The Operating Console

Computed tomography imaging systems can be equipped with **two or three consoles.**

- One console is used by the **CT radiologic technologist to operate the imaging system.**
- Another console may be **available for a technologist to post process images to annotate patient data on the image** (e.g., hospital identification, name, patient number, age, gender) and to provide identification for each image (e.g., number, technique, couch position). The secondmonitor also allows the operator to view the resulting image before transferring it to the physician's viewing console.
- A third console may be **available for the physician to view the images and manipulate image contrast, size, and general visual appearance**. This is in addition to several remote imaging stations available to the radiologist and other physicians.

The operating console contains **meters and controls for selection of proper imaging technique factors, for proper mechanical movement of the gantry and the patient couch, and for the use of computer commands that allow image reconstruction and transfer.**

The physician's viewing console accepts the reconstructed image from the operator's console and displays it for viewing and diagnosis.

A typical operating console contains **controls and monitors for the various technique factors**. Operation is usually in excess of 120 kVp .The maximum mA is usually 400mA and is modulated (varied) during imaging according to patientthickness to minimize the patient radiation dose.

Patient Table or Couch

The patient table is **an important** and **highly integrated component** of the CT scanner. The CT computer controls table **motion using precision motors with telemetric feedback**, for patient positioning and CT scanning. This is critically important in helical scanning where the coordination of tube rotation and table movement is essential. The patient table (or couch) can be retracted from the bore of the CT gantry and lowered to sitting height to allow the patient to comfortably get on the table, usually in the supine position as shown in Figure 1. Under the CT technologist's control, the system then moves the table upward and inserts the table with the patient into the bore of the scanner. A series of laser lights provide references in multiple directions to allow the patient to be centered in the bore (both laterally and in terms of table height) and to adjust the patient longitudinally, as mentioned in the previous lecture.

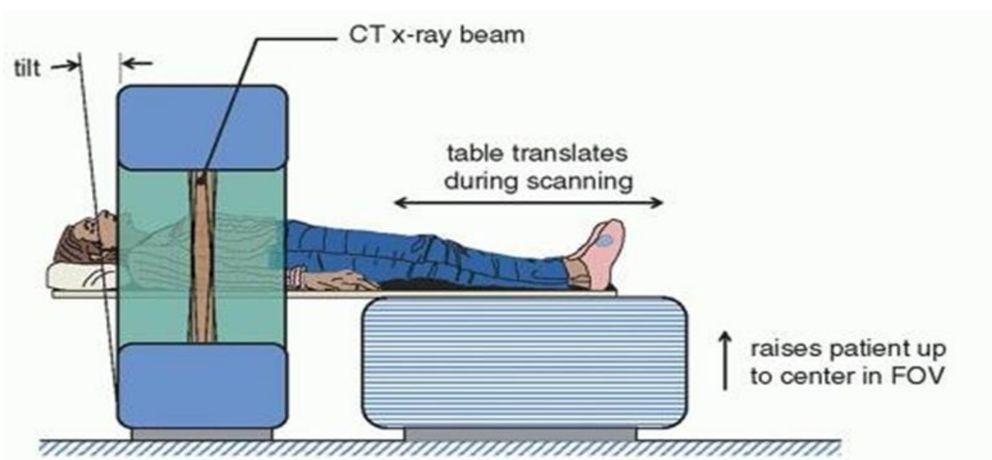

Fig. (1): The patient table is a perfunctory but surprisingly high-tech component of a CT scanner. The patient table lowers to sitting height to allow patients—including the elderly and physically impaired—to sit on the table and reposition to a prone or supine position, with help from the attending technologist.

Image Display, Storage, and Communication

The third and final step in the CT process involves image display, storage, and communication. After the CT image has been reconstructed, it exits the computer in digital form. This must be converted to a form that is suitable for viewing and meaningful to the observer.

Display device. The grayscale image is **displayed on a television monitor** (Cathode ray tube [CRT]) or liquid crystal display, which is an essential component of the control or viewing console. In the display and manipulation of grayscale images for diagnosis, it is important to optimize image fidelity (i.e., the faithfulness with which the device can display the image). *This is influenced by* physical characteristics such as luminance, resolution, noise, and dynamic range.

Resolution, however, is an important physical parameter of the grayscale display monitor and is related to the size of the pixel matrix**,** or matrix size. The display matrix can range from 64 × 64 to 1024 ×1024, but high-performance monitors can display an image with a 2048 × 2048 matrix.

Windowing

Because the human eye cannot distinguish all of the possible 5,000–10,000 shades of gray, the grayscale of the CT image is limited to be composed of a range of (+1000 to −1000) that represent varying shades of gray, that appreciated to the human eye. The process of limiting the number of shades of gray presented on the CT image to optimize viewing by the human eye is called windowing. In other words, windowing is a term used to refer to the fine adjustments made in the image on the computer screen to enhance viewing and emphasize various tissues of interest. Windowing is performed by the reader at the workstation (are located on the control console) after the image is obtained, reconstructed and transferred to the viewing workstation. The specific number of shades of grey chosen for presentation the CT image's on the compressed scale is called the window width (WW) and artificially defines the number of shades of grey presented to the viewer; (controls the CT image contrast). While the window level (WL) is defined as the center or midpoint of the CT number range that composes a CT image's gray scale; (controls the CT image brightness).

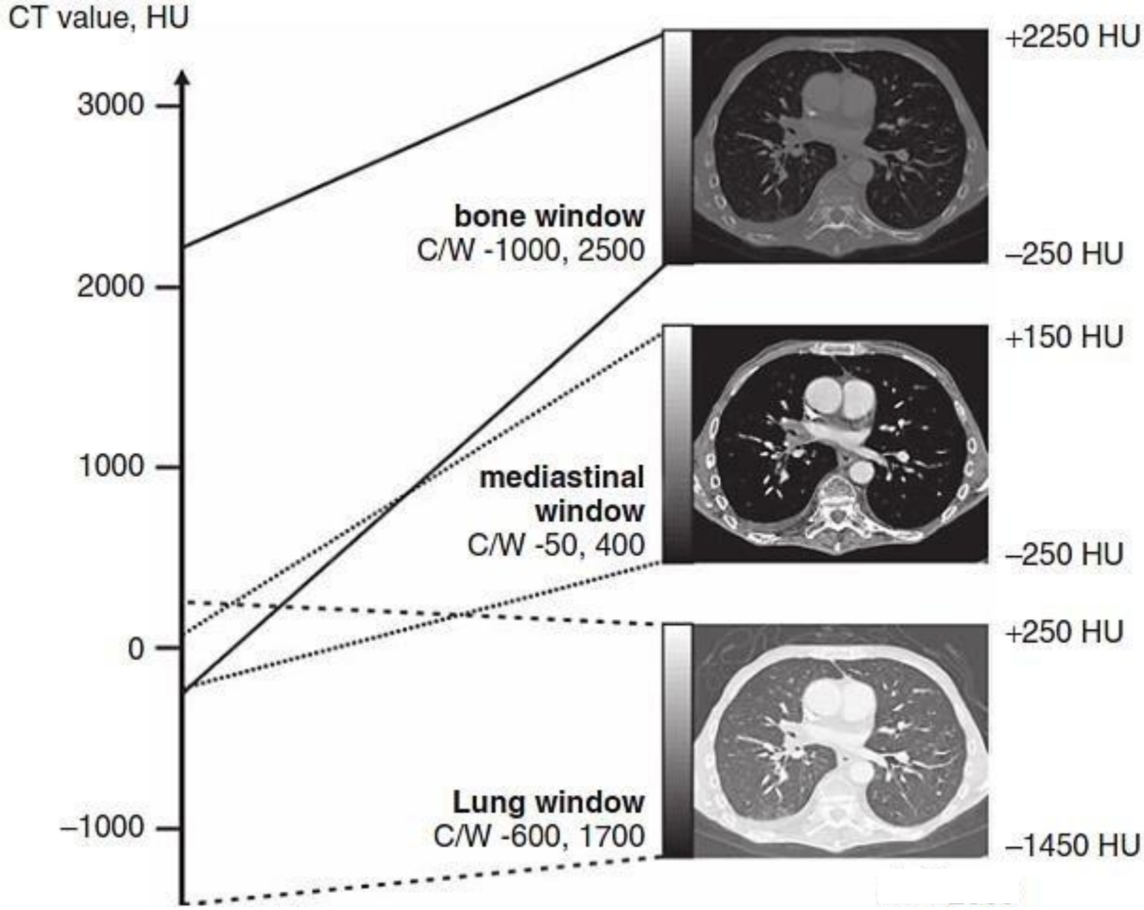

Fig. 2: Windowing is a digital image postprocessing operation intended to alter the image contrast (a function of the WW) and the image brightness (a function of the window center, C, or WL, as it is often referred).

The image contrast is optimized for the anatomy under study; therefore, specified values of WW and WL or C must be used during the initial scanning of the patient. Note that in (Figure 2), three windows are shown: the bone window (optimized for imaging bone), the mediastinal window (optimized for imaging the mediastinal structures), and the lung window (optimized for imaging the lungs).

Image Reconstruction

The image obtained in CT is different from that obtained in conventional radiography, Fig.1, in which rays form an image directly on the image receptor. While with CT imaging systems, it is created from data received and represent a depictions of relative attenuation of x rays as they pass through the body. The x-rays from a stored electronic image that is displayed as a matrix of intensities

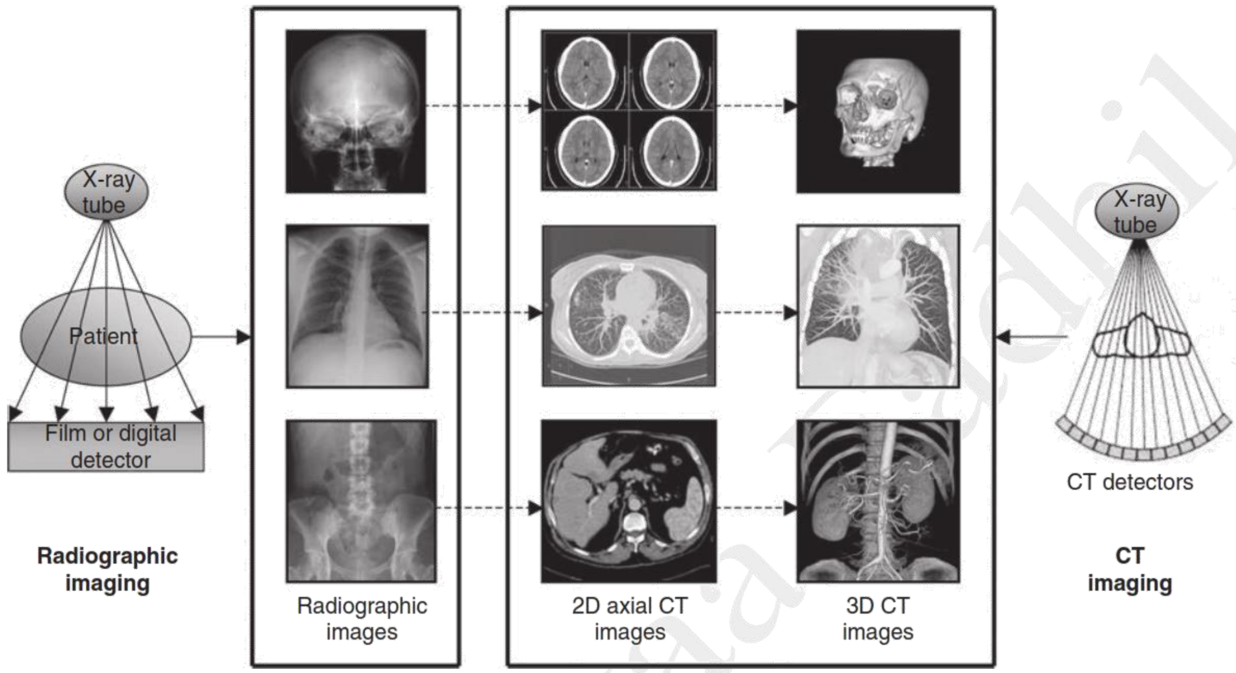

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Fig. (1): The most conspicuous difference between conventional radiographic imaging and CT imaging

A tissue's attenuating ability is related to its density and represents the likelihood that an x ray photon will pass through the tissue to be recorded by the detectors rather than interacting with tissue's atoms (absorption of the x rays into the tissue) which prevents the photon from reaching the detector at all. A particular tissue's x-ray attenuating ability is expressed by its attenuation coefficient, μ (explained earlier). The higher the μ value, the lower number of photons that reach the detector when passing through that tissue type. The μ value is directly related to the tissue's density. That is, the higher the tissue density, the higher its μ value.
However, the attenuation coefficient of a tissue is not constant and may be altered by the tissue thickness and the energy of the x ray photon (KeV).

◣ Image Reconstruction Techniques

Image reconstruction is a mathematical process that generates tomographic images from x-ray projection data acquired at many different angles around the patient. The reconstruction process is based on the use of an algorithm that uses the attenuation data measured by detectors to systematically build up the image for viewing and interpretation.

Image reconstruction involves several algorithms to calculate all the μ from a set of projection data. The algorithms applicable to CT include back-projection, iterative methods, and analytic methods.

Currently, there are currently two forms of image reconstruction:

- ➥ Filtered back-projection (FBP) and
- ➥ Iterative reconstruction (IR).

Back-Projection

Back-projection is a simple procedure that does not require much understanding of mathematics. Back-projection, also called the "summation method" or "linear superposition method. Back- projection can be best explained with a graphical or numerical approach. Consider four beams of x rays that pass through an unknown object to produce four **projection profiles** $P1$, $P2$, $P3$, and $P4$ (Fig. 2). The problem involves the use of these profiles to reconstruct an image of the unknown object (black dot) in the box. The projected datasets are back-projected to form the corresponding images *BP1*,*BP2*, *BP3*, and *BP4*. The reconstruction involves summing these back-projected images to form an image of the object.

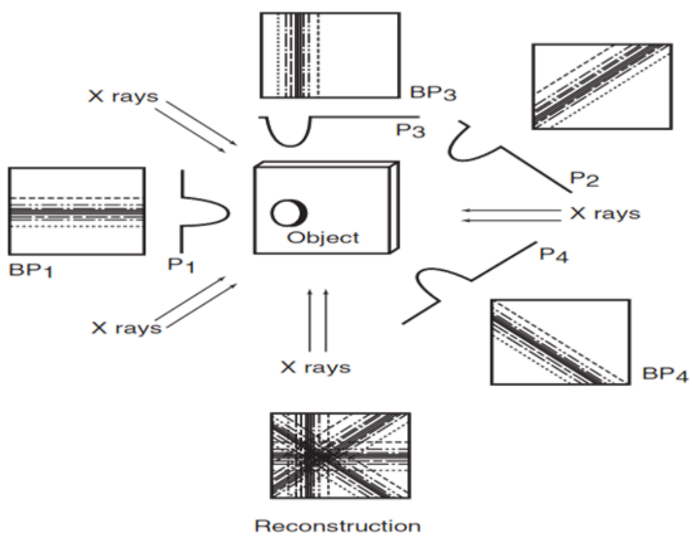
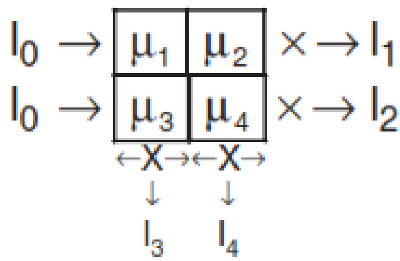


Fig.2: Graphic representation of the back-projection reconstruction technique

BP involves summing the data from hundreds of projection angles to reconstruct the image. Since the data from a projection angle of 0° is identical to the data from a projection angle of 180°, only the data from a 180° gantry rotation is necessary to reconstruct the full CT image. The displayed CT image is composed of the CT number data (Hounsfield unit data) from the summed projection information

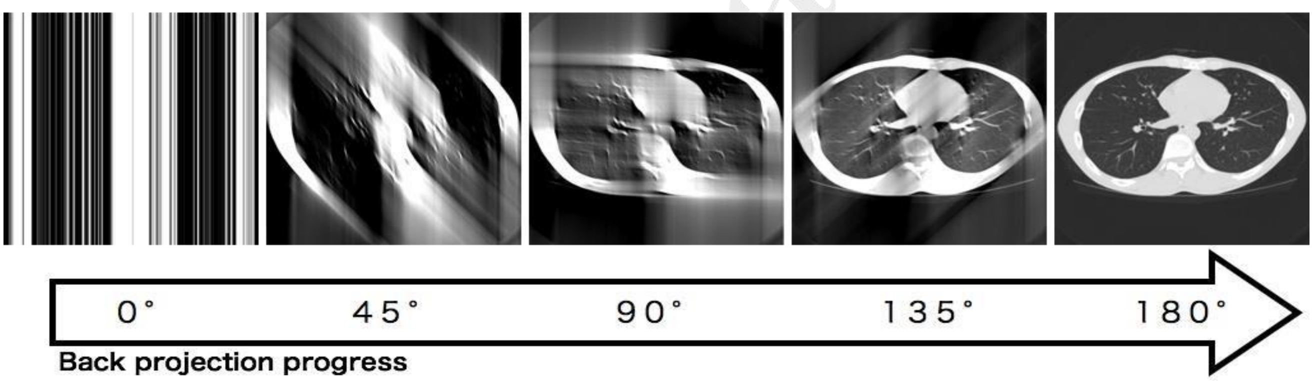
Back-projection can also be explained with the following 2 × 2 matrix:



Four separate equations can be generated for the four unknowns, μ1, μ2, μ3, and μ4:

$$I_1 = I_0 e^{-(\mu_1 + \mu_2)x}$$
$$I_2 = I_0 e^{-(\mu_3 + \mu_4)x}$$
$$I_3 = I_0 e^{-(\mu_1 + \mu_3)x}$$
$$I_4 = I_0 e^{-(\mu_2 + \mu_4)x}$$

A computer can solve these equations very quickly.

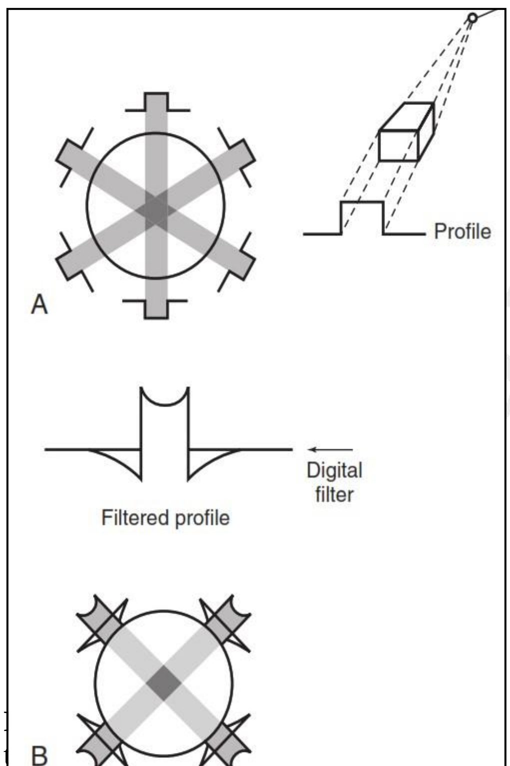


BP advantages include its relatively short time for complete reconstruction (≤30–40 slices per second). *The problem with the back-projection technique* is that it does not produce a sharp image of the object and therefore is not used in clinical CT. The most striking artifact of back-projection is the typical star pattern that occurs because points outside a high- density object receive some of the back-projected intensity of that object.

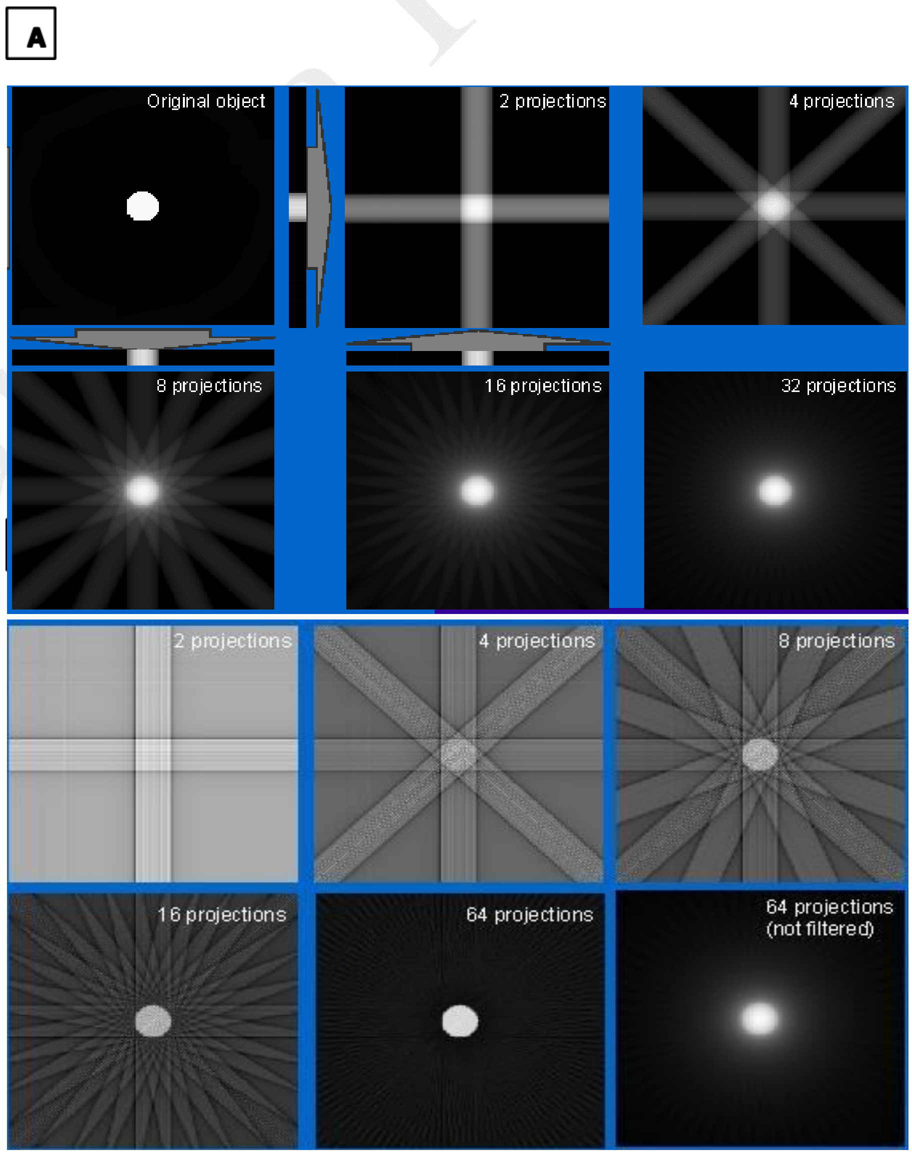
Filtered Back-Projection

Filtered back-projection is also referred to as the ***convolution method*** (Fig. 3). The projection profile is filtered or convolved to remove the typical starlike blurring that is characteristic of the simple back-projection technique. The steps in the filtered back-projection method (Fig. 3, *B*) are as follows:

1. All projection profiles are obtained.
2. The logarithm of the data is obtained.
3. The logarithmic values are multiplied by a digital filter, or convolution filter, togenerate a set of filtered profiles.
4. The filtered profiles are then back-projected.
5. The filtered projections are summed and the negative and positive components aretherefore canceled, which produces an image free of blurring.



A, Back-projection results in an unsharp image.**B,** Filtered back-projection uses a digital filter to remove blurring, which produces a sharp image.



The image quality is acceptable, but not optimal and thus, its major disadvantage is its limitations in image quality due to the necessary filtering used with this technique. These filtering techniques accentuate noise and mandate the need for higher radiation doses to permit adequate image quality. The excess image noise using FBP results from the inaccuracy of several assumptions used in this technique that limit spatial resolution and lead to increased streak artifact and relatively poor low contrast detectability. FBP tends to falter in larger patients due to increased tissue attenuation and in intentional low radiation dose scanning, which is becoming more important as understanding and awareness of the effects of cumulative radiation dose are realized. However, the advantages and acceptability of FBP have traditionally limited the incentive to change reconstruction methods. However, with the increased numbers of CT scans and the advanced applications such as cardiac CT angiography, the importance of more radiation efficient reconstruction methods has been emphasized, mandating the onset of IR.