2020 NCC 의학물리 아카데미 교육프로그램

Physics of CT Clinical Applications

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Specifications & Performances of CT

Parameters deciding the specifications and performances of x-ray CT modality are closely related to each other, and are various.

Scan time: short scan time is required to reduce the artifacts by patient's movement, digestives canal's movement, respiration etc.
Full scan (one rotation of gantry): 0.5 ~ 5 sec.
Image reconstruction time: 2 ~ 10 sec.
Imaging width: 240 mm for head, 400 mm for chest/abdomen.
Slice thickness: in general, 1-10 mm slice thickness, 1-2 mm slice thickness for ear's small bone, head blood vessel, or 3 D image processing.

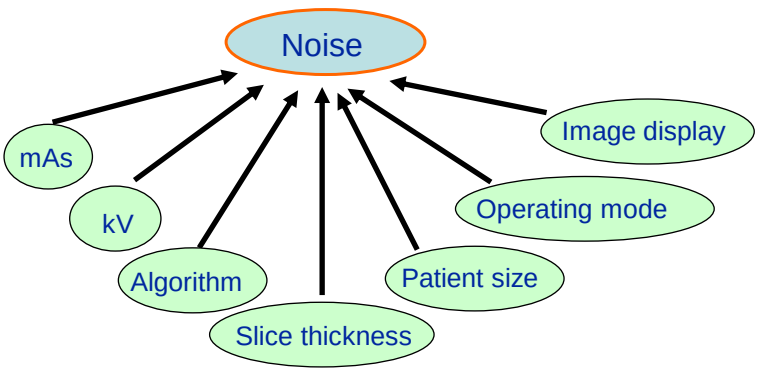
Acquisition Operating Parameters

Through-put: Number of examination per hour → indicate the ability of scan processing.

Exposure dose: Ex: abdomen scanning conditions: (120 kV, 200 mA, 2 sec, 100 mm slice, ϕ 320 mm phantom) 21 mGy at the center of phantom, 35 mGy at the peripheral of phantom.

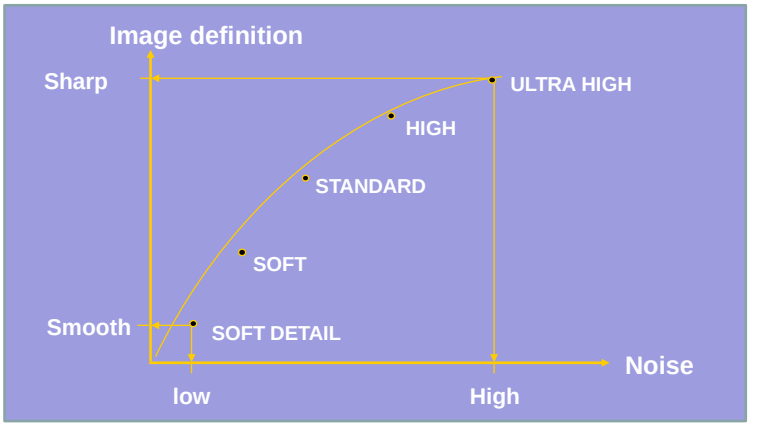
Image Noise

Image **"noise"** is determined
by the number of x-ray quanta that reach the detector
and then contribute to the image.
It depends on:



Reconstruction Algorithms

Provide the recipe for mathematical image calculation



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Reconstruction Algorithms

- An edge-enhancing (HighRes) algorithm produces good edge definition, but also a high noise level.
- A smoothing algorithm produces a low noise level, but also poorer edge definition.
- For routine studies, a standard algorithm is normally recommended.

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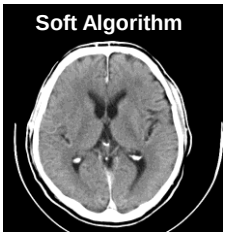
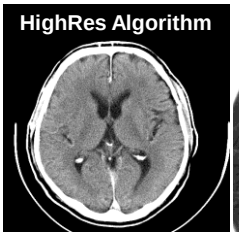
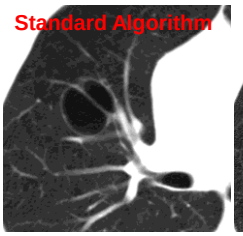
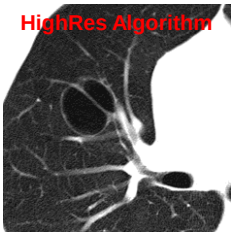
Algorithm Effects









Soft algorithms provide better contrast detectability with less noise.	HighRes algorithms provide better spatial resolution, but with more noise.

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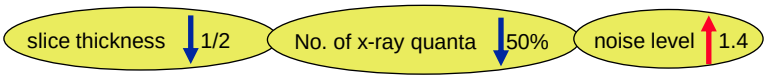
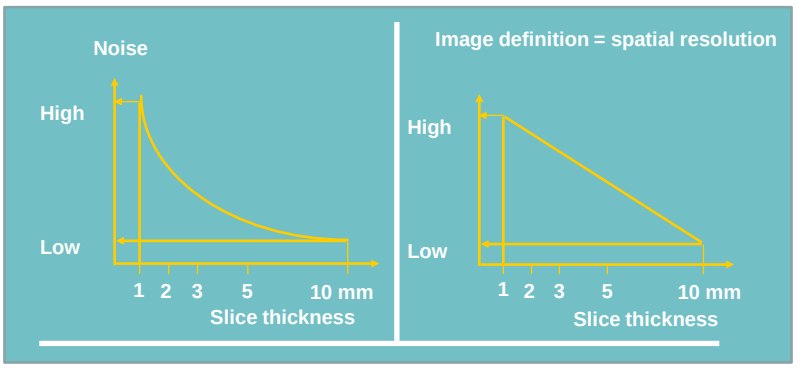
Slice Thickness





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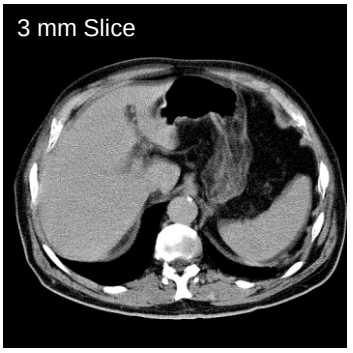
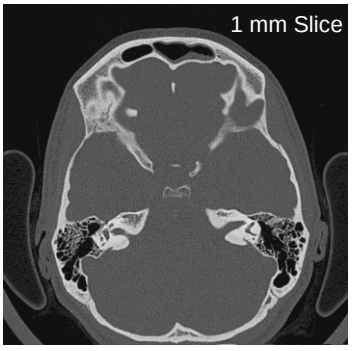
Effect of Slice Thickness



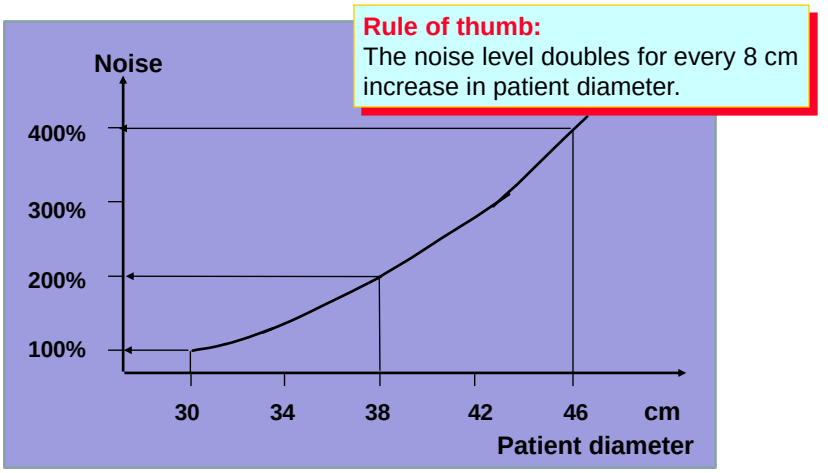
Thicker slices give less noise & better contrast detectability for soft tissue

Effect of Slice Thickness



Thinner slices give better spatial resolution for bony structures.

Patient Size



Rule of thumb:
The noise level doubles for every 8 cm increase in patient diameter.

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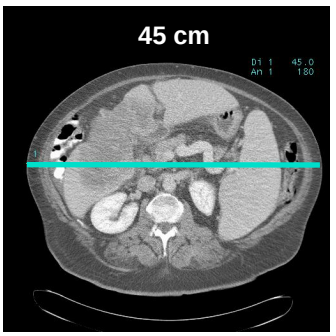
Patient Size

An attenuation by a factor of 2 results from each 4 cm increase in patient thickness
→ thus increasing the pixel noise.



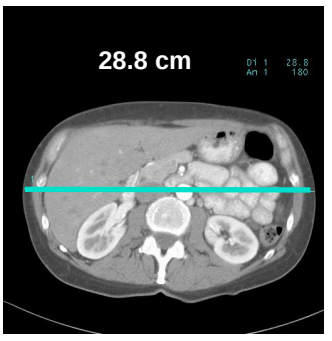


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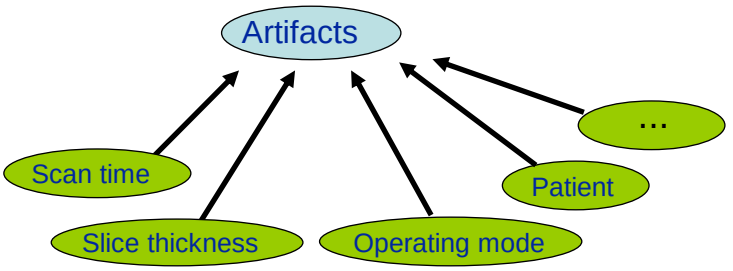
Image Artifacts

The various structures or patterns that appear in a CT image, but are not found in the original object. They depend on:



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Selecting Slice Thickness

Selecting a suitable slice thickness is a balance between edge definition and noise because of their mutually offsetting effects.

A thick slice means:

- **low noise**
- **better contrast resolution**
- poorer edge definition
- partial volume artifacts

A thin slice means:

- high noise
- poorer contrast resolution
- **better edge definition**
- **no partial volume artifacts**

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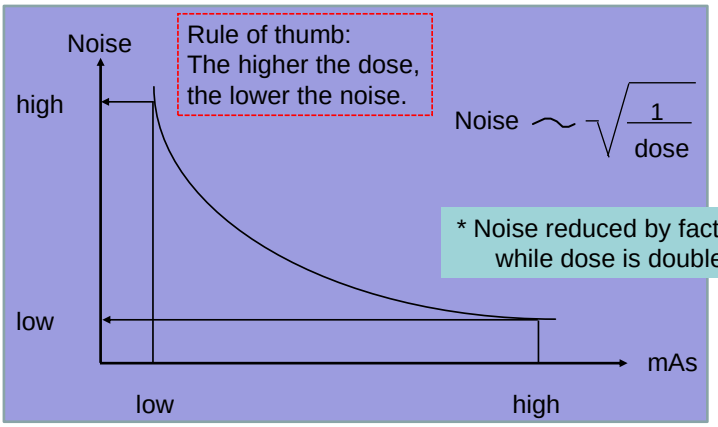
mAs and Noise

Tube current and scan time determine dose.



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mAs and Noise

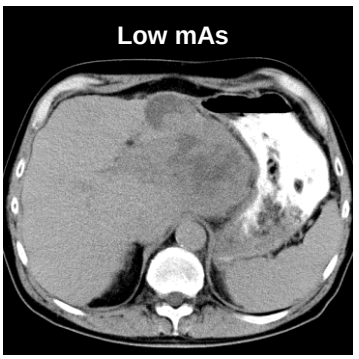

Image 1:
Low mAs value -
high noise level

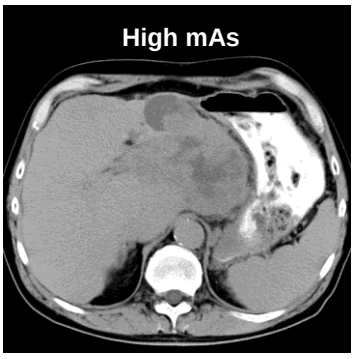

Image 2:
4 times the mAs value-
half the noise level

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Recommendations for mAs

- In the case of a soft tissue study, it is most important to keep noise to a minimum by using higher mAs.
- The lower the noise level, the easier it is to recognize structures with minute differences in density.
- But for bone or lung studies, higher mAs is not necessary.

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CT Image Viewing

General CT Image	CT Angiography

Axial View Image

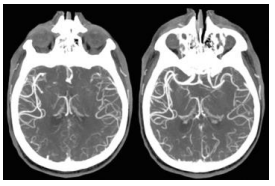
Maximum Intensity Projection

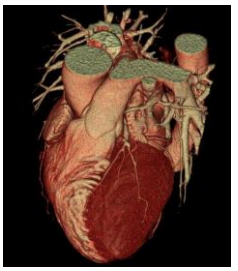
Minimum Intensity Projection

Multi Planner Reconstruction

CT Cine

3 D Visualization





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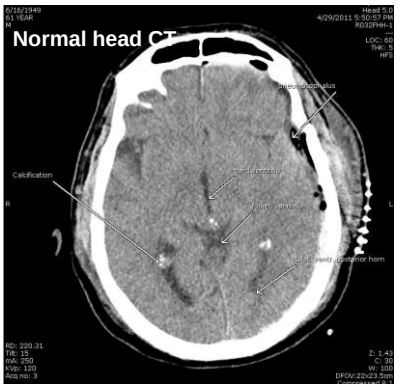
Viewing Normal CT Images



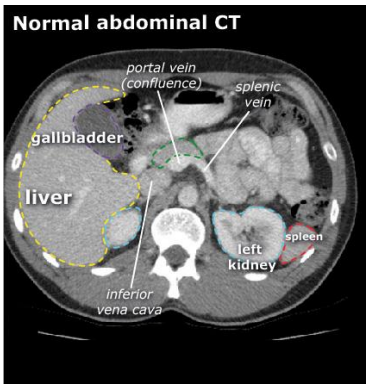


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Image Display - Windowing

Window width (W):

Density range represented within the gray scale

Window center (C):

Center of the density range

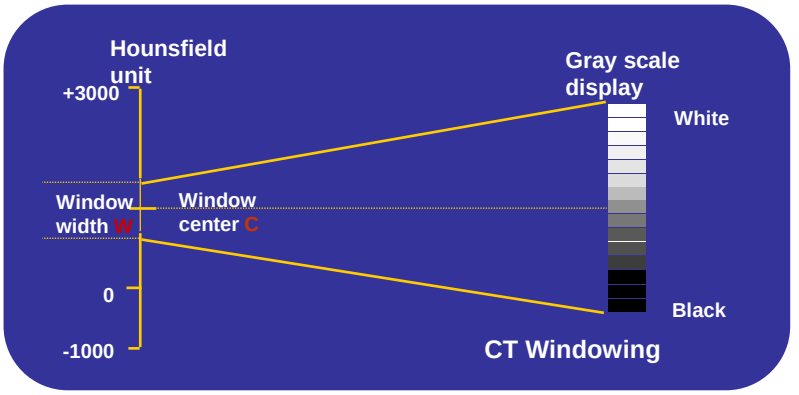

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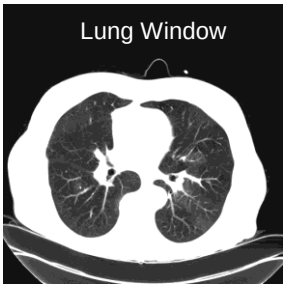
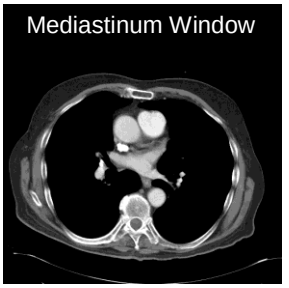
Image Display - Windowing

The range of CT density values is defined from -1000 to +3000, but the human eye can distinguish only 30 - 40 gray scales at best.





So, the window settings must be in accordance with the structures to be visualized

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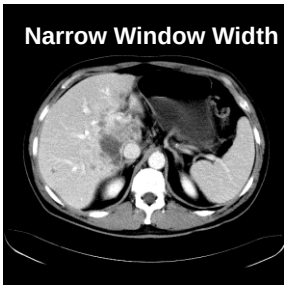
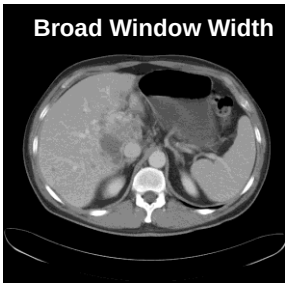
Image Display - Windowing





Narrow window width:
High-contrast image, but structures outside that window range may be inadequately represented or overlooked.

Broad window width:
Minor density differences appear homogeneous and may be masked.

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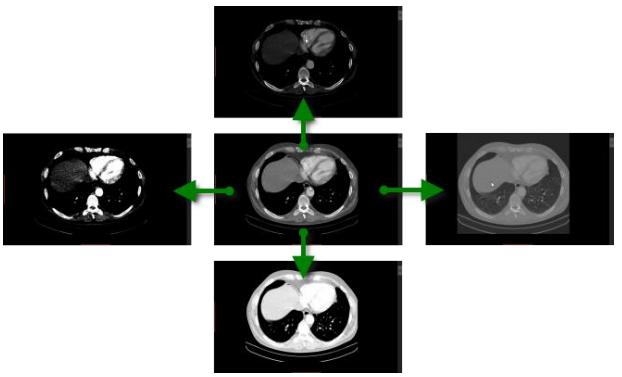
Adjust CT Image



- Up to decrease brightness (window level goes up)
- Down to increase brightness (window level goes down)
- Left to increase contrast (window width shrinks)
- Right to decrease contrast (window width expands)

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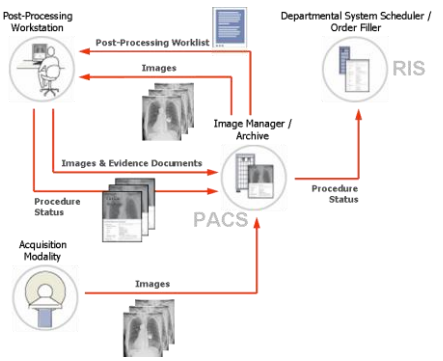
Image Processing Workstation



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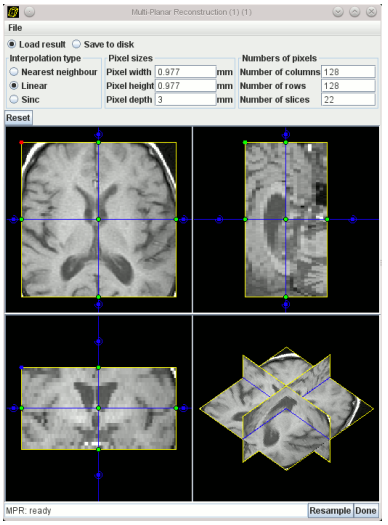
MPR (Multi Planar Reconstruction)

- From the 3D reconstruction of a sequence of tomography images, the MPR display can be used to generate interactive slices in Cartesian planes (axial, sagittal, and coronal), or even in free, oblique planes.
- This means the doctor can obtain views of the patient's internal structures that provide greater clarification than the images from the original sequence.



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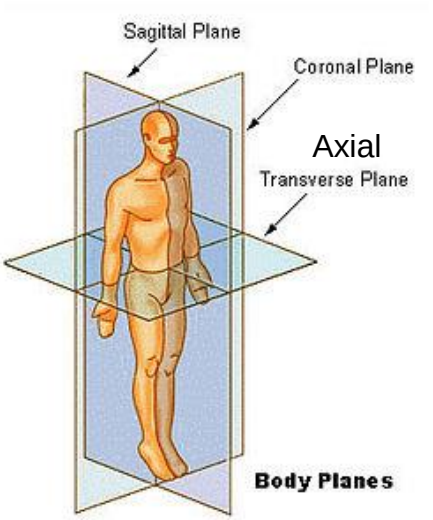
Body Planes



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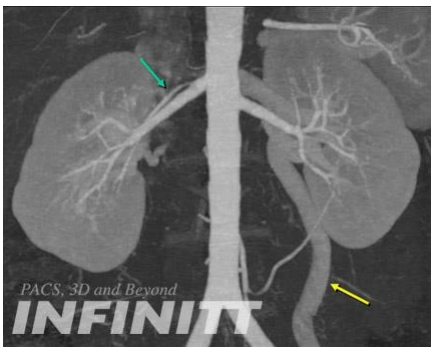
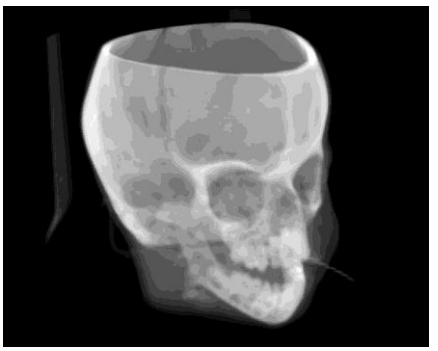
MIP (Maximum Intensity Projection)

- A method for 3D data that projects in the visualization plane the **voxels with maximum intensity** that fall in the way of parallel rays traced from the viewpoint to the plane of projection.





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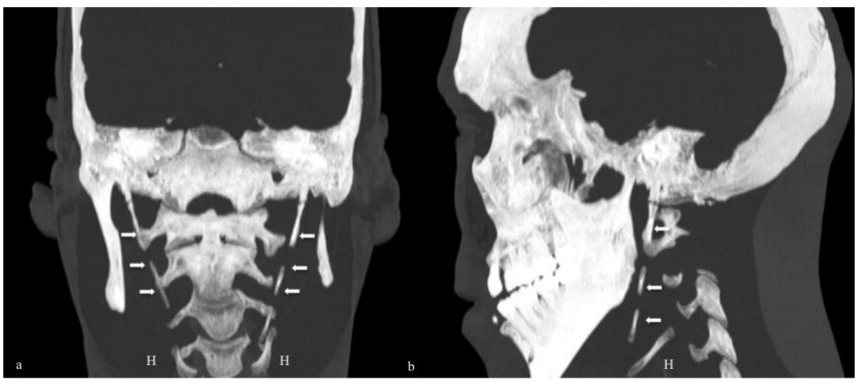
MIP (Maximum Intensity Projection)



CT coronal (a) and sagittal (b) CT view with Maximum Intensity Projection (MIP) reconstructions show bilateral elongated styloid process with stylohyoid ligament ossi cation (white arrows) extending from the base of the hyoid bone (H).

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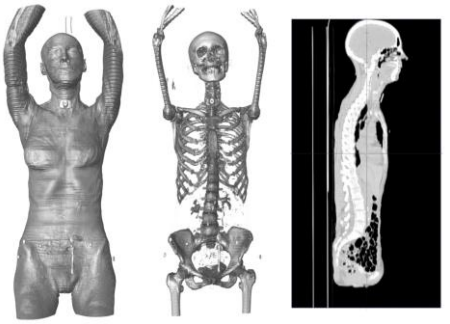
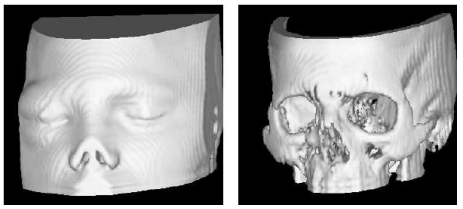
Surface Rendering

Surface rendering of human head CT data, corresponding to (a) skin and (b) skull.





Surface rendering of human head CT data, corresponding to (a) skin and (b) skull.

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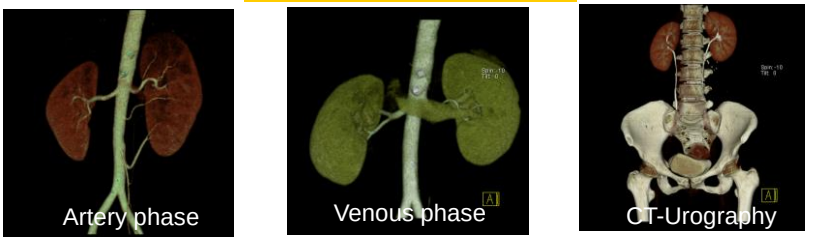
3D Viewing in MDCT

Extremity

Renal Transplantation



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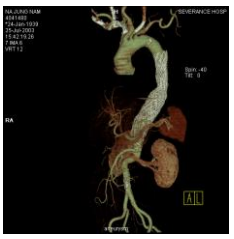
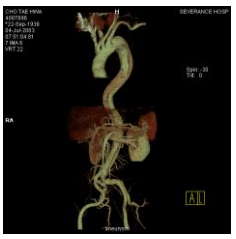
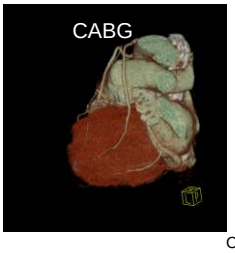
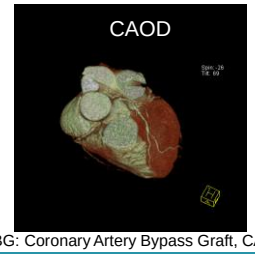
3D Viewing in MDCT

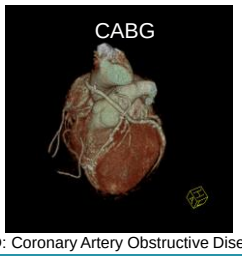
Aortic Dissection


Heart







CABG: Coronary Artery Bypass Graft, CAOD: Coronary Artery Obstructive Disease

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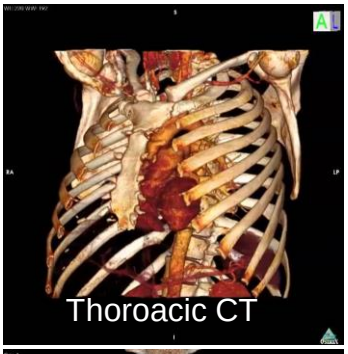
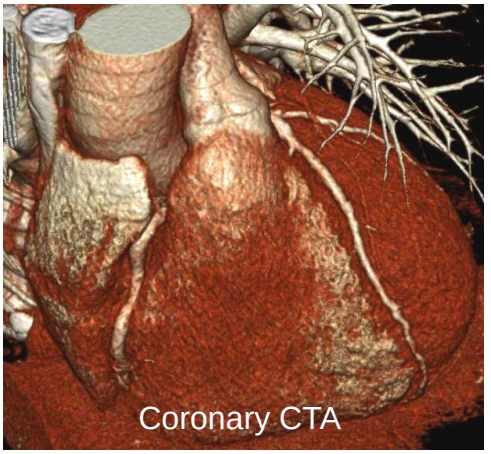
3D Volume Rendering





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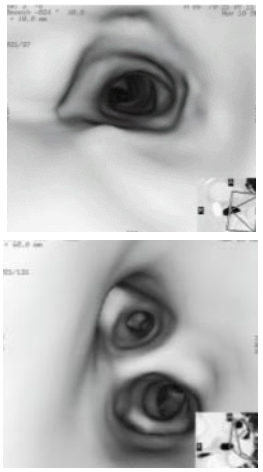
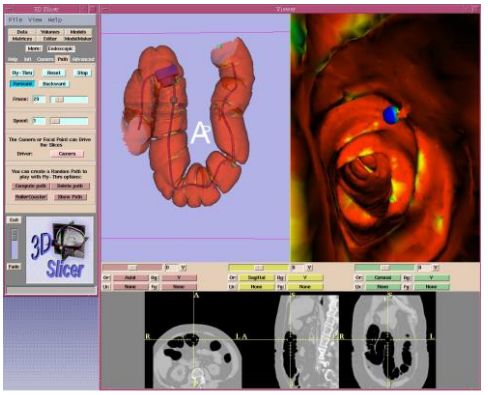
3D - Virtual Bronchoscopy & Endoscopy





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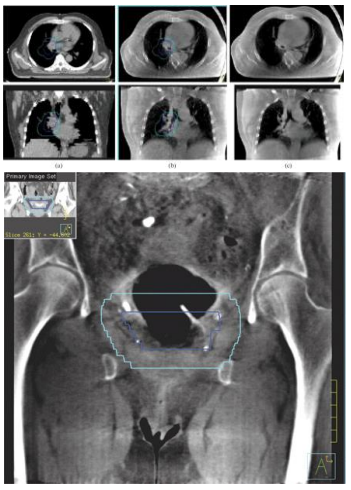
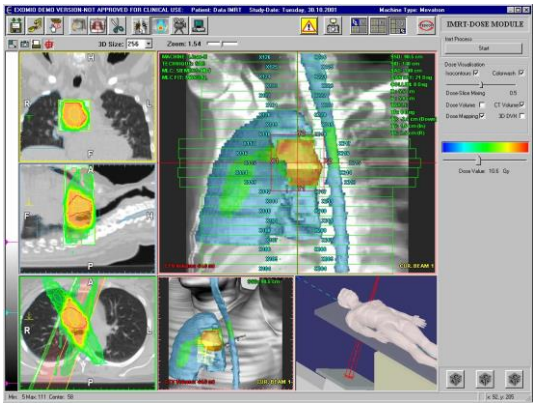
Radiation Therapy Planning (RTP)





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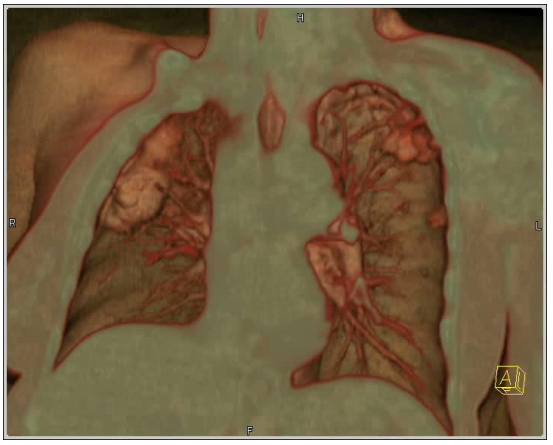
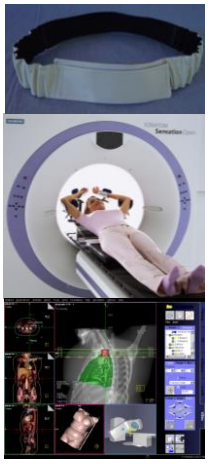
MDCT in Radiation Oncology

Respiratory Gating for Therapy Planning





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Radiation Dose from CT

Diagnostic Procedure	Typical Effective Dose (mSv)[1]	Number of Chest X rays (PA film) for Equivalent Effective Dose[2]	Time Period for Equivalent Effective Dose from Natural Background Radiation[3]
Chest x ray (PA film)	0.02	1	2.4 days
Skull x ray	0.07	4	8.5 days
Lumbar spine	1.3	65	158 days
I.V. urogram	2.5	125	304 days
Upper G.I. exam	3.0	150	1.0 year
Barium enema	7.0	350	2.3 years
CT head	2.0	100	243 days
CT abdomen	10.0	500	3.3 years

1. Effective dose in millisieverts (mSv).

2. Based on the assumption of an average "effective dose" from chest x ray (PA film) of 0.02 mSv.

3. Based on the assumption of an average "effective dose" from natural background radiation of 3 mSv per year in the United States.

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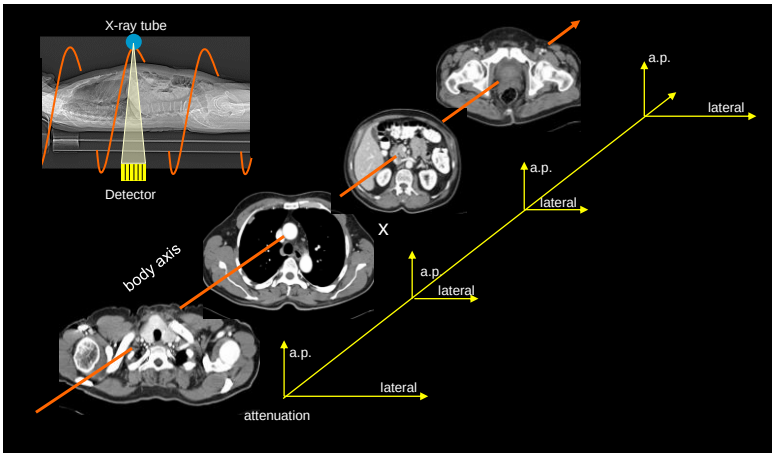
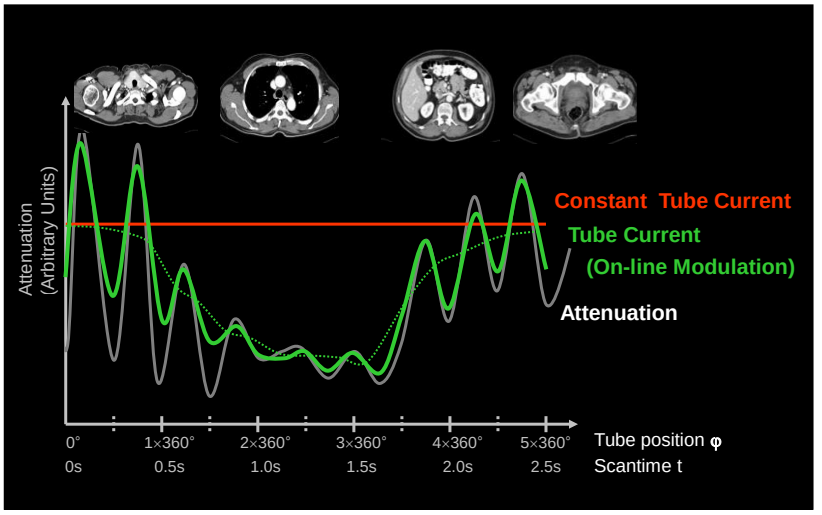
Advanced Dose Reduction Techniques
Anatomical Dose Modulation

Strong variation of attenuation for different body regions and different projection angles (a.p. / lateral).



37

Advanced Dose Reduction Techniques
Anatomical Dose Modulation



38

Low-dose CT

- Using a variety of techniques, including adjusting the **radiation dose based on patient size** and **new software technology**, the amount of radiation needed to perform a chest CT scan can be significantly reduced.
- A low-dose spiral chest CT scan is different from a regular CT scan in only a few ways.
- The main difference is the amount of radiation emitted, which is over **five times lower in a low-dose CT scan** than that absorbed during a full-dose CT scan.
- This difference is very important in testing as radiation should always be avoided as much as possible.

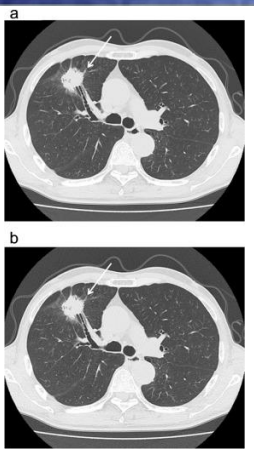
39

Low-dose CT

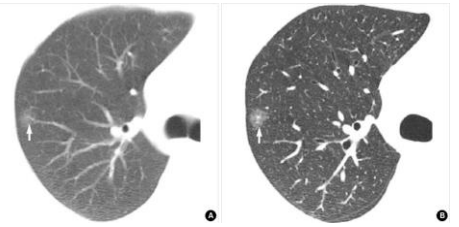
- Low-dose CT scans are generally used only on people with a very high-risk of developing or having lung cancer since the margin of error is usually too great with people who are low-risk, often resulting in more tests than necessary.

40

Low-dose CT Chest Images



(**a, standard dose image; b, low dose image**) 75 year-old-male (body weight 46 kg) who had a chest CT examination for a suspected lung tumor in the right upper lobe. Visualization of a tumor with partially irregular margin and spicula (arrow) is clear in both images.



A 48-yr-old man with adenocarcinoma. (A) Lung window of initial screening low-dose CT scan obtained at level of right upper lobar bronchus shows 10-mm-sized ground-glass opacity nodule (arrow) in right upper lobe. (B) Lung window of thin-section (2.5-mm thickness) CT scan obtained at similar level to A shows clearly ground-glass opacity nature of nodule (arrow). Right upper lobectomy disclosed adenocarcinoma.

41

Cine

A stationary volume scanning mode in planar geometry with patient being consecutively scanned in space and continuously in time.

Cardiac CT cine clip demonstrating multiple embedded bullet fragments.

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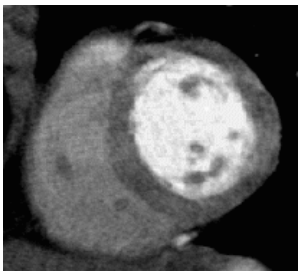
CT Cine



- Cine image is sequentially displayed continuous slice images on display device with 3-D data as like a movie.
- It is easy to distinguish difference between each slices images, and to observe the shape of organ and working of blood vessel, because slice images were continuously reviewed.

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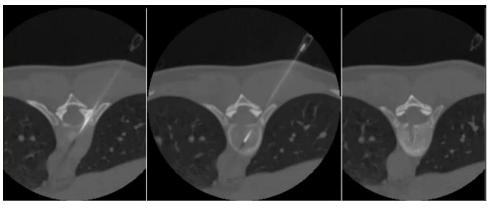
CT Fluoroscopy

- Realtime continuous observation is become available during scans as like x-ray fluoroscopy according to the realization of high speed image reconstruction.



SUREFluoro™ technology provided by AVMI's new Toshiba PRIME 80 slice CT scanner allows real time image guided biopsy of the most hard to reach areas

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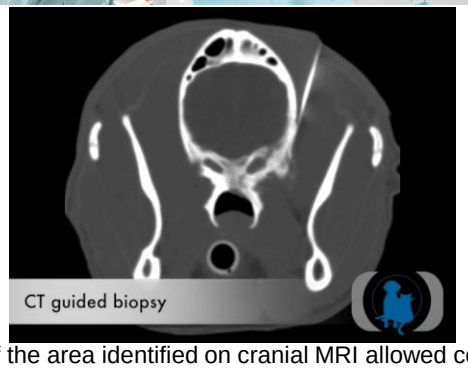
CT Fluoroscopy Guided Biopsy



CT guided biopsy of the area identified on cranial MRI allowed confident collection of representative tissue that resulted in a firm diagnosis of cryptococcosis infection.

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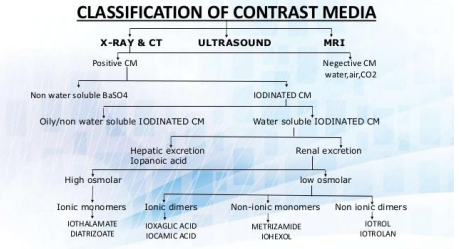
CT Contrast Media

CT contrast agent injector



- In general, CT contrast media is the **colorless and transparent iodine compounds**.
- In one CT exam, the amount of approximately 100 - 150 cc is injected to a vein at the speed rate of 2-3 cc per a second.

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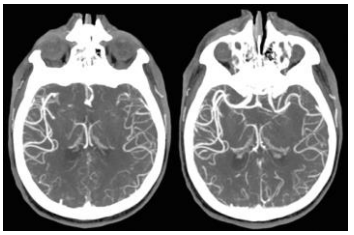
CT Angiography (CTA)



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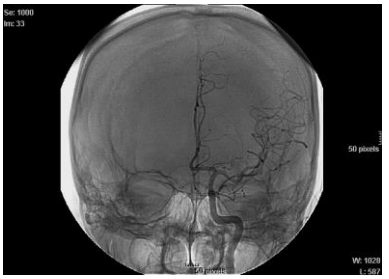
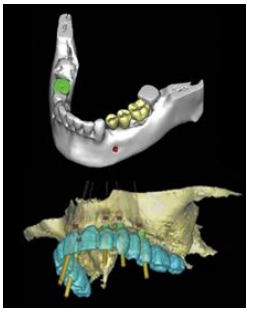
CT Angiography (CTA)

CTA: CT Angiography



48

Dental CT



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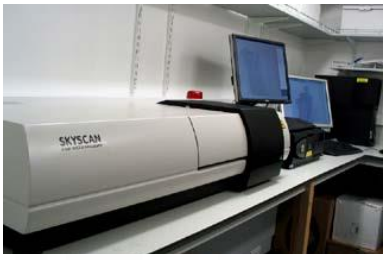
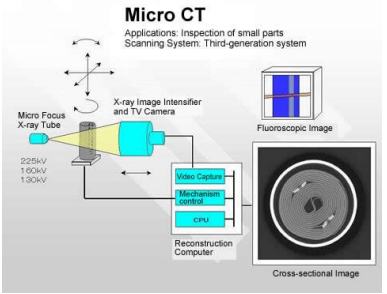
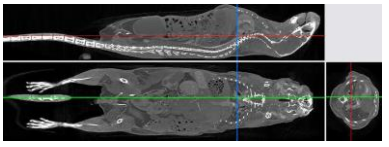
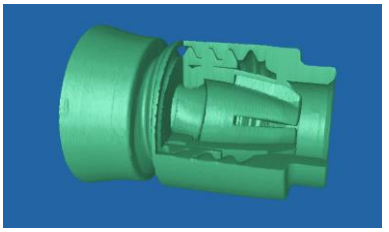
Micro CT









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Portable & Mobile CT

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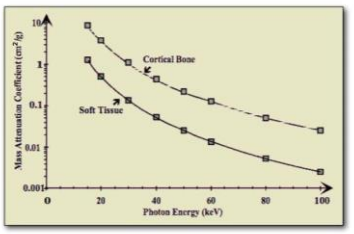
Dual Energy Radiography

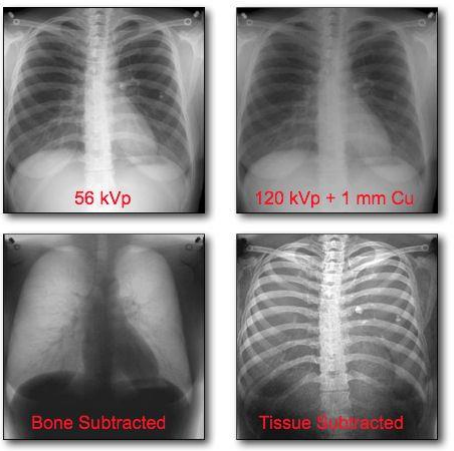


Energy dependence of the mass attenuation coefficients of soft tissue and cortical bone

$$I_{lo} = \mu_{tlo}\, x_t + \mu_{blo}\, x_b$$

$$I_{hi} = \mu_{thi}\, x_t + \mu_{bhi}\, x_b$$

(DEXA): Dual Energy X-ray Absorptionmetry



Dual-energy images: A low and a high energy chest radiograph are shown in the top row, above the results for energy processing.

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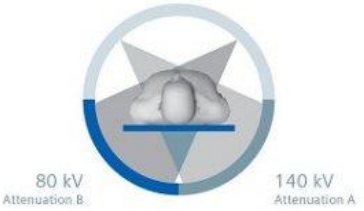
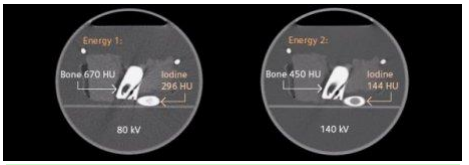
Dual Energy CT





Changing the tube's kilo voltage results in a material-specific change of attenuation.

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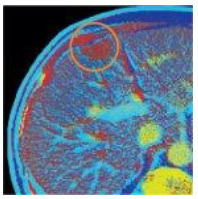
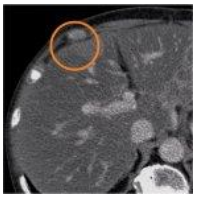
Spiral Dual Energy CT

Spiral Dual Energy exploits this effect:

- Two X-ray sources running simultaneously at different energies acquire two data sets showing different attenuation levels.
- In the resulting images, the material-specific difference in attenuation enables an easy classification of the elementary chemical composition of the scanned tissue.
- In addition, a fused image is provided for initial diagnosis.





Dual Source CT: enables easy tissue differentiate,
Single source CT: insufficient information makes diagnosis difficult

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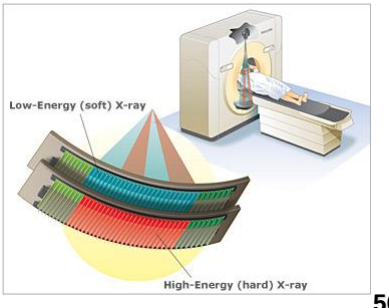
Dual Energy CT

Siemens Dual Energy Imaging (SOMATOM Definition Edge CT)

55

Spectral CT

- Spectral CT can already facilitate better discrimination of tissues, making it easier to differentiate between materials, such as tissues containing calcium and iodine, that can appear similar on traditional, monochromatic CT techniques.
- It also can potentially increase diagnostic accuracy in a wide range of clinical applications, such as enhancing the conspicuity and detection of smaller vessels associated with sub-segmental pulmonary emboli.



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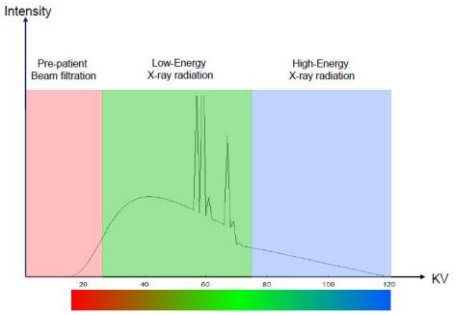
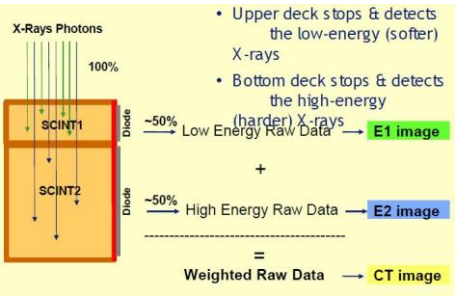
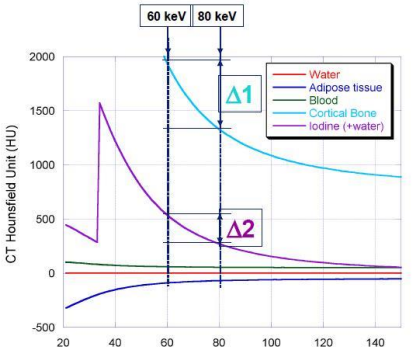
Spectral CT

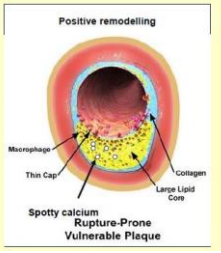


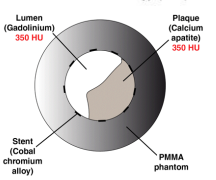


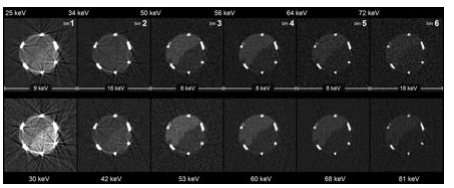
Spectral CT



Visualization of lipid components & determination of the calcification pattern are potential targets of Spectral CT







Spectral Detector CT

Philips Introduces IQon, World's First Spectral Detector CT at RSNA 2013.

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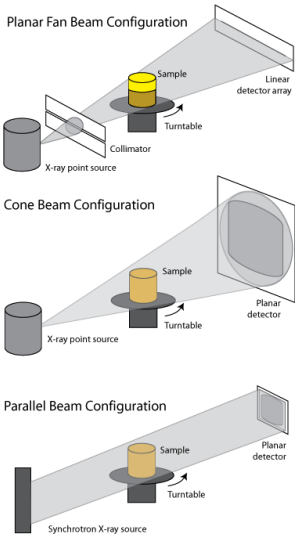
Corn Beam CT



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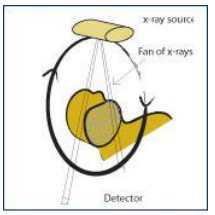
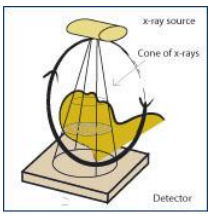
Cone Beam CT (CBCT)

- A single rotation around the patient produces a complete 3D volumetric data set.
- 1 rotation / 1 min. (500-1000 projections).
- More projections leads to higher-quality CT images.



Fan Beam



Cone Beam

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Commercial CBCT

Elekta Synergy™
kV CBCT

Siemens Artiste™
kV/MV CBCT

Varian Triology™/iX™
kV CBCT

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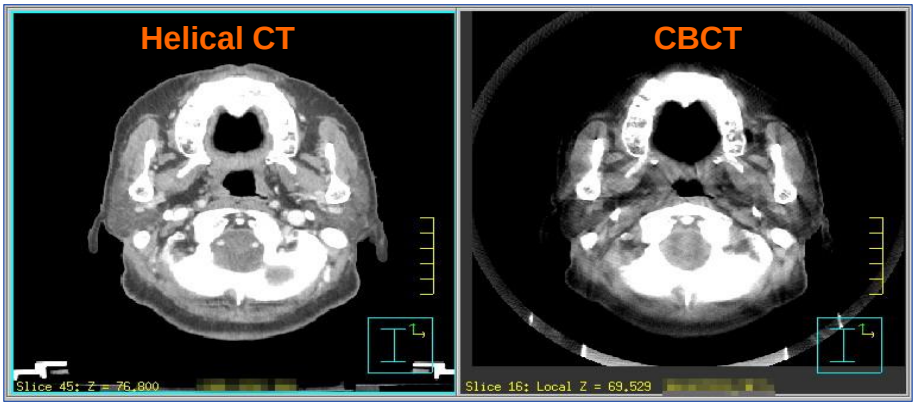
CBCT images (Head & Neck)



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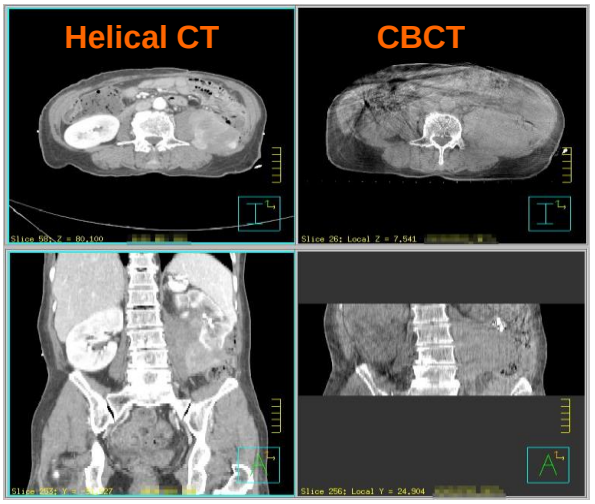
CBCT images (Abdomen)



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3D/3D Matching using CBCT

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Challenges in using CBCT

- Aditional 10-15 min. for CBCT. (Daily CBCT might not be efficient for 30-45 fractions.
- Off-line retrospective is not abailable. (Physician/Residnet should be present at the time of CBCT acquisition.)
- Additional dose to patients. (2 – 8 cGy)
- Image quality is not compatible to CT.

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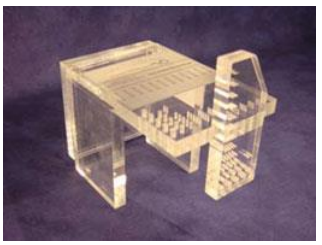
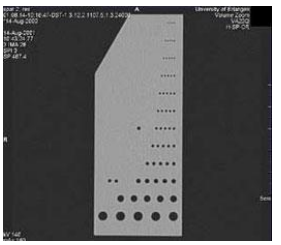
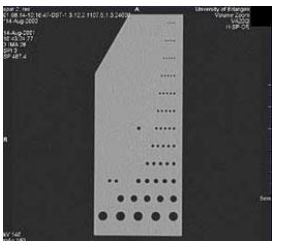
Spatial Resolution of CT

- CT spatial resolution means the ability of object discrimination in a image having the big different absorption coefficient between one object and its surroundings.
- The factors to decide spatial resolution are sampling pitch, area of x-ray focal spot, image reconstruction function which were fixed according to the width of detector.

The 3D High Contrast Resolution Phantom is used to evaluate the resolution of CT scanner in x-y-plane as well as in z-y plane. It offers resolution tests from 1.25 lp/cm to 12.5 lp/cm in both planes.

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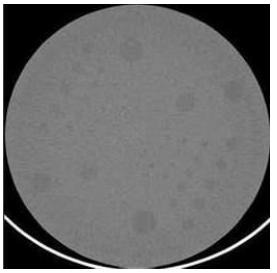
Contrast Resolution of CT

- Image noise is mostly caused by photon noise included in the intrinsic incident x-rays, the magnitude of noise is expressed by the standard deviation CT value in region of interest.
- Contrast resolution is called low contrast resolution, usually, it is appeared as product of detection possible size (mm) and % contrast.



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CT Performance Phantoms

CT Performance Phantom

ACR CT Phantom

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THANK
YOU