Theoretical Lecture: CT Image

CT Image:

CT image is composed of ***pixels*** (picture elements). Each pixel on the image represents a measurement of the average x-ray attenuation of a box-like (small volume) element (**voxel**) extending through the thickness of the tissue section. In addition, in a real CT image, all tissues within a single pixel would be the same shade of gray (Figure1).

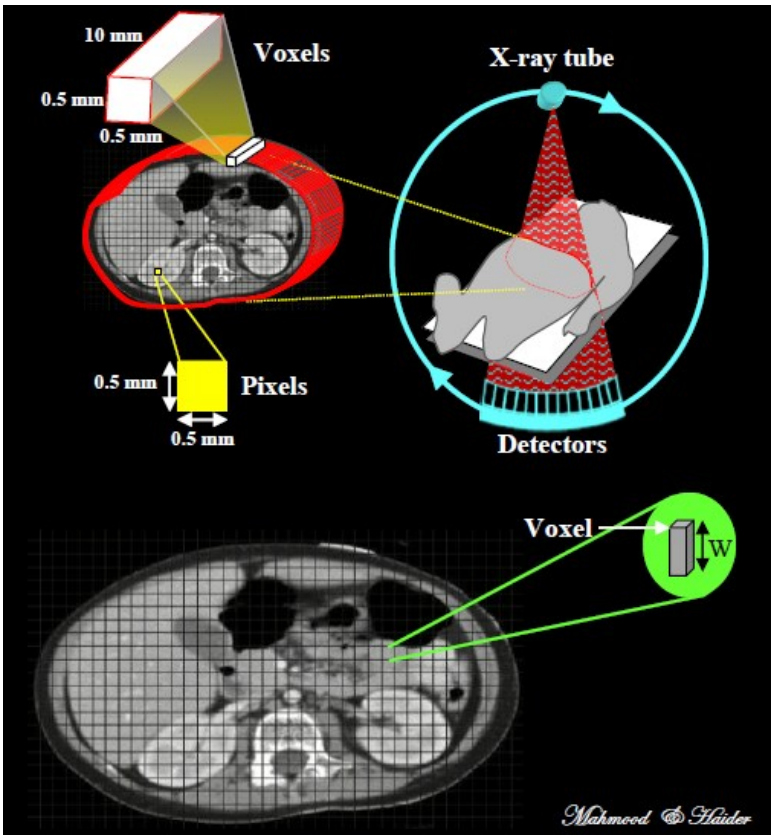

Figure1: Sample CT image.

An X-ray beam which is transmitted through a voxel, is given by the relation:

$$I = I_0 \, e^{-\mu x}$$

Where, $\mathbf{I_0}$ is the number of initial X-ray photons, **I** is the number of transmitted photons, **e** is the base of natural logarithm (2.718) and **μ** is the linear attenuation coefficient of the voxel. The value of $\mathbf{I_0}$, **I** and **x** can be measured and the only unknown is **μ**. If the X-ray beam passes through four voxel as shown in the Figure2, then:

$$I = I_0 \, e^{-(\mu_{13} + \mu_{23} + \mu_{33} + \mu_{43})\, x}$$

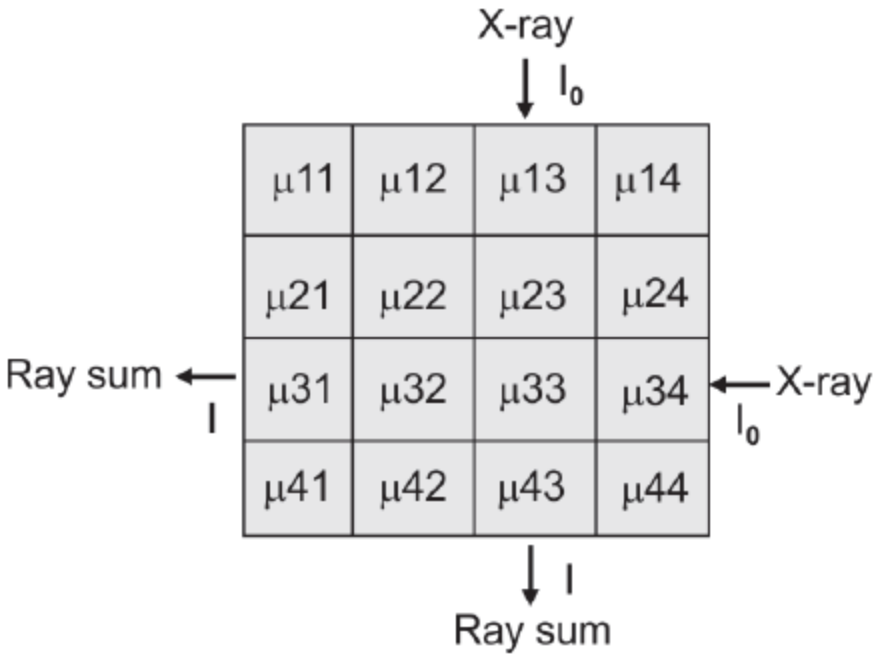

Figure 2: Scanning voxel in different directions

To solve the above equation, additional equations are required. Hence, the voxel are scanned in different directions, which give rise to four more equations.

CT Number:

The intensity scale (called the CT number) used in the reconstructed CT image is defined by:

$$CT_{number} = \frac{\mu - \mu_{water}}{\mu_{water}} \times 1000$$

Where;

μ is the measured attenuation of the material in the voxel, **μ** $_{water}$ is the linear attenuation coefficient of water (0.195). This unit is often called **the Hounsfield unit (HU).**

Voxels containing materials that attenuates more than water (e.g. muscle tissue, liver, and bone) have positive CT numbers, whereas materials with less attenuation than water (e.g. lung or adipose tissues) have negative CT numbers. With the exception of water and air, the CT numbers for a given material will vary with changes in the x-ray tube potential and from manufacturer to manufacturer.

Water has a CT number of zero. The CT number for air is –1000 HU, since μ_{air}=0. Soft tissues (including fat, muscle, and other body tissues) have CT numbers ranging from –100 HU to 60 HU. Cortical bones are more attenuating and have CT numbers from 250 HU to over 1000 HU.

Image Display:

The reconstructed image is displayed on a cathode ray tube monitor, by allotting shades of gray to each CT number. There are 256 shades of gray in the system and each CT number is allotted one shade of gray. The monitor has a matrix size of 512 × 512 and each pixel represents 12 bits or 4096 gray levels, which is greater than the display range of monitor.

- **The window width** (WW): is the measure of the range of CT numbers that an image contains (The range of grayscale above and below the window

level (center number), which determines the contrast (Figure 2). A narrow window width provides higher contrast than wide window width.

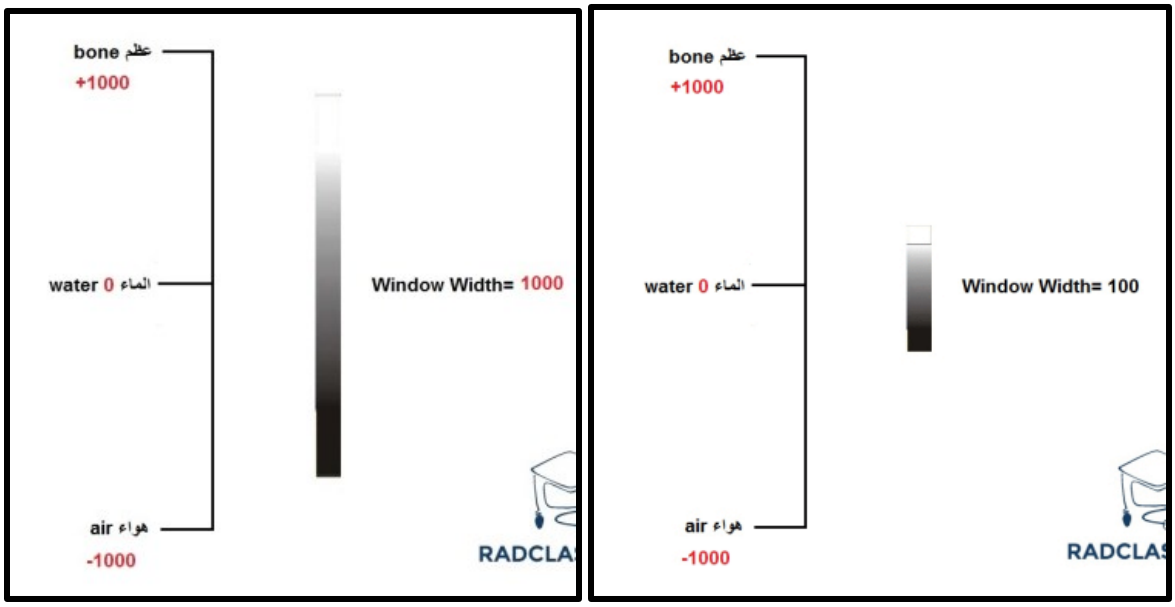

Figure 2: window width, left: wide window width, right: narrow window width.

- The **window level** (WL): is the midpoint of the range of the CT numbers displayed (the center of grayscale) determines the brightness level, When the window level is decreased the CT image will be brighter and vice versa (Figure 3).

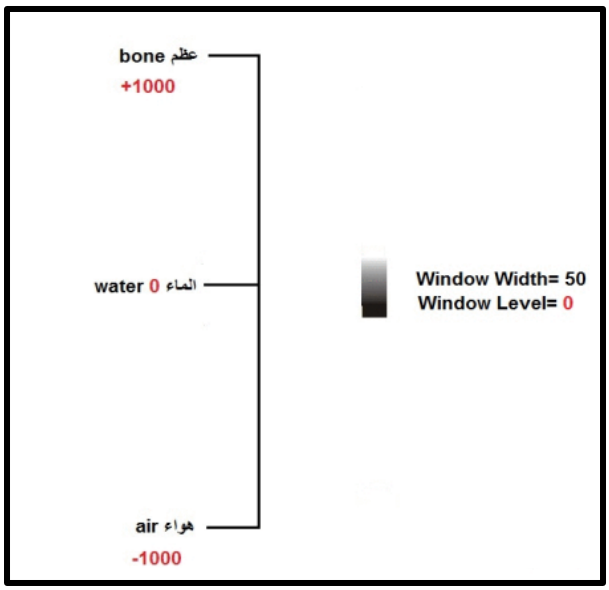

Figure 3: window Level.

The typical window level of head, chest (lung) and abdomen (liver) are 40, –500 and 60, respectively. The corresponding window widths are 80, 1500 and 150, respectively. Figure4 show an example of window level and window width of brain.

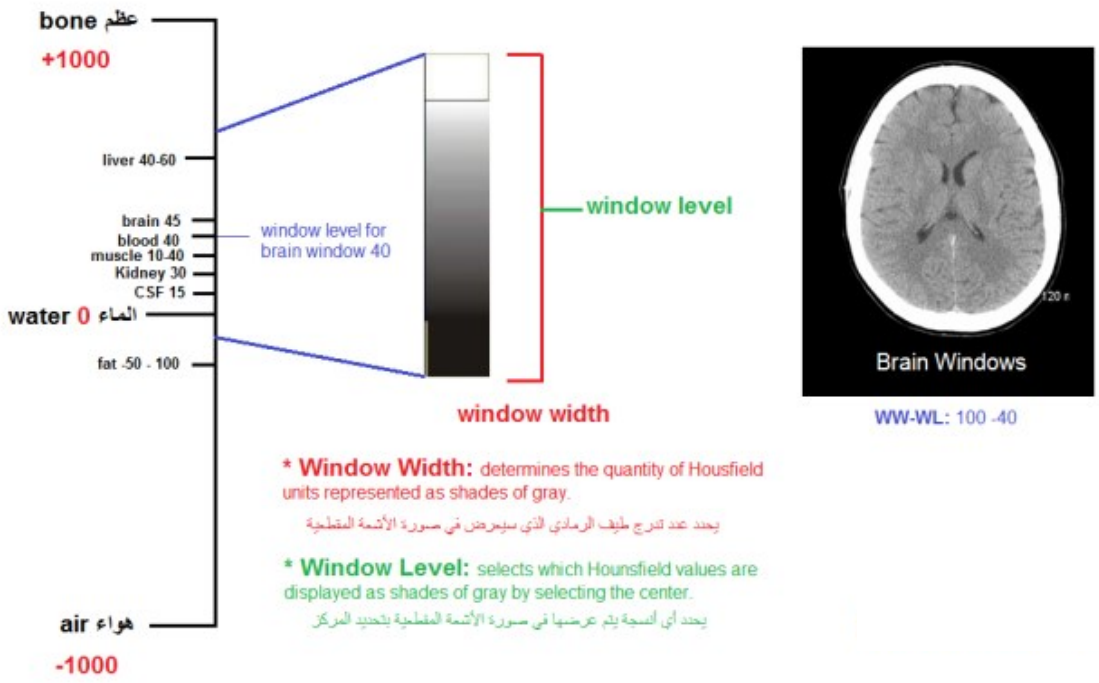

Figure 4: Example of the window width and window level of brain.

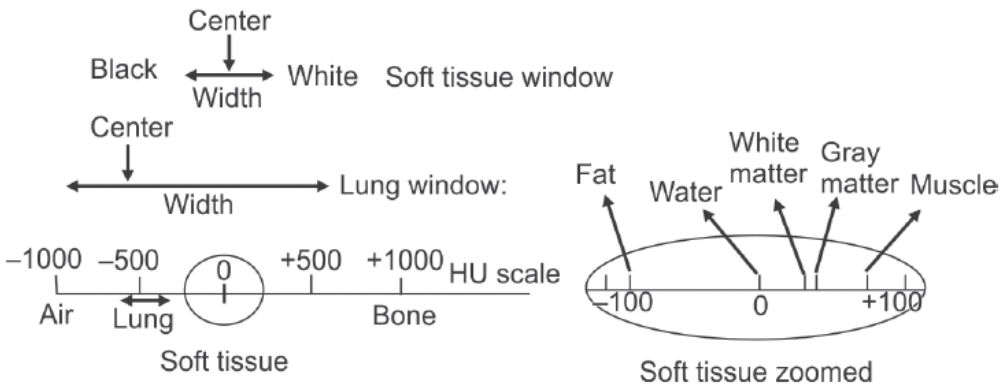

Figure 5: Window level and window width in a CT scan display.