NYCU

醫學影像原理與實務
電腦斷層與組織特性關聯性

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NBA

本週學習目標

1. **認識電腦斷層影像基本特性**
   CT數值的定義
   影像對比調整
   CT影像常見假影

2. **理解電腦斷層影像之臨床應用**
   電腦斷層神經影像應用
   電腦斷層心血管疾病應用
   電腦斷層骨科應用

Reference:
Fundamentals of Medical Imaging (2nd Ed.)
Chapter 3

Chia-Feng Lu, http://cflu.lab.nycu.edu.tw

電腦斷層影像基本特性

NBA

CT Number: Hounsfield Unit

- The CT number (expressed in Hounsfield unit, HU) is defined as:

$$CT\ number\ (in\ HU) = \frac{\mu - \mu_{H_2O}}{\mu_{H_2O}} \cdot 1000$$

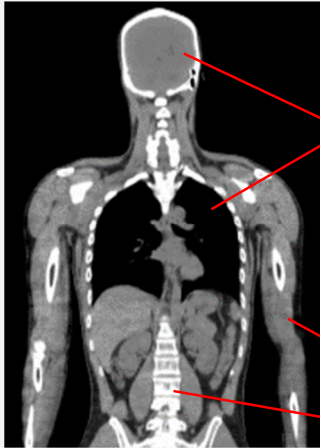Voxels contains water ($\mu = \mu_{H_2O}$)
CT number = 0 HU

Voxels contains air ($\mu \approx 0$)
CT number = -1000 HU

Chia-Feng Lu, http://cflu.lab.nycu.edu.tw

CT Number of Tissues

Substance	Hounsfield Unit (HU)
Air	-1000
Lung	-700
Soft tissue	-300 to -100
Fat	-100 to -50
Water	0
Cerebrospinal fluid (CSF)	15
Blood	+30 to +45
Muscle	+40
Bone	+700 (cancellous bone) to +3000 (dense bone)

Iodine Contrast Agent

CT Angiography

Hepatocellular Carcinoma

w. contrast injection

w. contrast injection arterial phase

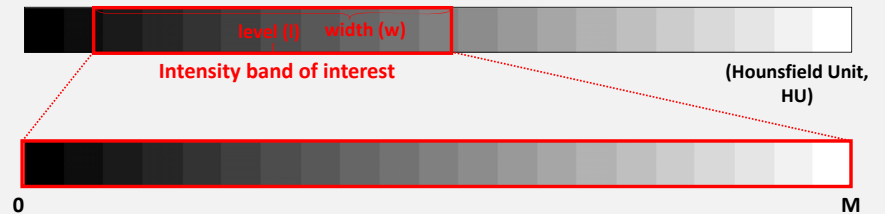# Image Window and Contrast

Full-range window
(Full-dynamic)

Lung window

Intensity scaling

- Allowing the observer to focus on specific intensity bands by modifying the image such that the intensity band of interest spans the dynamic range of the display.
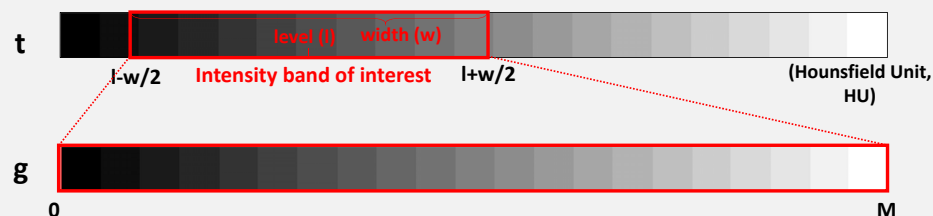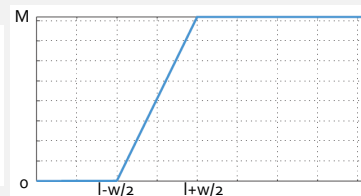
level (l)   width (w)

Intensity band of interest

(Hounsfield Unit, HU)

0

M

Slide 9

Intensity scaling

$$g_{l,w}(t) = \begin{cases} 0 & \text{for } t < l - \dfrac{w}{2} \\[2mm] \dfrac{M}{w}\left(t - l + \dfrac{w}{2}\right) & \text{for } l - \dfrac{w}{2} \le t \le l + \dfrac{w}{2} \\[2mm] M & \text{for } t > l + \dfrac{w}{2}, \end{cases}$$
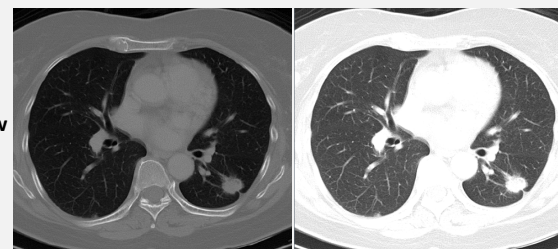

t

l-w/2   level (l)   width (w)   l+w/2   (Hounsfield Unit, HU)

Intensity band of interest
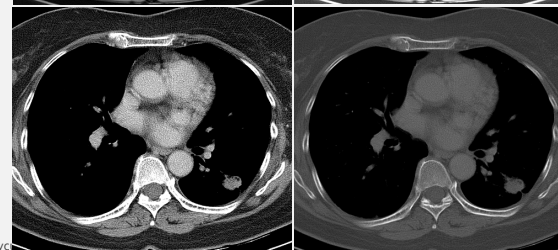
g

0   M

Slide 10

Intensity scaling

Full-range window

Lung Window (-600/1200)

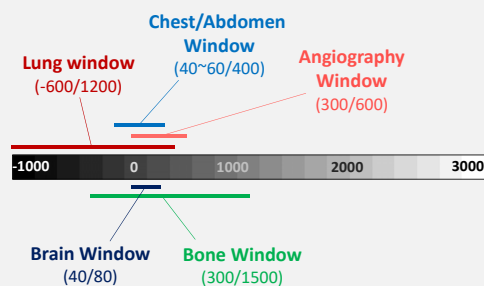Chest Soft Tissue Window (40/400)

Bone Window (300/1500)

Slide 11

Intensity scaling

Window Level/Width

Chest/Abdomen Window (40~60/400)

Lung window (-600/1200)

Angiography Window (300/600)

-1000   0   1000   2000   3000

Brain Window (40/80)

Bone Window (300/1500)

Substance	Hounsfield Unit (HU)
Air	-1000
Lung	-700
Soft tissue	-300 to -100
Fat	-100 to -50
Water	0
Cerebrospinal fluid (CSF)	15
Blood	+30 to +45
Muscle	+40
Bone	+700 (cancellous bone) to +3000 (dense bone)

Slide 12

CT Image Artifacts

- Under-sampling 取樣不足
- Beam hardening 射束硬化
- Scatter 散射
- Motion artifact 移動假影
- Windmill artifact 風車假影
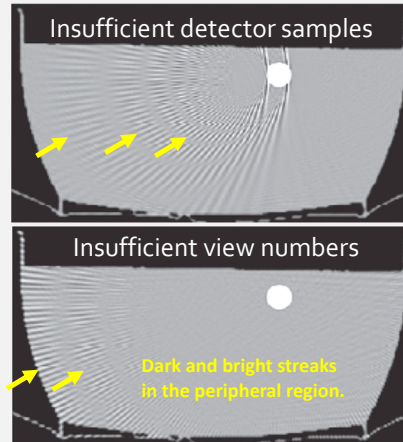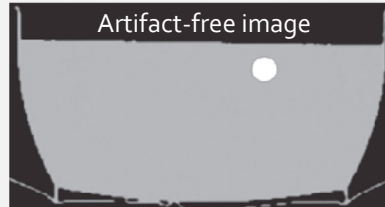- Stairstep artifact 階梯狀假影
- Partial volume effect 部分體積效應

Under-sampling

- A minimum number of **detector samples** and **views** are required.
- Under-sampling will cause **aliasing**.
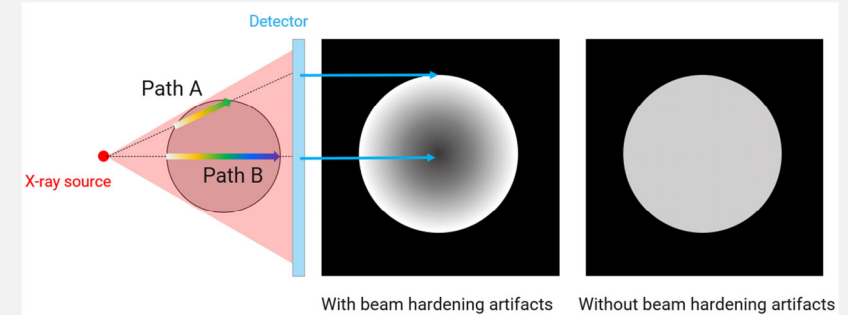
A simulated water bowl with iron rod.

Artifact-free image

Insufficient detector samples

Insufficient view numbers

Dark and bright streaks in the peripheral region.

Beam Hardening

- Low-energy photons are absorbed more as an X-ray beam passes through tissue. ➔ Beam energy increases (hardening).

With beam hardening artifacts   Without beam hardening artifacts

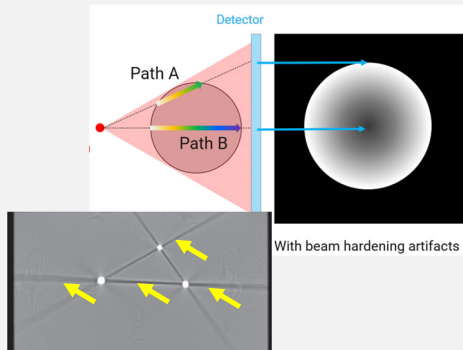https://rigaku.com/products/imaging-ndt/x-ray-ct/learning/blog/what-is-beam-hardening-in-ct

Beam Hardening

- The difference in the path length is wrongly translated into a difference in density because of beam hardening.

With beam hardening artifacts

	Path A	Path B
Path length	Short	Long
Beam hardening	Less hardening	More hardening
Resulting X-ray energy	Low	High
Calculated absorption rate	High	Low
Reconstructed density	High (bright)	Low (dark)

Scatter

- Not all photons that arrive at the detector follow a straight path from the X-ray tube.
- Typically, up to 30% of the detected radiation is due to scatter.
- Scatter yields **streak artifacts**.

A plexiglass plate with 3 amalgam fillings
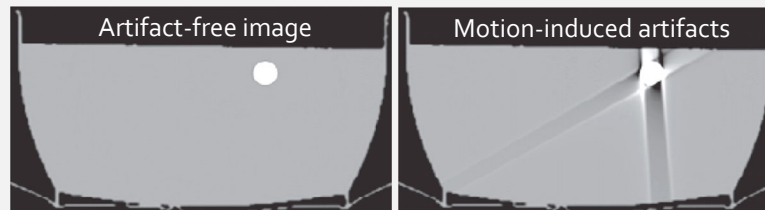

Artifact-free image   With scatter

Slide 1: Motion artifact

- A short object movement during acquisition causes inconsistent measurements and two streaks.
- One links the object to the X-ray tube at movement and another to its start-stop position.
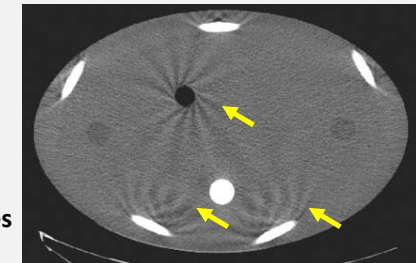
A simulated water bowl with iron rod.

Artifact-free image | Motion-induced artifacts

Slide 2: Windmill artifact

- The windmill artifact (also called **bearclaw artifact**) is a z-aliasing artifact that occurs primarily in helical cone-beam CT.
- The amount of blur introduced by this interpolation process changes as a function of view angle due to the helical motion.
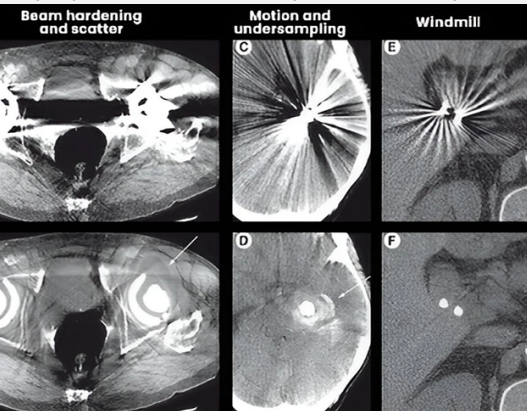

Black and white spokes

Slide 3: CT Image Artifacts

Hip replacement | Aneurysm coil | Cholecystectomy clips

Beam hardening and scatter | Motion and undersampling | Windmill

With artifacts

Corrected images

https://www.medical-professionals.com/en/understanding-ct-artifacts-a-comprehensive-guide/

Slide 4

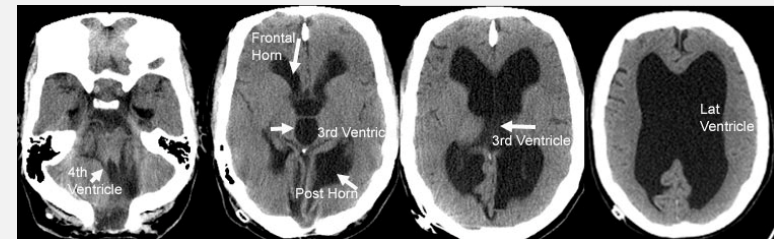電腦斷層之臨床應用

Neurological CT Scan

- Hydrocephalus
- Blood clots or stroke
- Traumatic brain injury
- Aneurysms or other vascular abnormalities
- Brain tumors or cysts
- Epilepsy
- Herniated spinal discs
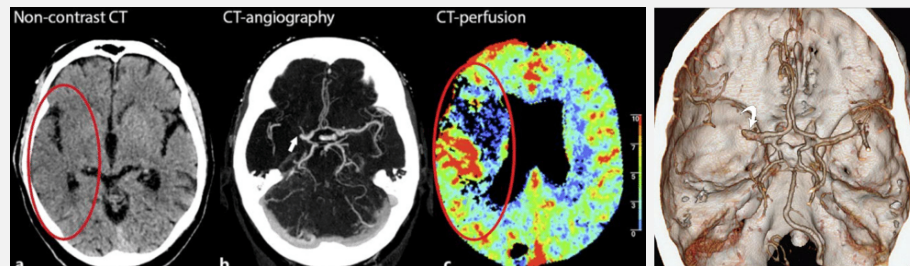- Multiple sclerosis

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CT in Obstructive Hydrocephalus

- CT scans without contrast show enlargement of lateral and third ventricles, but not the fourth ventricle, due to aqueductal stenosis.
- Sulci and gyri are flattened against skull and are effaced.

https://www.stritch.luc.edu/lumen/meded/radio/curriculum/neurology/hydrocephalus_2013.htm
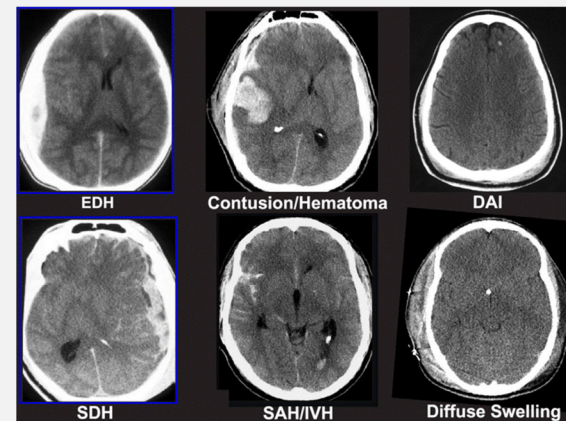

CT in Ischemic Stroke

- (a) Early signs of ischemic stroke (red oval);
- (b) CT angiography with occlusion (white arrow) of the proximal middle cerebral artery;
- (c) CT perfusion showing perfusion deficit in the territory of the right middle cerebral artery (red oval).

https://www.researchgate.net/figure/Head-computed-tomography-CT-images-of-the-patient-at-admission-and-at-follow-up-Top_fig1_325461408
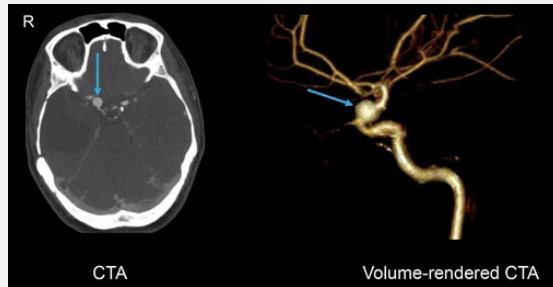

CT in Traumatic Brain Injury

- EDH: epidural hematomas
- DAI: diffuse axonal injury
- SDH: subdural hematomaSAH: subarachnoid hemorrhage
- IVH: intraventricular hemorrhage
- Diffuse brain swelling

https://www.researchgate.net/figure/Heterogeneity-of-severe-traumatic-brain-injury-TBI-Computed-tomography-CT-scans-of_fig2_12311521

CT in Aneurysms
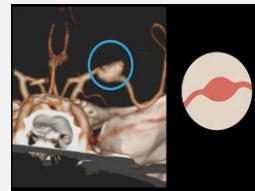

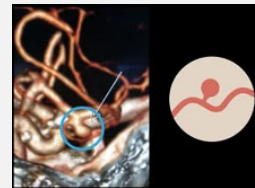CTA — Volume-rendered CTA

Fusiform aneurysm

Saccular aneurysm

- An unruptured fusiform aneurysm of the distal right carotid artery.

https://www.medmastery.com/guides/brain-ct-clinical-guide/common-locations-aneurysms-brain-computed-tomography-ct-scans

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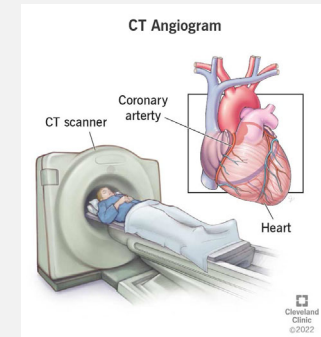## Cardiac CT Scan

Coronary artery disease (CAD)
- Cardiac Computed Tomography Angiography (CCTA)
- Calcium score

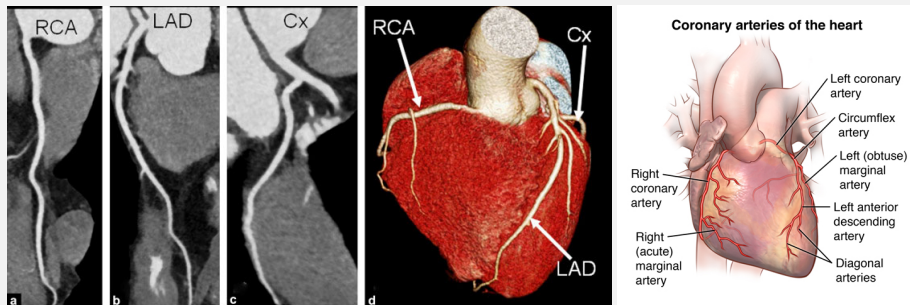https://my.clevelandclinic.org/health/diagnostics/16899-coronary-computed-tomography-angiogram

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Cardiac CT Angiography (CCTA)

$$Pitch = \frac{Table\ Travel\ per\ Rotation}{Beam\ Width}$$

Images of excellent image quality using the prospective ECG-triggered (flash spiral technique) coronary CTA (pitch 3.4, 68 mL at 5.5 mL/s).
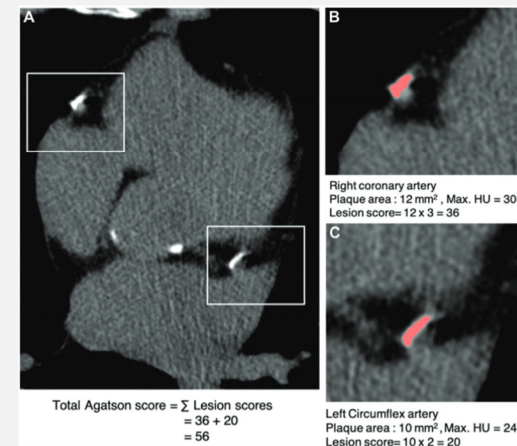

Curved reformation images

Volume rendering

Diagnostic and Interventional Imaging, 97(4): 461-469, 2016.
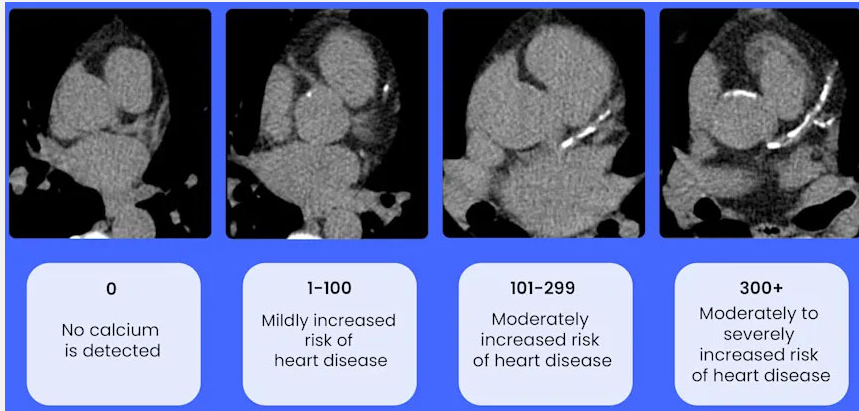

CT for Coronary Artery Calcium Scoring

- **Agatston score**
  = plaque area × attenuation-weighting factor

- The CAC Consortium suggests that the CAC score is useful in predicting the risk of cardiovascular events and disease-specific mortality.

RadioGraphics, 42:947–967, 2022.

CT for Coronary Artery Calcium Scoring

0	1-100	101-299	300+
No calcium is detected	Mildly increased risk of heart disease	Moderately increased risk of heart disease	Moderately to severely increased risk of heart disease

https://www.healthcentral.com/condition/high-cholesterol/coronary-calcium-test

Orthopedic CT Scan

- Fracture Detection and Evaluation
- Joint and Bone Conditions
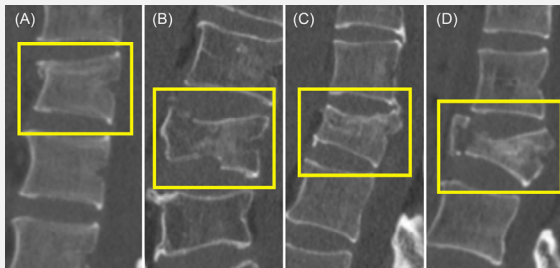- Spinal Conditions
- Trauma and Sports Injuries

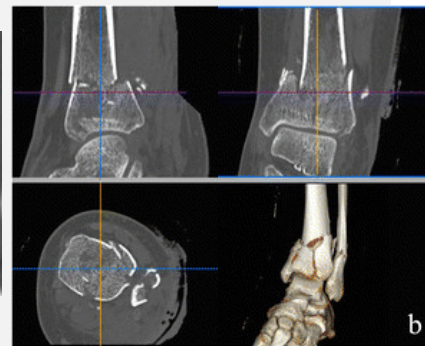https://www.ganeshdiagnostic.com/blog/ct-scans-and-orthopedic-imaging-a-comprehensive-guide

CT in Fracture Detection

Acute vertebral body fractures

Ankle fracture

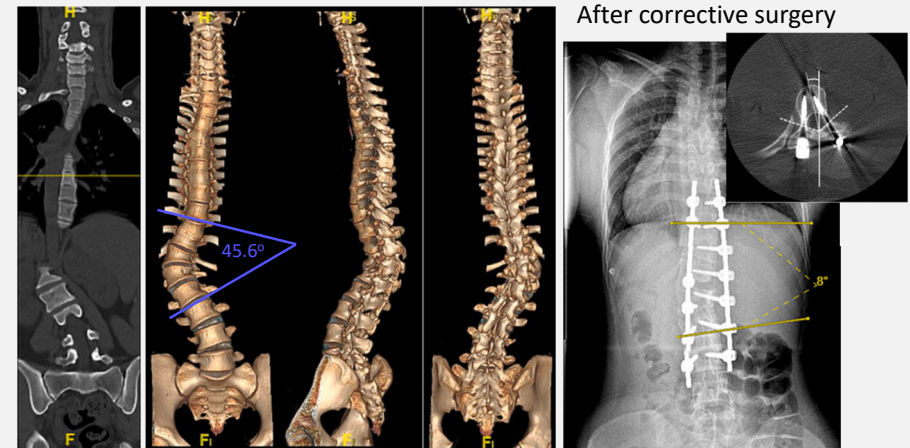https://www.frontiersin.org/journals/endocrinology/articles/10.3389/fendo.2023.1132725/full
https://www.researchgate.net/figure/D-CT-scan-a-3D-Volume-rendering-b-3D-Printed-Replica-of-an-ankle-fracture-with_fig6_307615840

CT in Congenital Scoliosis

After corrective surgery

45.6°

重點回顧

- CT數值(HU)是以組織與水的衰減係數對比來表現。
- 空氣之CT數值約為-1000 HU，水為0 HU。
- 選擇適合觀察目標組織的window，將有助於病灶偵測。
- CT影像會因為造影條件、移動、金屬、植入物而產生各類型之假影(例如：streak artifacts, windmill artifacts,...)。
- CT用於神經學檢查，可幫助急重症診斷(水腦症、顱內出血、缺血性中風、血管瘤,...)。
- CT用於心血管檢查，可幫助冠狀動脈狹窄與鈣化分數的評估，有效協助治療。
- CT用於骨科學檢查，可幫助骨頭、脊柱、關節等的診斷與治療。

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