CT Numbers, Hounsfield Unit, and Gray Scale

CT number is a special number which is a normalized value of the calculated X-ray absorption coefficient of a pixel (picture element), in a computed tomogram. The absorption coefficient of a tissue varies with the nature of the tissue and the energy (kV) of X-ray beam. However, if the tissue absorption coefficient is related to that of water absorption coefficient at the same kV, a reference number independent of kV change can be obtained. This number is called CT number. CT number is represented by a specific unit or number called Hounsfield unit (HU). CT number or Hounsfield unit can be calculated as follows:

$$HU = \left\{\frac{\mu_{tissue} - \mu_{water}}{\mu_{water} - \mu_{air}}\right\} \times 1000$$

Since the absorption coefficient of air is negligibly small, therefore, Eq. (1) modifies to:

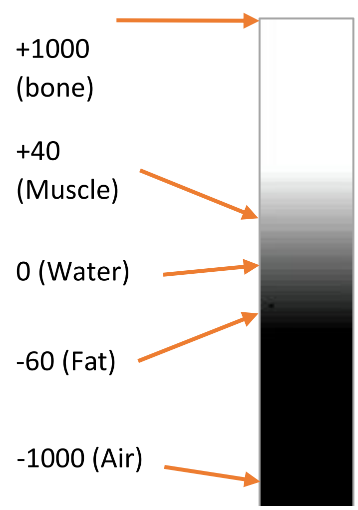
$$HU = \left\{\frac{\mu_{tissue} - \mu_{water}}{\mu_{water}}\right\} \times 1000$$

The following example will help calculating CT number or HUS for muscle and bone.

Example 1 Calculate the CT number for the muscle with the following available data:

μ	80 Kev	100 Kev	150 Kev
μ_{water}	0.1835	0.1707	0.1504
μ_{muscle}	0.1892	0.1760	0.1550

Tissue	Range of CT Numbers (HU)
Bone	500 to 3000
Liver	40 to 60
Grey Matter (Brain)	35 to 45
White Matter (Brain)	20 to 30
Blood	30 to 45
Muscle	10 to 40
Water	0
Fat	-60 to -150
Lung	-500
Air	-1000



Grav Scale

Table 1 Tissues' CT numbers and gray scale.

Table 1 gives CT numbers of various tissues in HUS.

Solution (CT)muscle.

$$HU = \left\{\frac{\mu_{tissue} - \mu_{water}}{\mu_{water}}\right\} \times 1000$$

At 80 keV

$$HU = \{(0.1892 - 0.1835)/(0.1835)\} \times 1000 = 31$$

At 100 keV

$$HU = \{(0.1760 - 0.1707)/(0.1707)\} \times 1000 = 31$$

At 150 keV

$$HU = \{(0.1550 - 0.1504)/(0.1504)\} \times 1000 = 31$$

Variation in CT Numbers with X-ray Energy

When an X-ray beam of varying energy over a range of energies is passed through the body of a patient, low-energy X-ray photons are absorbed and removed from the beam within a short length. As a result the average energy of the remaining beam gets higher. This process is called hardening of the beam. The hardening of the beam continues as the beam further penetrates in the body. Since the average energy of the hardened beam is higher than the original beam allowed to fall on the body, therefore, its penetration ability also increases. Since the CT numbers depend upon the absorption ability of X rays, therefore, variation in X-ray energy causes a change in CT numbers of the same tissue as illustrated in Fig. 1.

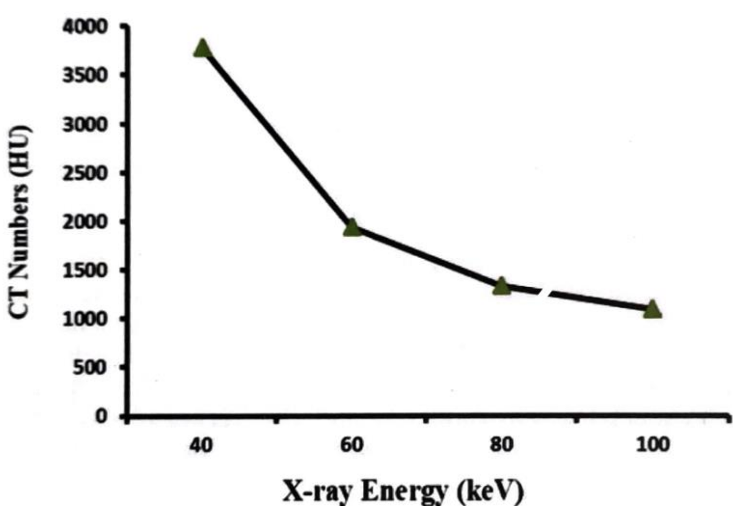


Fig. 1 Variation in CT number with X-ray beam energy

Figure 1 shows variation in the CT numbers of cartilage bone with the energy of X-ray beam. The figure shows that the CT number of a tissue decreases with increasing beam energy. This variation in CT number also brings changes on the gray scale, causing complications in the imaging process. Therefore, a better option is to use a monochromatic beam of X-ray photons. The energy of X-ray beam is controlled by and proportional to the X-ray tube voltage. The higher the tube voltage, the more energetic X-ray beams are obtained. Thus, controlling the tube voltage can solve the problem of variation in energy and can produce a monochromatic beam to avoid variation in CT numbers. Proper X-ray generator calibration is important for accurate and reproducible CT numbers.

Example 2 Calculate the CT number for fat and cartilage bone with the following data:

μ	40 kV	60 kV	80 kV	00 kV
μ_{water}	0.268	0.206	0.184	0.171
μ_{fat}	0.228	0.188	0.171	0.160
$\mu_{cartbone}$	0.128	0.604	0.428	0.356

H.W.

Dynamic Range

In the digital image formation, analogue-to-digital converter (ADC) needs to be capable of responding to a wide variation of attenuation in the part of patient's body under irradiation. The dynamic range shows the ratio of the largest signal (in the absence of any absorption) to the smallest signal (with maximum absorption) that can be detected. This allows obese and slim patients to be imaged with the same standard and definition including bone (high density) and soft tissues (low density).

CT Numbers and Windowing

CT numbers are just numbers expressed in Hounsfield units. On the other hand, gray scale is a way CT numbers are expressed. In general CT numbers in an image are mapped onto an 8-bit gray scale. When the dynamic range of the CT number scale exceeds the gray scale, all numbers cannot be accommodated on the gray scale. In that condition the way in which CT numbers are mapped needs to be adjusted by windowing. The display window represents the CT number interval of interest and is defined by two parameters: window level and window width.

Window level is the CT number on which the window is centered. On the other hand, window width is the magnitude of the range of CT numbers covered by the window. The window width determines the contrast in the displayed image. CT window describes the difference between the upper and lower limits of the window.

Tissue	Window level (HU)	Window width (HU)
Lungs	-500	1500
Brain	40	80
Chest	50	350
Abdomen	60	400
Bone	300	1500

Table 2 Window settings in computed tomography

Pixel values

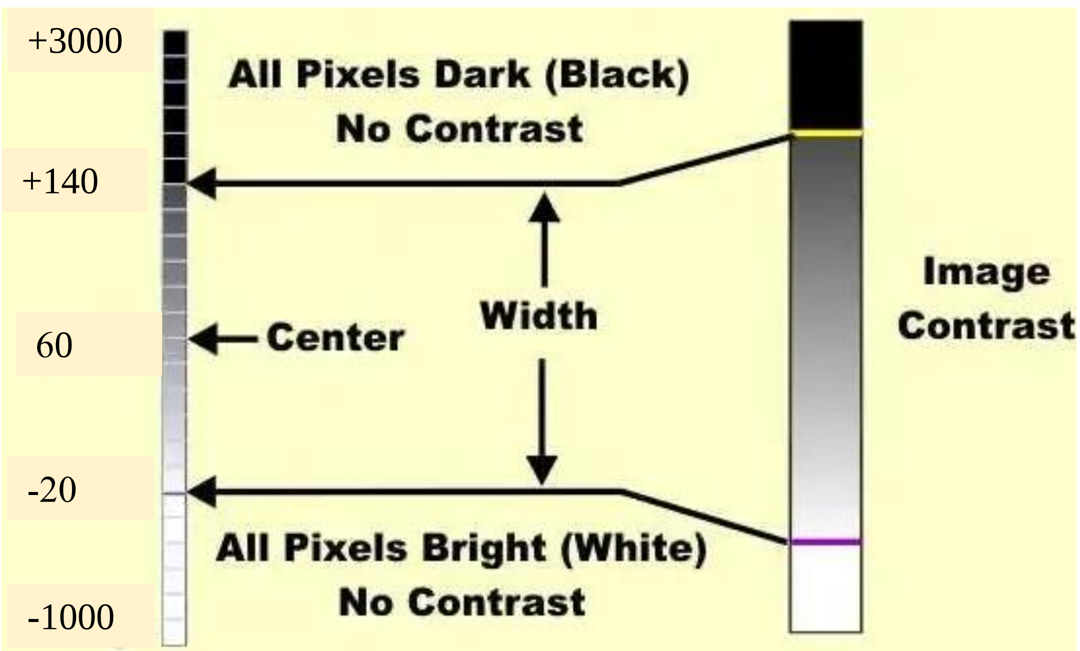


Image Windowing for Liver

Fig. 2 Image window level and window width for liver

Typical window settings for various body parts in CT imaging are given in Table 2. Figure 2 shows image windowing for the liver.

Data Matrices

After calculating the CT numbers, they are stored in computer memory and represent a volume slice element called voxel. A voxel along with tissue slice is given in Fig. 3.

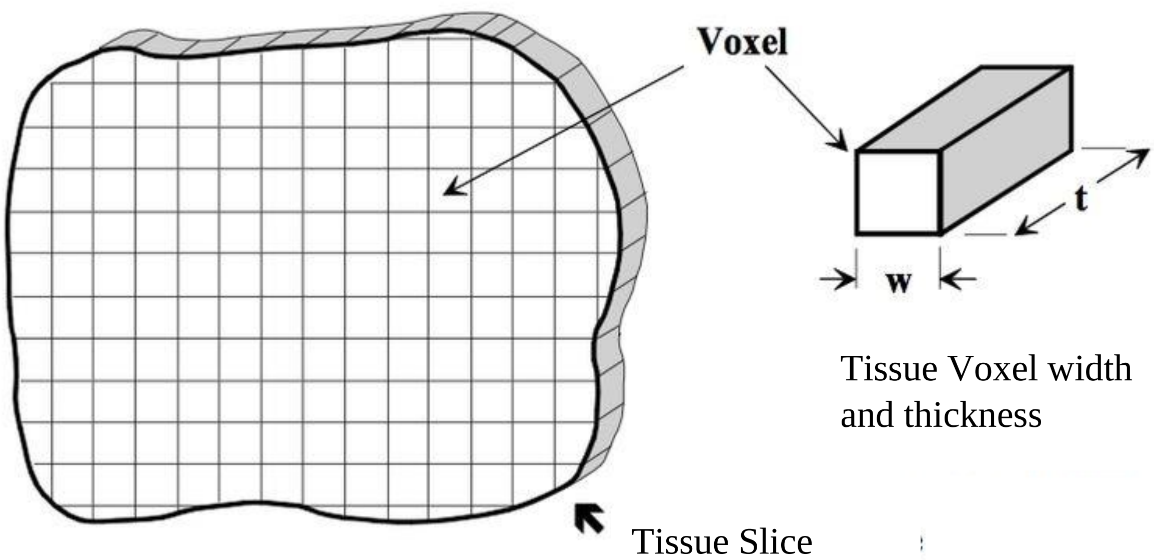


Fig. 3 A single voxel and tissue slice