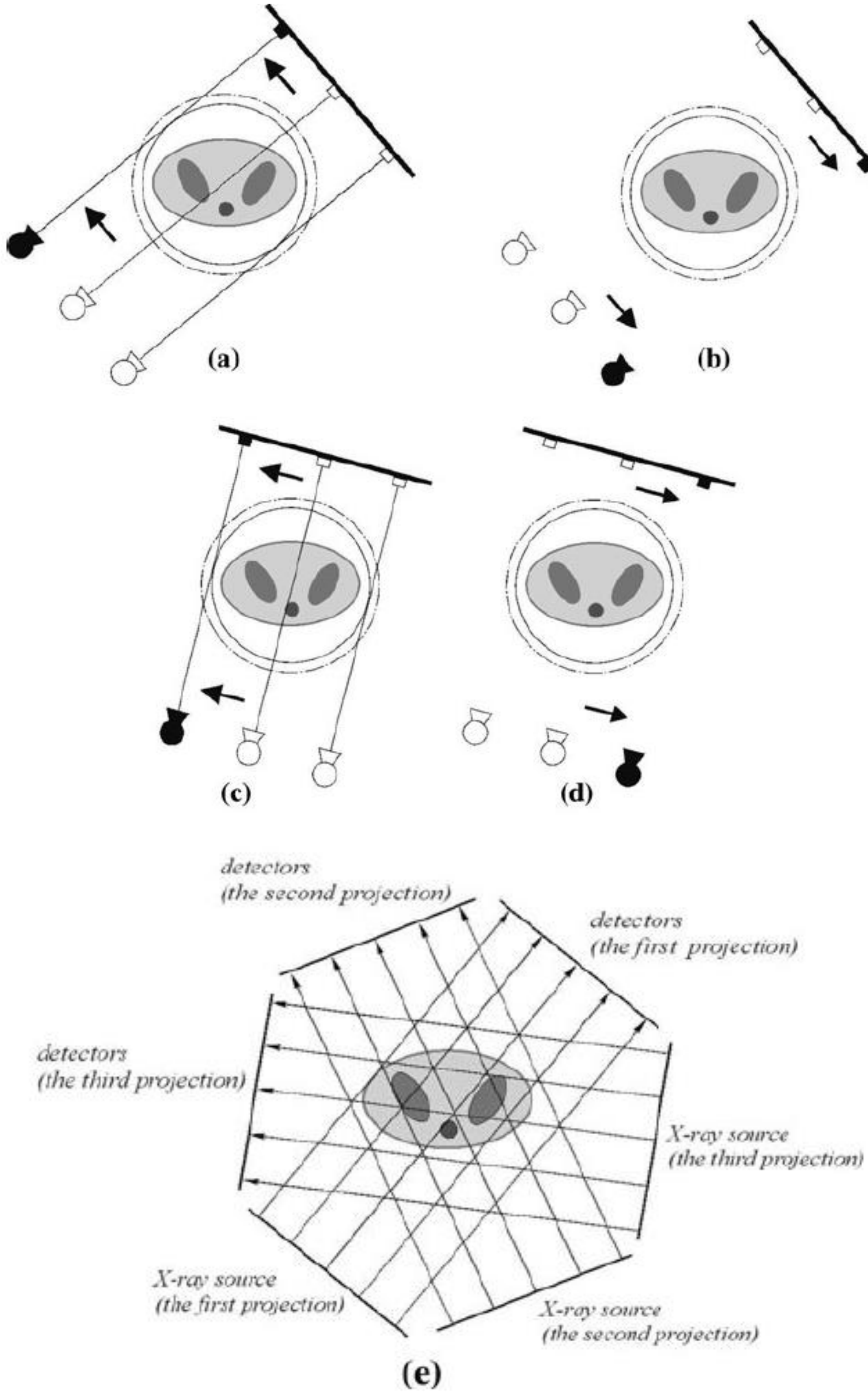

Fig. (4) The projection sequence in first generation scanners: (a) the first projection, (b) the return pass, (c) the second projection, (d) the return, (e) a series of three projections.

First-generation scanners are prime examples of devices having a parallel-beam projection system. The procedure for obtaining images of successive cross-sections with this type of scanner is explained in Fig. (5).

The short arrows in the diagram show the positioning of the patient lying on the table while successive cross-sections are obtained. They represent the small sliding movements of the table that take place after all the projections needed to reconstruct the image of a single slice have been performed. After each movement, the procedure for the collection of the projections for the next image is repeated.

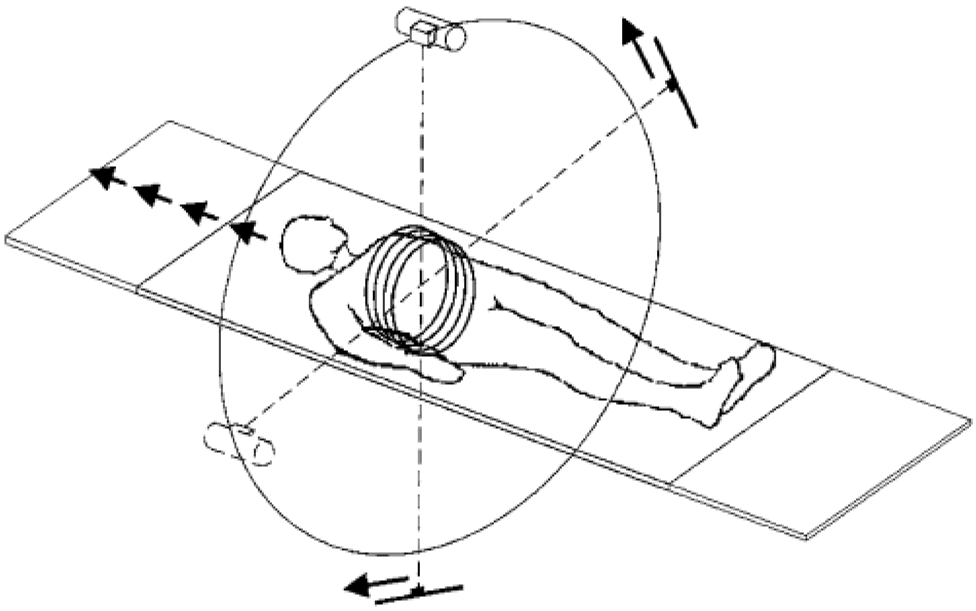

Fig. (5) Obtaining a sequence of image slices in a parallel beam scanner

Second-Generation Scanners

Great progress was made when scanners with a larger number of detectors in the array were introduced around 1972. These second-generation scanners, sometimes called partial fan beam or translation/rotation multiple detector scanners, had between 3 and 52 detectors in the array. The use of the fan-shaped radiation beam enabled the projections to cover a larger area of the patient's body at any one time and resulted in the reduction of the number of projections needed to reconstruct an image of satisfactory quality. Figure (6) illustrates the scanning sequence for this generation of scanner.

In this approach, the time to obtain the projections necessary for the reconstruction of one image was reduced to about 300 s, even though the movement of the tube-detector array was still a combination of lateral and rotational motion. This system can be considered as a transitional stage between the parallel-beam projection system and the fan-beam system.

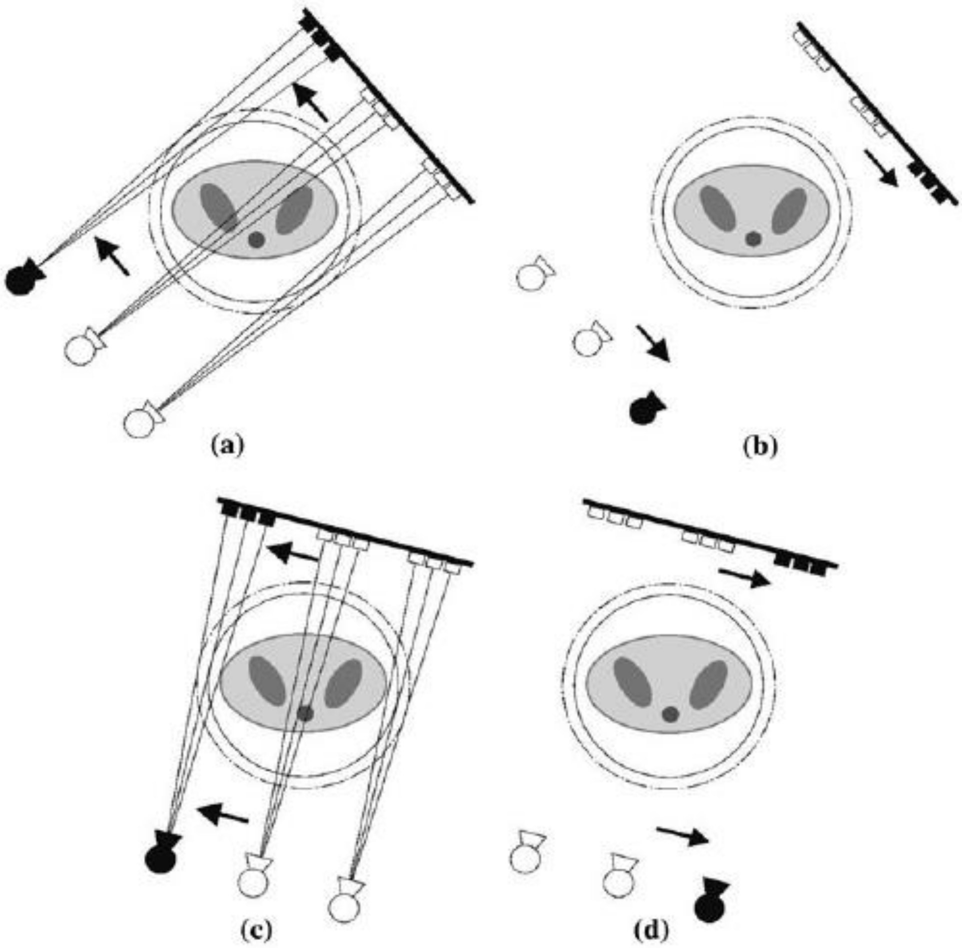

Fig. (6) The projection sequence in second generation scanners: (a) the first projection, (b) the return pass, (c) the second projection, (d) the return.

Third-Generation Scanners

Further steps to improve the CT scanner were next directed towards the elimination of the lateral movement of the tube-detector system. In 1976, scanner designers managed to limit the movement in the projection system exclusively to rotational movement. This was the so-called fan-beam or continuous rotation scanner. By fan-beam, we mean here a projection system with a beam of radiation in the shape of a fan with an angular spread of between 40 and 55 degrees, enough to encompass the whole of the test object, as shown in Fig. (7).

The sequence of individual projections for this type of scanner is shown in Fig. (8). An obvious consequence of this modification was the need to increase the number of detectors in the array moving synchronously with the rotating X-ray tube (up to 1,000 detector elements). As a result of these design changes, the time to acquire a reconstructed image was reduced to about (5 s). Scanners of this generation are examples of the implementation of the fan-beam projection system in its purest form.

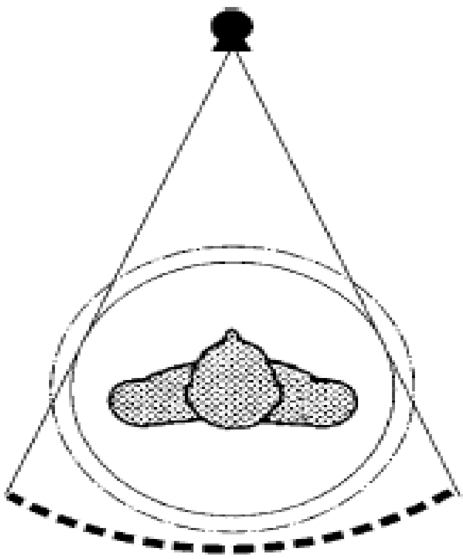

Fig. (7) A fan beam system

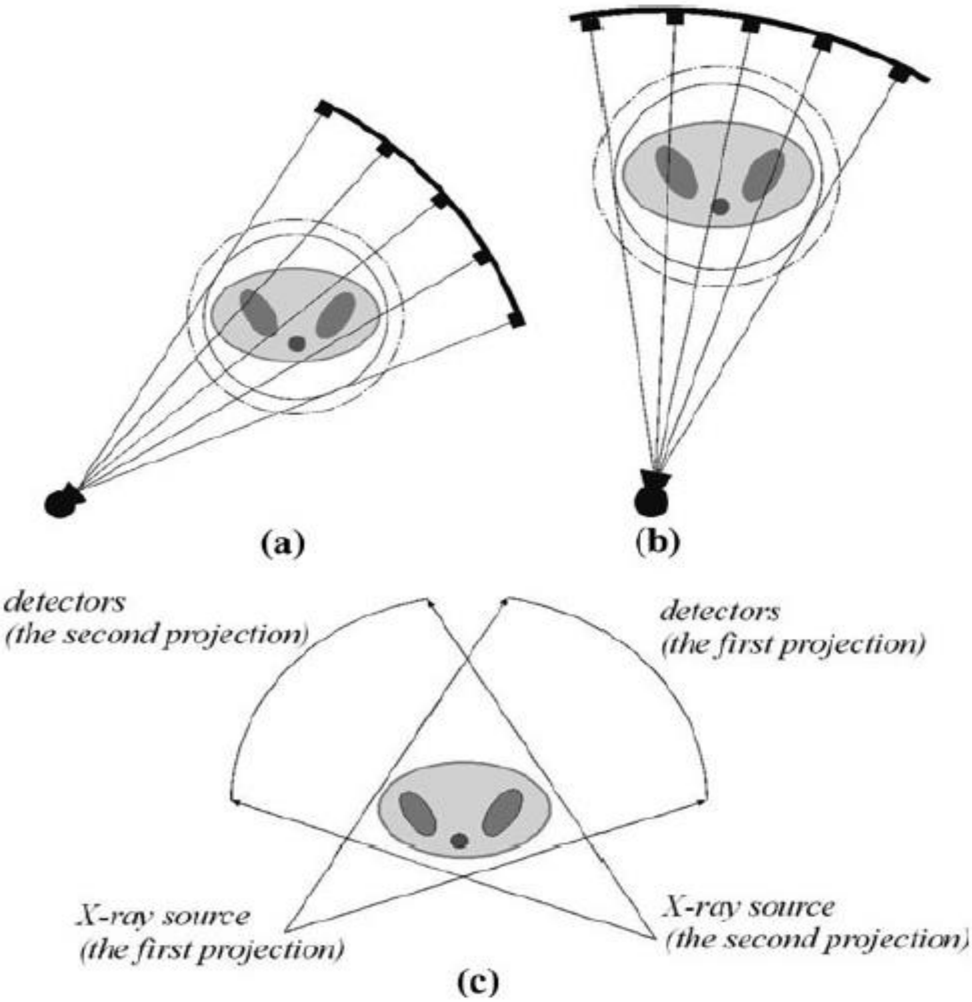

Fig. (8) The projection sequence in third generation scanners: (a) the first projection, (b) the second projection, c a set of two projections

In this scanner, after all the projections have been made for the first image, the table moves and the whole procedure is repeated for the next cross-section of the body. The sequence of projections for reconstructing the images of successive slices of the patient's body is shown in Fig. (9), where the short arrows once again indicate the positioning of the patient lying on a table.

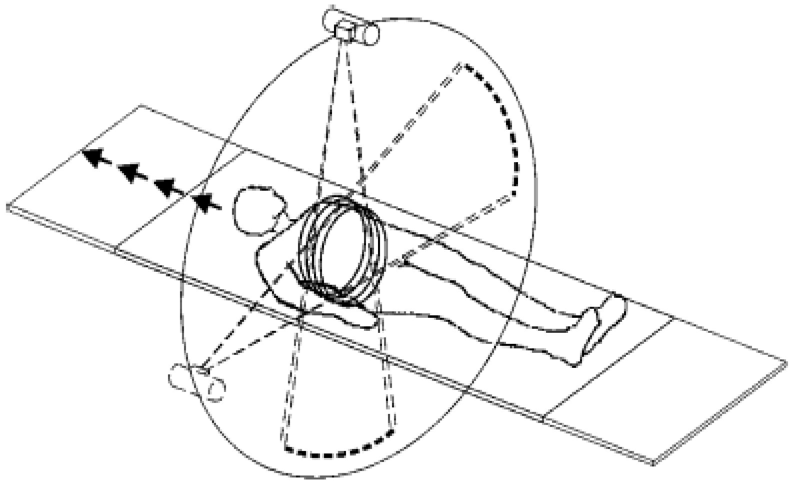

Fig. (9) Obtaining a sequence of image slices in a fan beam scanner

Fourth-Generation Scanners

The next, fourth generation of scanners, introduced in 1978, differed only slightly from the third generation. In the earlier designs, the detector array moved around the test object together with the X-ray tube. Now the rotation of the array was eliminated by arranging it on a stationary ring. The result was a scanner known as the rotate-fixed scanner; the word rotate in the name refers to the movement of the tube and the word fixed to the array of detectors.

The number of detectors in the array was increased and now ranged from 600 to 5,000 detector elements. The time taken to obtain one image using this design however was still about 5 s.

It was still classified as a fan beam scanner. The projection sequence for this type of scanner is shown in Fig. (10).

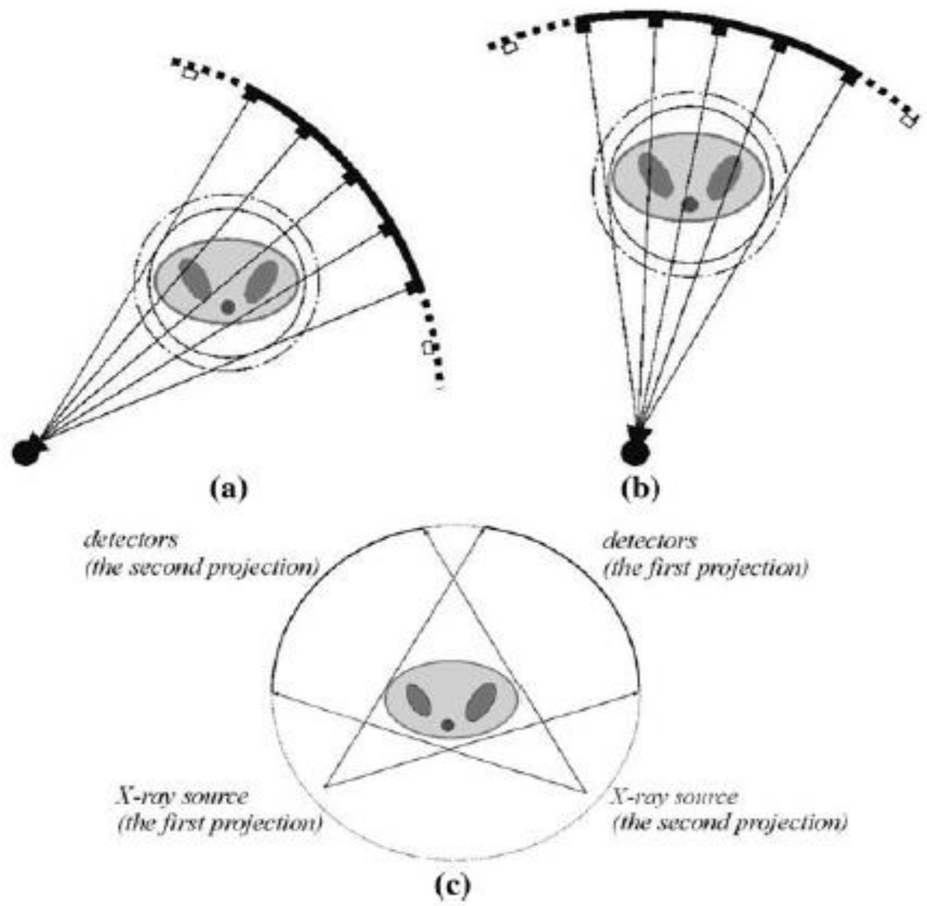

Fig. (10) The projection sequence in fourth generation scanners: (a) the first projection, (b) the second projection, (c) a set of two projections.

Spiral Scanners

We saw earlier that successive generations of scanners used either parallel beams of radiation or fan beams. In the previous generations there were no movement along the axis of the patient during each of the projections. In 1989 the first designs of scanners appeared which combined the movement of the tube around the patient with a simultaneous smooth displacement of the patient into the opening of the gantry. The projection system moved in a spiral around the patient. In another word the table of the patient moved continuously, in Z direction during rotation of the X-ray tube so that a whole volume rather than serial discrete slice could be acquired.

In the initial phases of the development of spiral tomography, the scanners used a detector array in shape of an arc of a circle, similar to the design of third generation scanners. The device was called a single-slice spiral computed tomography scanner or SSCT. Figure (11)shows the spiral motion of the tube and detectors around the patient.

In 1998, an improved design of scanner emerged: the multi-slice spiral computed tomography scanner (MSCT). The projection system still moved in a spiral but the detector array was made up of between 8 and 34 rows of detectors, making it possible for this design of scanner to obtain four adjacent slices simultaneously.

The beam now took the shape of a cone (see Fig. 12); this cone-beam was the most natural shape for a beam of X-rays. Previous designs of spiral scanner had used a radiation beam in which the individual rays were almost parallel to each other. The new design permitted three-dimensional projection techniques to be mastered.

The first cone-beam spiral CT scanners (CBCT) were put into operation in the years 2001 2002. The cone-shaped radiation beam made it possible to increase the width of the detector array to 16 or even 320 elements, thereby allowing the simultaneous acquisition of up to 256 adjacent image slices with these scanners.

The main advantages of this design were the increased scanning speed and the reduction of the impact of collimation inaccuracies on the quality of the reconstructed image. The reduction in collimation losses had the additional advantage of allowing a reduction in the power of the X-ray tube.

The combination of the cone-beam and the spiral motion of the projection system resulted in a <u>significant reduction in the time</u> taken to complete the scan (down to 2 min, or even less) and during this time, the images of many adjacent slices could be reconstructed. The principle of the spiral path cone-beam scanner is illustrated in Fig. (13).

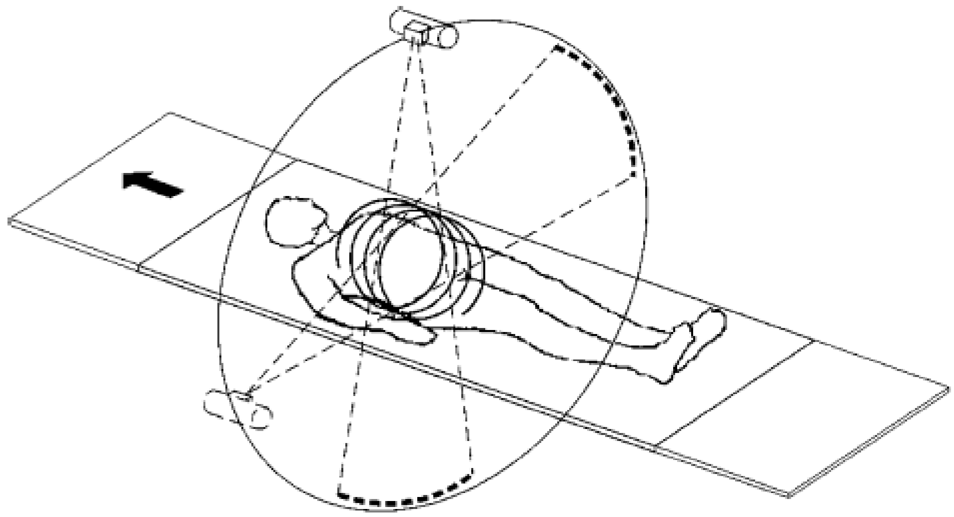

Fig. (11) Rotation of the tube around the patient combined with a smooth displacement of the patient through the gantry

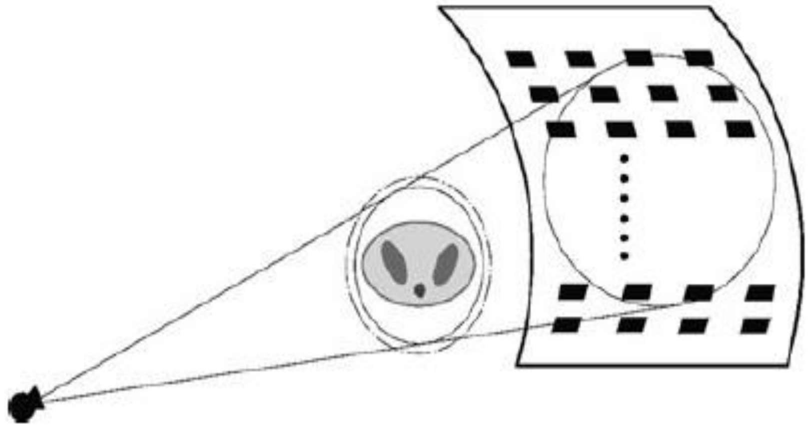

Fig. (12) A cone beam projection system

Spiral scanners are currently the standard tomographic equipment used in clinical practice. <u>Because of the reduced time needed to complete a scan, they can be used to study organs, such as the heart or lungs, which are</u>

physiologically in motion. In addition, by synchronizing the working phases of the heart with the acquisition of the projections, it is even possible to obtain a dynamic tomographic image. Spiral tomography with its short exposure time also makes it possible to examine people, who for various reasons, cannot remain motionless for long, such as children or emotionally disturbed patients.

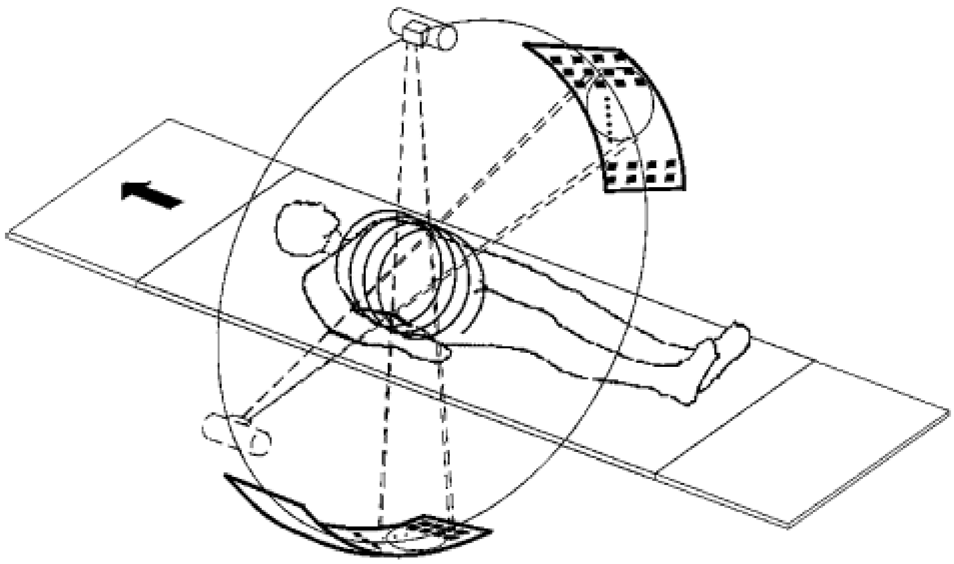

Fig. (13) The movement of the projection system relative to the patient in a spiral scanner.