Lecture 6 –X ray Imaging Application

This lecture will cover:

- Digital Subtraction Imaging (*CH2.9-2.10.1*)
    - X-ray contrast agents
    - Digital Subtraction Angiography
    - Dual-energy Subtraction
- Specialized X-ray imaging techniques (*CH2.10.2-2.10.3*)
    - Digital Fluoroscopy
    - Digital mammography
- Clinical applications

(*Supplementary reading: The Essential Physics of Medical Imaging CH7.11, CH8-9*)

Contrast agent (造影对比剂)

Referring to the chemical substance introduced into the body

- Orally or injected into the bloodstream;
- Accumulated in a particular organ or structures
- Enhance the contrast between the structure and surrounding tissue
- Used in X-ray, Ultrasound, MRI, entirely for nuclear medicine
- Provide maximum contrast for the minimum administered dose
- Adverse side-effect: give the maximum contrast for the minimum administered dose

X-ray Contrast agent

- Efficient at absorbing X-ray — strong contribution from photoelectric interaction
- Two classes of X-ray contrast agent
  - Gastrointestinal (GI) tract (胃肠道疾病)
    - ✓ Orally, rectally, nasal cannula
  - Iodine-based agent
    - ✓ Water-soluble iodinated compounds (水溶性碘化物)
    - ✓ Injected into the bloodstream
    - ✓ For visualization of vasculature

Agent for the GI tract

- Barium sulphate (硫酸钡)
- Orally (upper GI tract), rectally(lower GI tract), nasal cannula
- With agent — white; without agent (low absorption) — dark

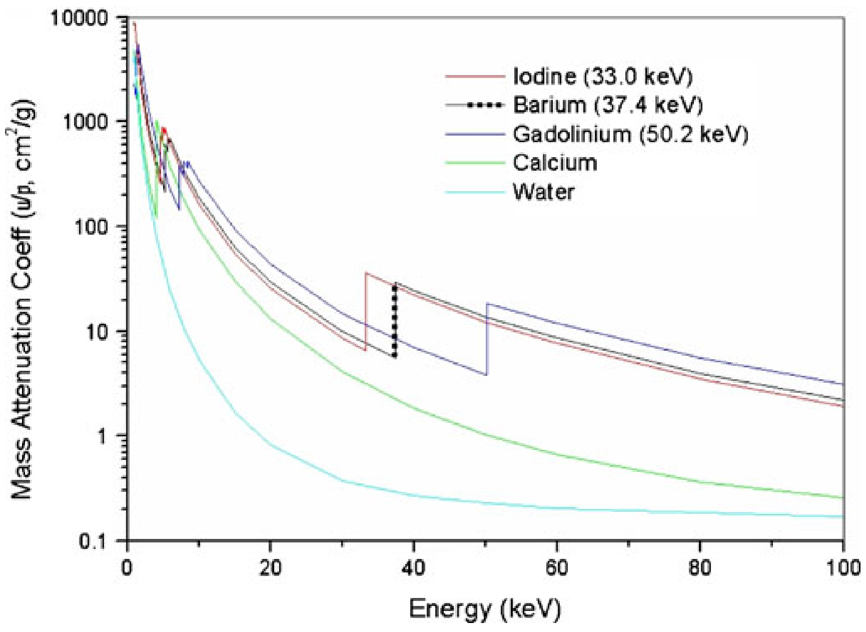


Figure. The mass attenuation coefficient of Iodine, Barium sulphate, and Gadolinium as a function of X-ray energy.

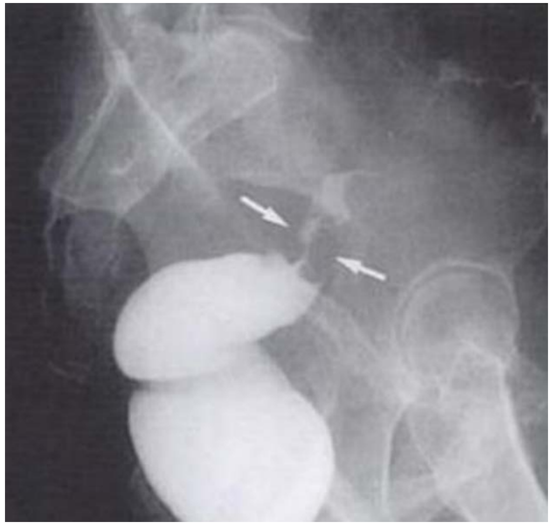
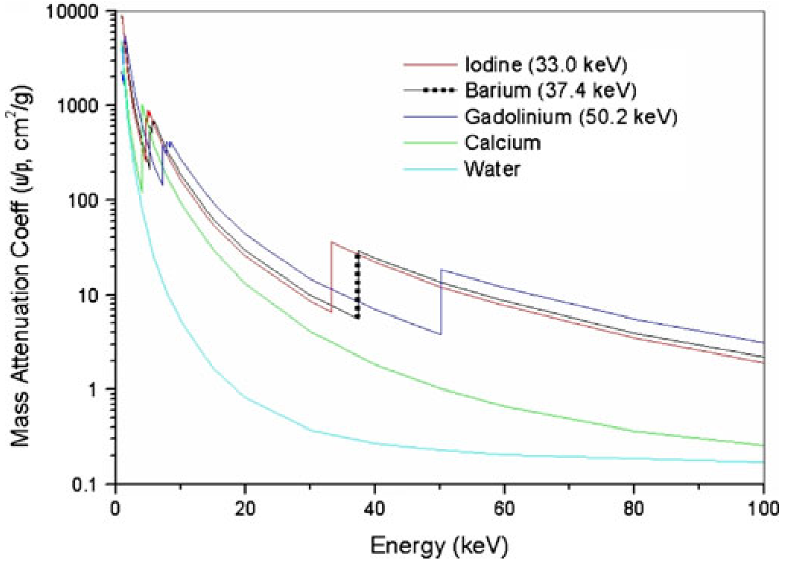


Figure. A barium sulphate enhanced image of the colon shows an adenocarcinoma (white arrows). The high attenuation of the barium sulphate produces a very high (white) image intensity.

Iodine-based contrast agent

- Iodine: K-shell binding energy 33.2 KeV
- Small vessel of ~50μm diameter to be detected
- Lowest dose applied to minimize the side-effect



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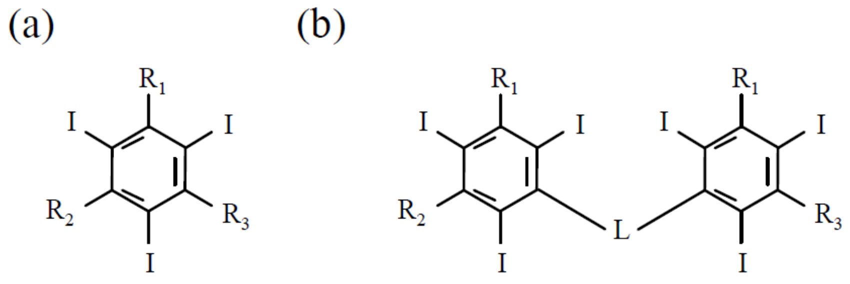

$R1=R2=R3= CONHCH_2CH(OH)CH_2OH$

$L=N(COCH_3)CH_2CH(OH)CH_2N(COCH_3)$

Figure. (a) Generic formula for a monomeric iodinated X-ray contrast agent. The side-groups R1, R2 and R3 can all be the same or different. (b) Generic form of a dimeric agent, in which the two benzene rings are joined by a chemical linker (L). The chemical structure of iodixanol, which is both iso-osmolar with blood and also non-ionic, is shown.

Digital Subtraction Angiography

Digital Subtraction Angiography (DSA, 数字减影血管造影):

- High resolution images of the vasculature
- Subtraction image between a regular image and an image acquired by injecting with Iodine-based contrast agent

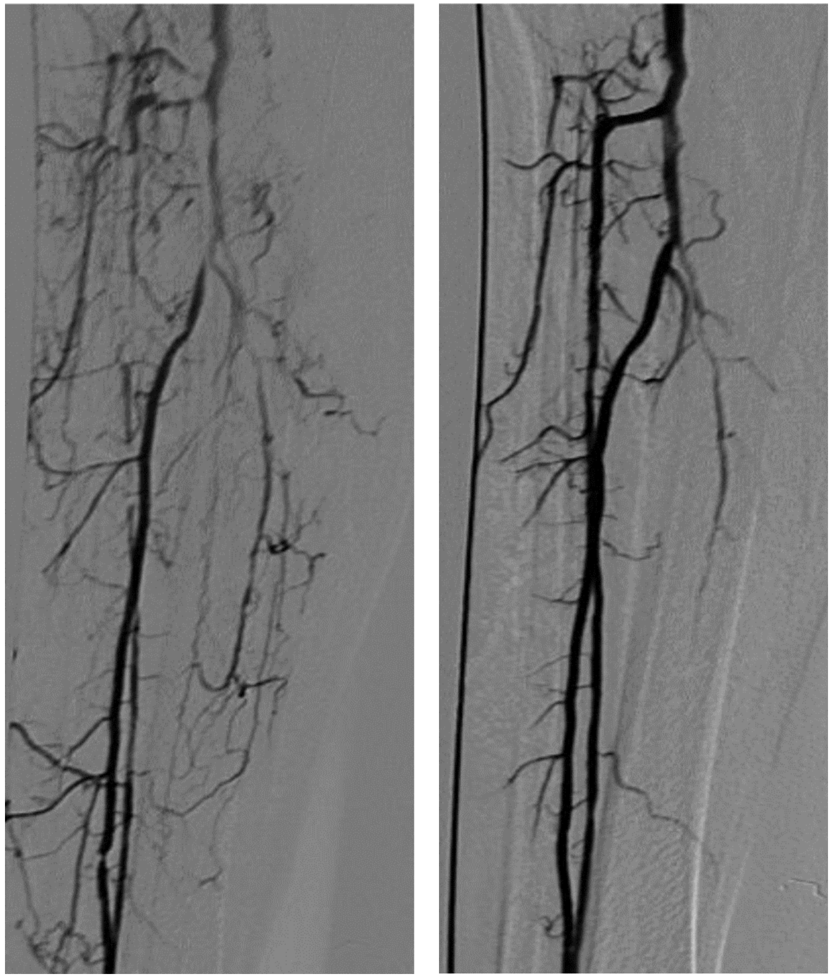

Figure. Digital subtraction angiograms showing fine vessel structures. The vessels containing iodinated contrast agent are shown as dark areas in the subtraction images

Digital Subtraction Angiography

The regular image:

$$I = I_0 e^{-(\mu_B d_B + \mu_T d_T)}$$

The injection image:

$$I_1 = I_0 e^{-[\mu_B d_B + \mu_T (d_T - d_I) + \mu_I d_I]}$$

The subtraction image

$$\ln I - \ln I_1 = (\mu_I - \mu_T) d_I$$

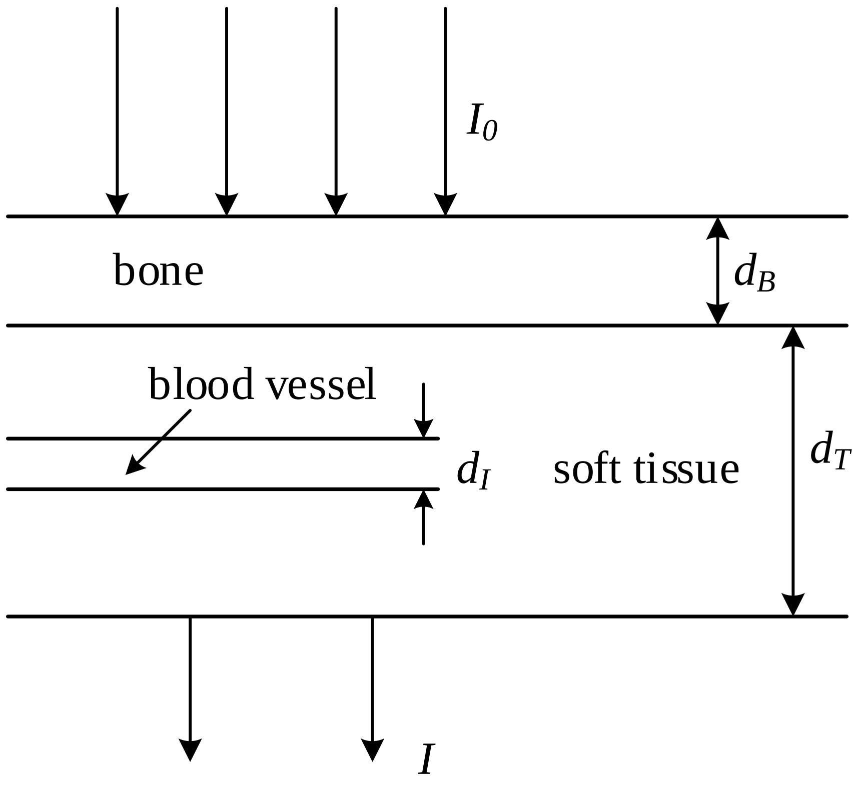

Figure. The schematic diagram of subtraction imaging.

Digital Subtraction Angiography

The subtraction image can be acquired

- **By sequencing**
  1. The mask (掩模、蒙片) image at t=0
  2. Producing images of the same area at a set rate (1 to 7.5 frames per second)
  3. Finding the subtraction image with the highest contrast.
- **By energy**
  - **K-edge**: acquire two images at lower and higher K-shell energy (33KeV) of iodine
  - **Dual energy**: subtract bone or soft tissue effect
- **By combination of sequencing and energy**

Dual-energy Subtraction

For lower energy:

$$\ln I_L = \ln I_{0L} - (\mu_{BL} d_B + \mu_{TL} d_T)$$

For higher energy:

$$\ln I_H = \ln I_{0H} - (\mu_{BH} d_B + \mu_{TH} d_T)$$

The subtraction image

$$\boldsymbol{S} = K_H \ln I_H - K_L \ln I_L$$

$$= K_H \ln I_{0H} - K_L \ln I_{0L} + (K_L \mu_{BL} - K_H \mu_{BH}) d_B + (K_L \mu_{TL} - K_H \mu_{TH}) d_T$$

- For bone subtraction: $\frac{K_H}{K_L} = \frac{\mu_{BL}}{\mu_{BH}}$
- For tissue subtraction: $\frac{K_H}{K_L} = \frac{\mu_{TL}}{\mu_{TH}}$

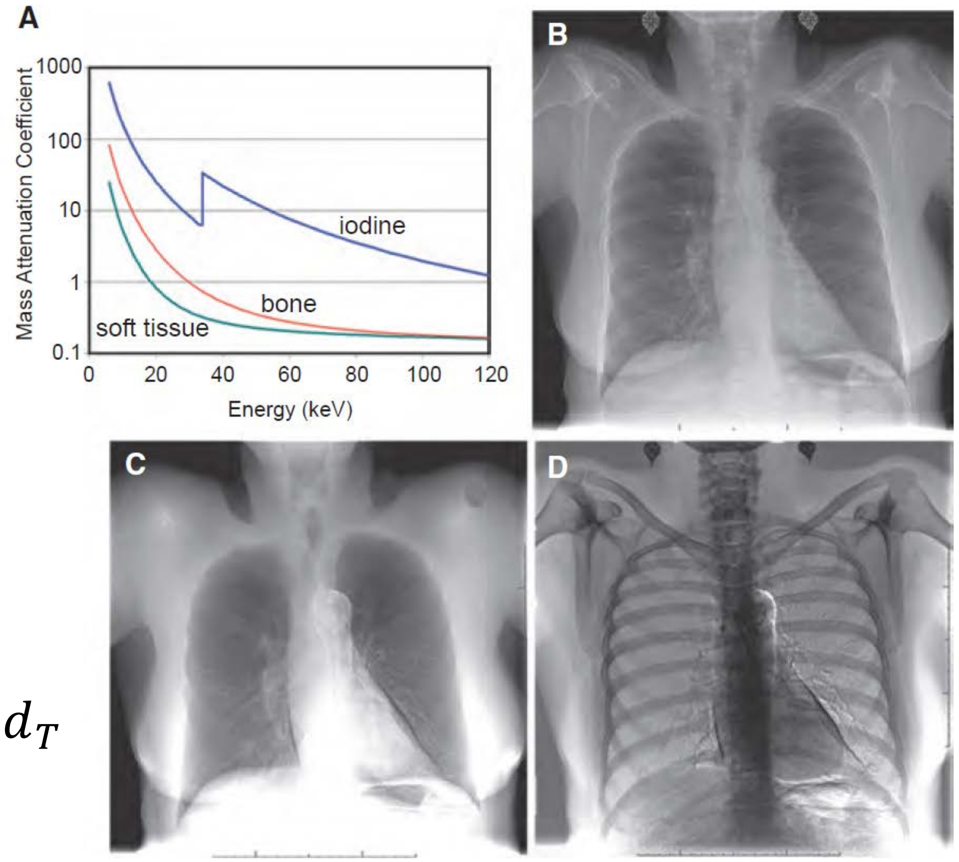

Figure. Dual-energy chest radiography is illustrated. A. The linear attenuation coefficients for soft tissue, bone, and iodine are shown. B. The single-energy (120 kV) radiograph is shown. C. The bone-subtracted, soft tissue–only image is illustrated. This image shows the lung parenchyma and mediastinum, which are the principal organs of interest on most chest radiographs. D. The soft tissue–subtracted, bone-only image is illustrated. Note that the earrings, which are made of metal and are more similar to bone than soft tissue in terms of composition, show up on the bone-only image.

Digital Subtraction Angiography

The subtraction image can be acquired

- **By combination of sequencing and energy**
  - Energy subtraction for soft tissue
  - Sequencing subtraction for hard tissue (bone)

I_{0L} : regular image from low energy

I_{0H} : regular image from high energy

I_{1L} : contrast image from low energy

I_{1H} : contrast image from high energy

S_{0T} : regular tissue subtraction image derived from I_{0L} and I_{0H}

S_{1T} : contrast tissue subtraction image derived from I_{1L} and I_{1H}

S : final subtraction image where $S = S_{0T} - S_{1T}$

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- **Specialized X-ray imaging techniques**
  - **Digital Fluoroscopy**
  - **Digital mammography**
- Clinical applications

Digital Fluoroscopy

Digital Fluoroscopy (荧光透视，数字透视):

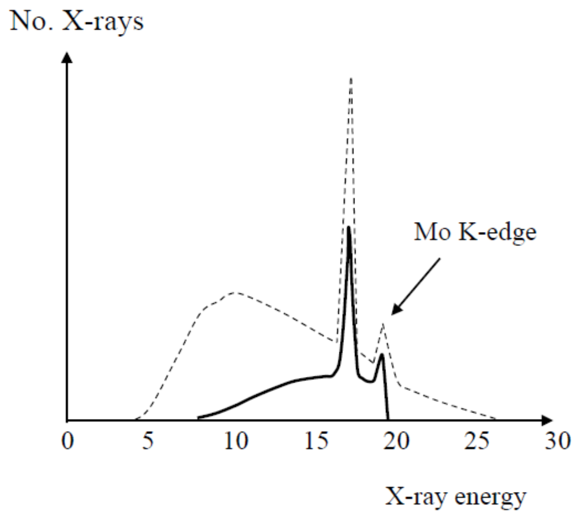
- ➢ Continuous X-ray imaging for monitoring interventional surgery or dynamic studies of contrast agent
- ➢ Minor modification of DR
  - Increase thickness of detector for higher detection efficiency
  - Short pulse of X-ray: ~5-20ms
  - 30 frame/second
  - Low dose for each frame, lower SNR and CNR

Figure. A neurointerventional unit, with a C-arm digital fluoroscopy unit.

Digital mammography

Digital mammography (乳腺X线摄影):

- ➢ Detecting small tumors or microcalcifications in breast
- ➢ Technique specification
  - High spatial resolution and CNR
  - Low radiation dose: Molybdenum anode (钼靶)
  - Small focal spot (≤0.3mm): (1) flat cathode (2) small bevel angle
  - Molybdenum filter: reduce high energy X-ray
  - Large focal-spot-to-detector distance (45-80cm)
  - Compression of breast during exam: to improve transmission and reduce Compton scatter.



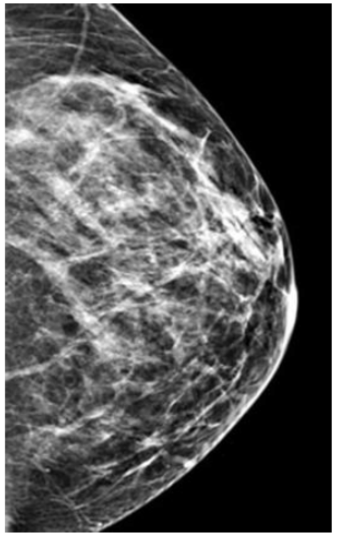


Figure. (Top) The X-ray spectrum used for digital mammography. The kVp of the X-ray tube is 26 keV. The anode is made from molybdenum and produces a substantial number of low energy X-rays (dashed line). A 30 μm thickness molybdenum filter is used to reduce the contribution from very low energy X rays (solid line). (Bottom) Example of a digital mammogram, showing very high spatial resolution.

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Bone fracture

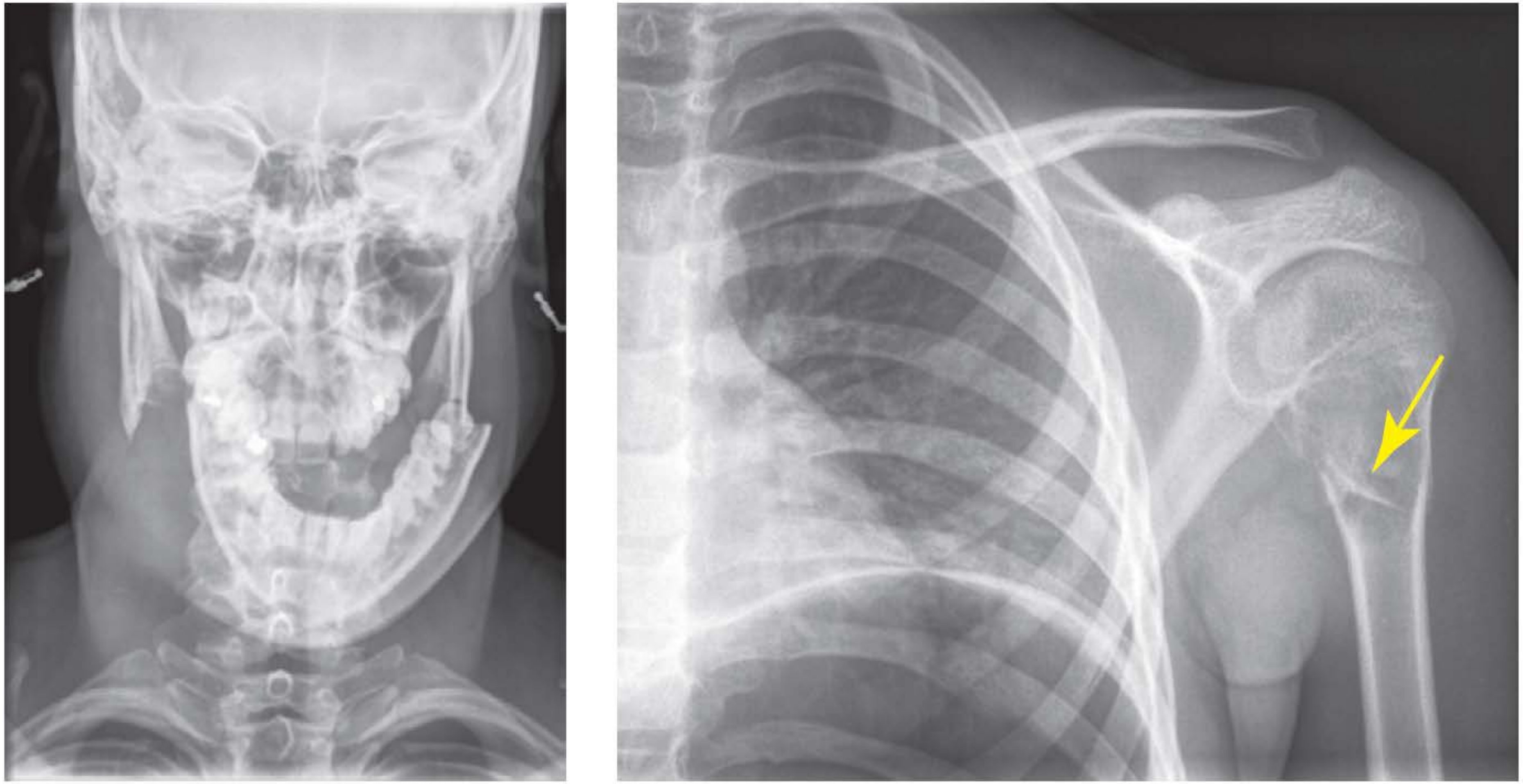

Figure. (Left) Double mandibular fracture with strong displacement to the left. (Right) Solitary humeral bone cyst known as ‘‘fallen leaf sign’’.

Lung metastases

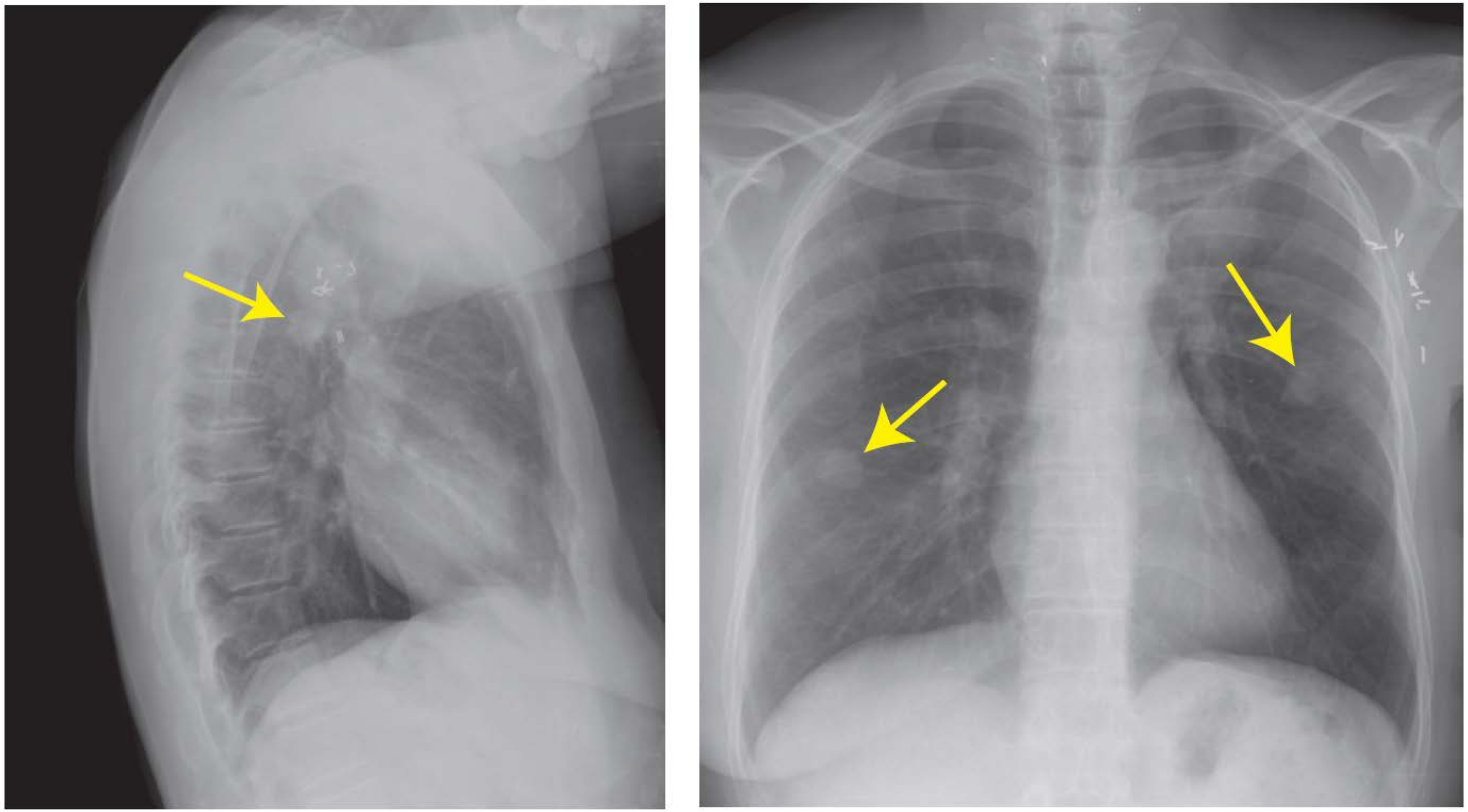

Figure. Radiographic chest image showing multiple lung metastases.

Breast carcinoma

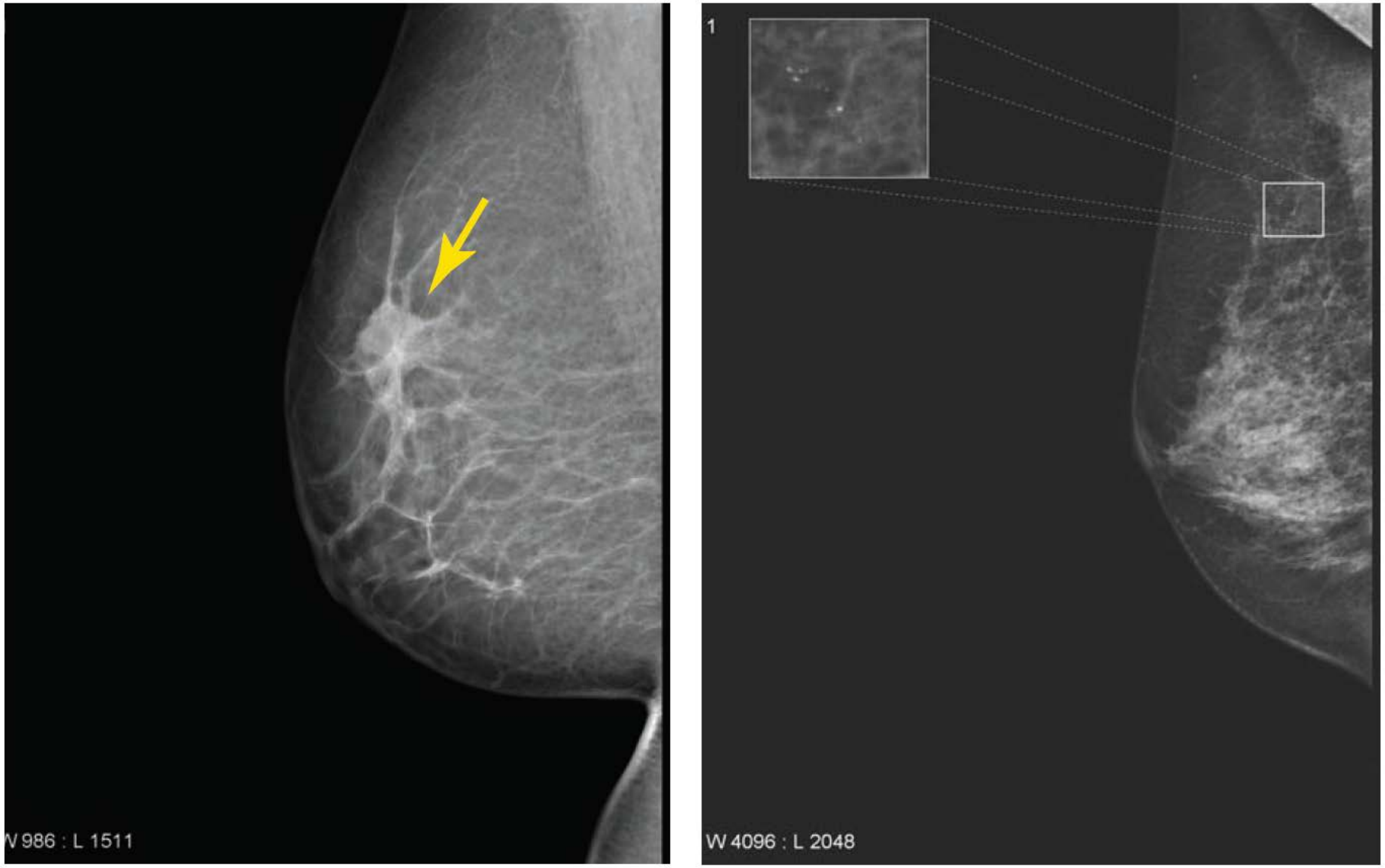

Figure. (Left) Dense opacity with spicular border in the cranial part of the right breast; histological proven invasive ductal carcinoma. (Right)Cluster of irregular microcalcifications suggesting a low differentiated carcinoma.

Bone fixation

Figure. (Left) Postoperative fluoroscopic control of bone fixation with plate and screws after a complete fracture of the humerus. (Right) Spine radiograph of scoliosis before and after surgical treatment.

Cerebral angiogram

Figure. Cerebral angiogram showing an aneurysm or saccular dilation of a cerebral artery.

GI tract

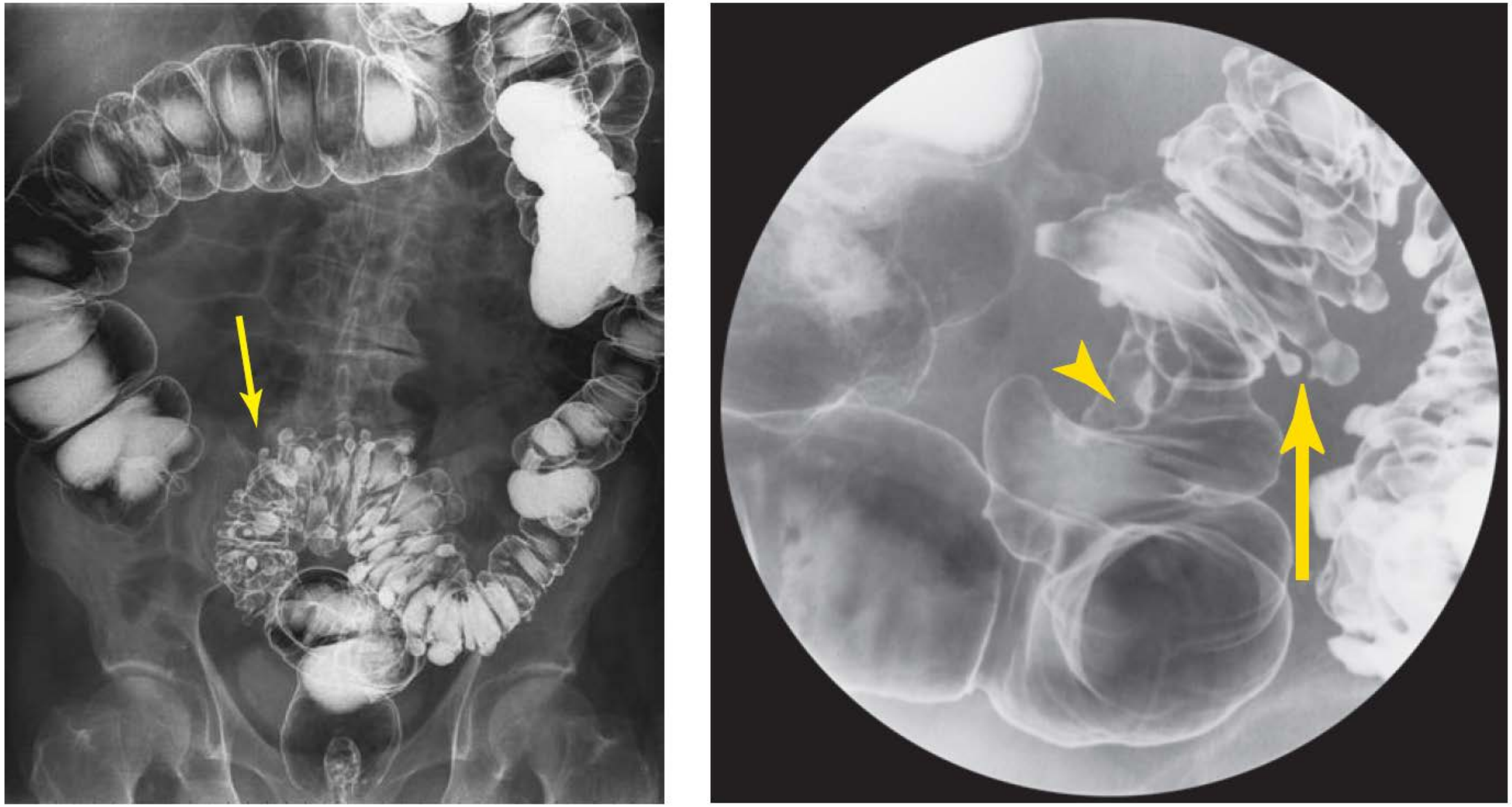

Figure. (Left) Double contrast (barium + gas insufflation) enema with multiple diverticula in the sigmoid colon (arrows). (Right) Polypoid mass proliferating intraluminally (arrowhead on the spotview).