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 is displayed as a matrix of intensities***.

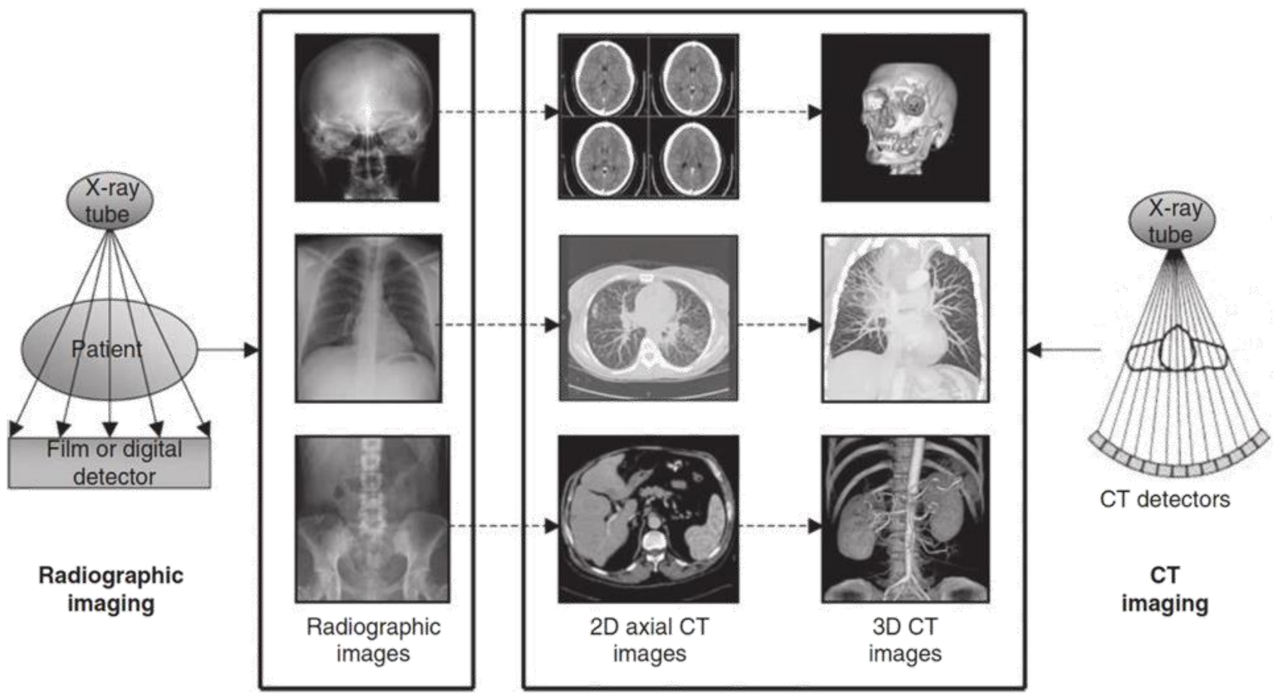


Fig. (1): The most conspicuous difference between conventional radiographic imaging and CT imaging.

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 d***etectors 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 the 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 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.

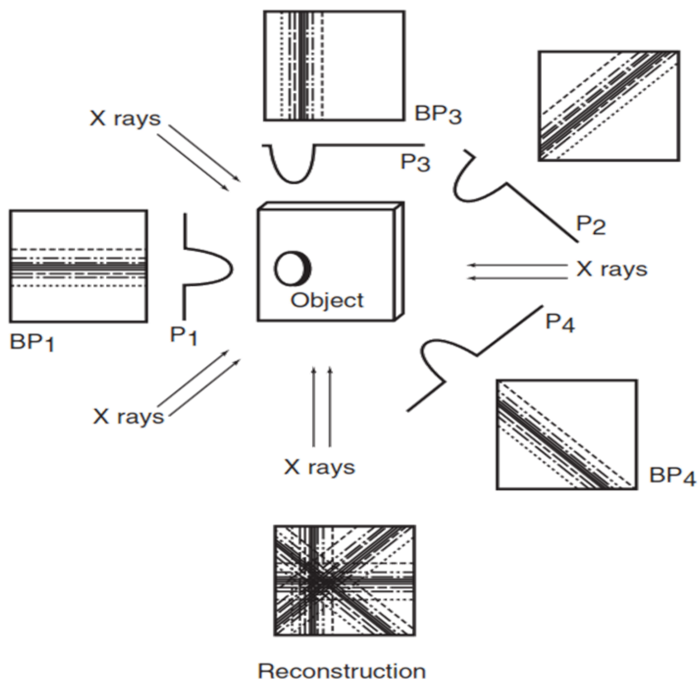
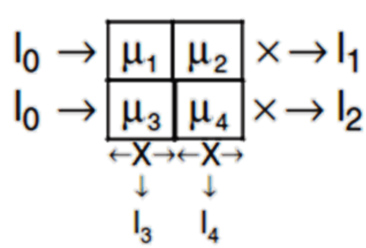


Fig.2: Graphic representation of the back-projection reconstruction technique.

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***.

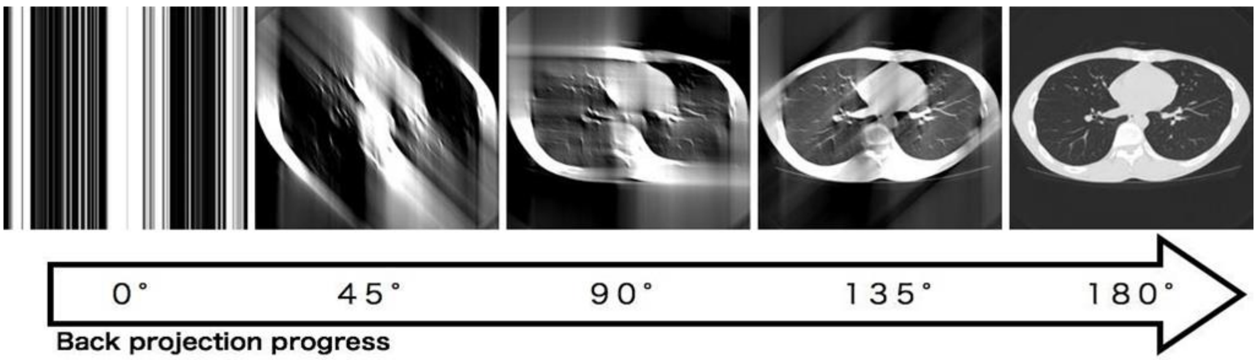
Back-projection can also be explained with the following 2 × 2 matrix:



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 star like 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, to generate 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 are therefore canceled, which produces an image free of blurring.

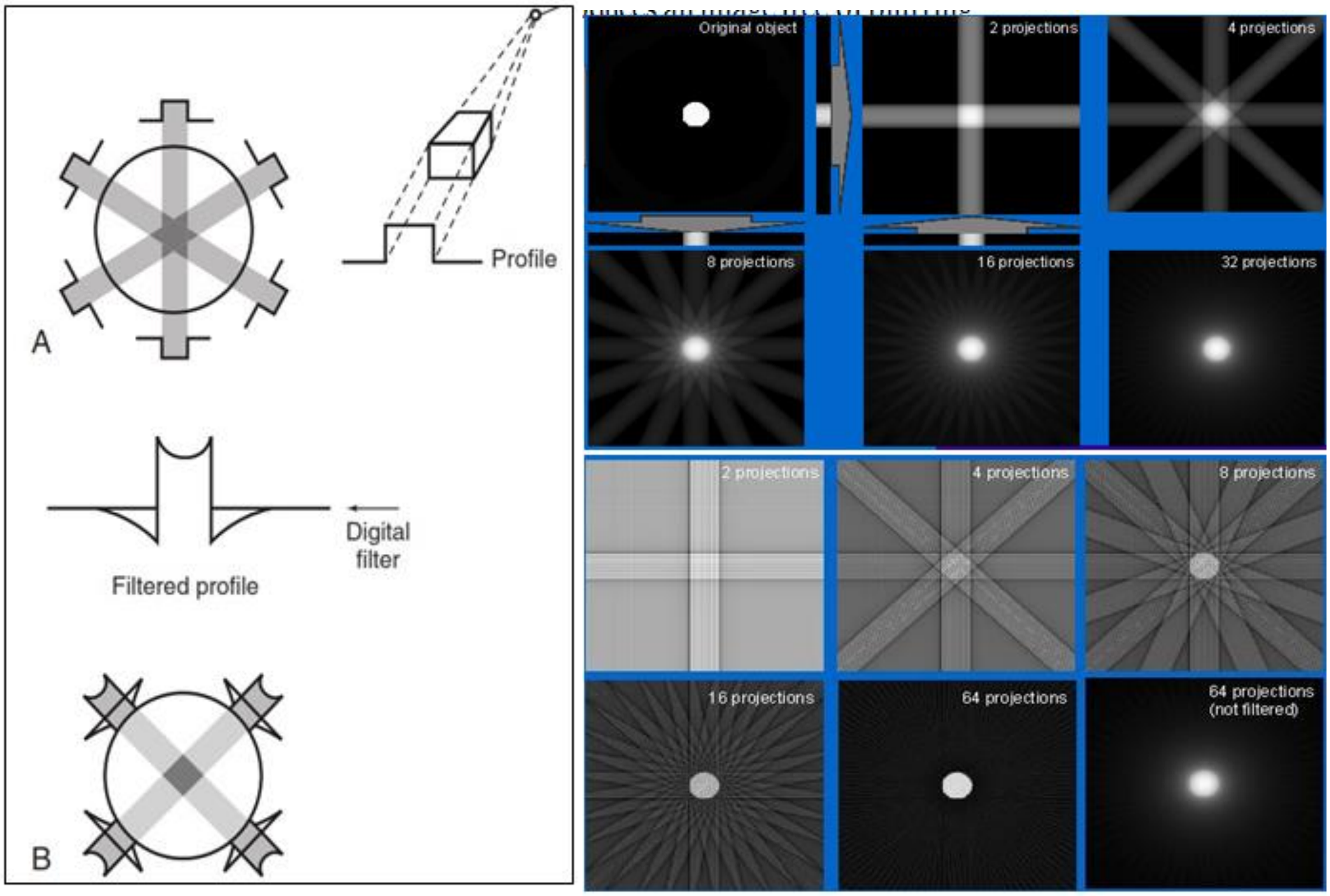


Fig. 3: Back- and filtered back projection techniques used in CT. A, Back-projection results in an unsharp image. B, Filtered back-projection uses a digital filter to remove blurring, which produces a sharp image.

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***

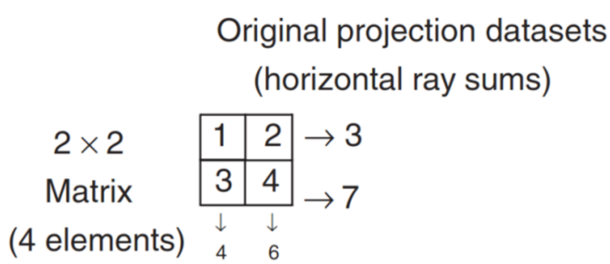
and in intentional low radiation dose scanning, which is becoming more important as understanding and awareness of the effects of cumulative radiation dose are realized. However, the advantages and acceptability of FBP have traditionally limited the incentive to change reconstruction methods. However, 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.

Iterative reconstruction

Another approach to image reconstruction is based on ***iterative techniques***. Iteration is defined as a procedure in which ***repetition of a sequence of operations results in values successively closer to a desired result***. Said another way, iteration is a ***computational, mathematical procedure*** in which a cycle of operations is repeated, often, to approximate the desired result more closely.

"An iterative reconstruction ***starts with an assumption*** (for example, that all points in the matrix have the same value) and compares this assumption with measured values, makes corrections to bring the two into agreement, and then ***repeats this process over and over until the assumed and measured values are the same or within acceptable limits***".

Consider the following numeric illustration:



1. Initial estimate: ***Compute the average of four elements and assign it to each pixel***, that is, 1 + 2 + 3 + 4 = 10; 10/4 = 2.5.

New projection datasets
(horizontal ray sums)

2.5	2.5	→ 5
2.5	2.5	→ 5

2. First correction for error (***original horizontal ray sums minus the new horizontal ray sums divided by 2***) = (3 − 5)/2 and (7 − 5)/2 = −2/2 and 2/2 = −1.0 and 1.0

(2.5 − 1) 1.5	(2.5 − 1) 1.5
(2.5 − 1) 3.5	(2.5 − 1) 3.5

3. Second estimate:

1.5	1.5
3.5	3.5
↓ 5	↓ 5

New projection datase
(vertical ray sums)

4. The second correction for error (***original vertical ray sums minus new vertical ray sums divided by 2***) = (4 − 5)/2 and (6 − 5)/2 = −1.0/2 and +1.0/2 = −0.5 and +0.5:

(1.5 − 0.5) 1	(1.5 − 0.5) 2
(3.5 − 0.5) 3	(3.5 − 0.5) 4

The final matrix solution is thus →

1	2
3	4

In this technique, repeated estimations of the ***X-ray photon counts*** that would be acquired in ***each projection are calculated*** , and ***compares them with the actual measured counts*** (***forward projection***) acquired by the scanner's detector array. At each step, the

ratio of estimated to actual X-ray counts is used to formulate a correction factor that is used to create the next estimate (***back projecting the ratio***).

This process is repeated over and over again resulting in movement of the estimated X-ray photon count distribution ever closer to the actual, measured photon count distribution, Fig. 1.

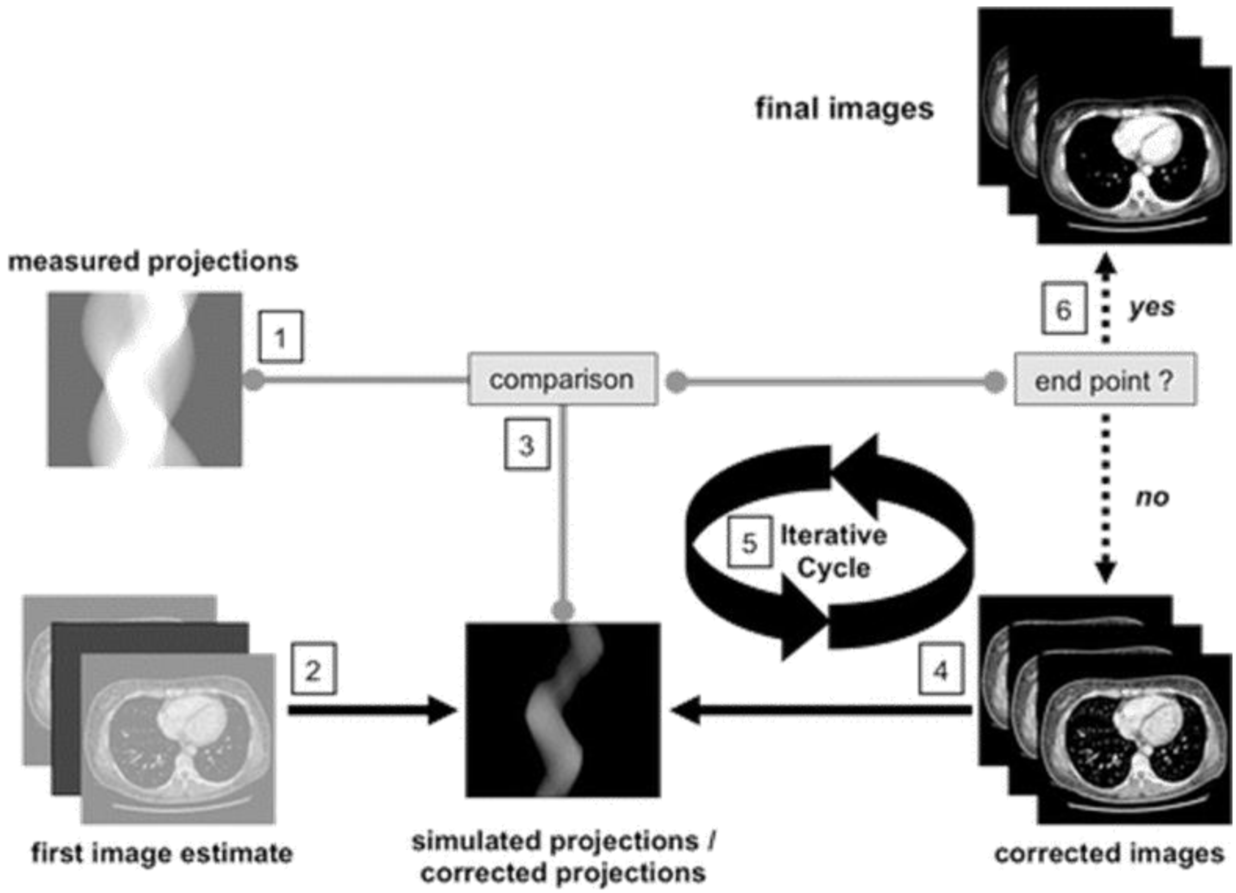


Fig. 1: Iterative reconstruction techniques used in CT.

Today, iterative reconstruction algorithms have resurfaced because of the availability of ***high-speed computing***. The ***primary advantages*** of iterative image reconstruction algorithms are to ***reduce image noise and minimize the higher radiation dose inherent in the filtered back-projection algorithm***.