Cardiac X-ray Imaging

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Why image with X-rays?

X-ray imaging can be used to detect soft tissue abnormalities, image bone, and with the use of contrast agents image the cardiovascular, GI and other internal structures.

It can also be used to visualise devices within the body as they are manipulated during interventions.

In cardiac imaging X-ray imaging plays a key role in both the diagnosis and treatment of coronary heart disease, and other cardiac conditions.
Producing X-rays

X-rays are produced by colliding electrons into a metal target in an evacuated **X-ray tube**.

Electrons are produced by passing a current through a **filament**, heating the filament, resulting in electron emission.

The electrons are accelerated towards a metal target **anode** by the application of a potential difference typically 40 – 120 kV for cardiac imaging.
Producing X-rays

Interaction between the electrons and the target produce X-rays as *Bremsstrahlung* and *characteristic* radiation.

A polyenergetic radiation beam is produced.

An **X-ray generator** is responsible for producing the electrical supply to the X-ray tube.

X-ray production is very inefficient (0.9 x 10^-9 ZV).
X-RAY INTERACTIONS
1. **Photoelectric Absorption**

An X-ray photon interacts with an inner electron of an atom, transferring all of its energy to the electron.

The electron is ejected from the atom and the electron hole is normally filled by a series of electron cascades from outer shell electrons, resulting in auger electron and characteristic photon emissions. The X-ray photon is effectively removed from the beam.

Chance of photoelectric absorption proportional to \((Z/E_p)^3\).
2. **Compton (Incoherent) Scatter**

An X-ray photon interacts with a *loosely bound* or free electron, transferring part of its energy to the electron.

The **X-ray photon is deflected**, but is *not removed* from the beam.

Scattered X-ray photons can:

- further interact with the patient, or
- escape the patient and interact with other objects such as the X-ray image receptor (degrading image quality) or members of staff.
Modern X-ray image receptors are highly efficient solid state ("flat panel") devices.

- Polished Al coating
- CsI scintillator converts x-ray photons to light
- a-Si TFT photodiode array
X-ray images are radiographic shadowgrams—three dimensional objects are projected onto a two dimensional image.
X-RAY CARDIAC IMAGING AND
THE CATH LAB
The cath lab
The X-ray cath Lab
## Coronary X-ray image sequences

<table>
<thead>
<tr>
<th>Feature</th>
<th>Typical</th>
<th>Optional</th>
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</thead>
<tbody>
<tr>
<td>Temporal resolution</td>
<td>15 x 5 ms pulses per second</td>
<td>30 fps also common clinically, but both higher and lower frame rates possible</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>1024 x 1024 pixels &lt;br&gt;20 x 20 cm receptor area &lt;br&gt;(200 (\mu)m pixel pitch; 100 (\mu)m effective pixel size in object plane)</td>
<td>Specialist image receptors can have smaller pixel pitch</td>
</tr>
<tr>
<td>Imaging mode</td>
<td>Fluoroscopy &amp; acquisition</td>
<td>User selectable</td>
</tr>
<tr>
<td>Field of view</td>
<td>25, 20 &amp; 15 cm</td>
<td></td>
</tr>
<tr>
<td>C-arm motion</td>
<td>(\pm 45^\circ) C-C, (\pm 120^\circ) Lat &lt;br&gt;18° - 25°/s motorised motion</td>
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EXAMPLE IMAGES
Blood has a very similar linear attenuation co-efficient to soft tissue, and therefore is very difficult to directly discriminate using X-ray imaging.

Blood is therefore temporarily replaced by an iodinated contrast medium with a much greater attenuation than blood for imaging.

A catheter is inserted into radial or femoral artery and advanced over the aortic arch to the aortic root. It is then selectively engaged with the ostium of the right or left coronary artery, allowing the injection of contrast medium or placement of interventional devices into the artery.
A stent is a metal mesh support structure placed in the artery to reduce the rate of restenosis.

The stent is positioned under fluoroscopic guidance…

… and inflated to expand the stent. The balloon is then withdrawn.
Post intervention angiograms are then acquired in order to confirm proper deployment, and restoration of vessel lumen.

More than one stent can be placed in the same artery, or further arteries treated as necessary.
Fluoroscopy (EP)
3D imaging in the cath lab
3D model
Dose rates on the image receptor dictate the level of noise within the image (noise $\propto \sqrt{\text{dose}}$).

X-rays have two main detrimental effects to humans:

- Deterministic effects, mainly damage to the skin
  - Threshold (2 Gy) before any effect seen
  - Severity increases with dose
- Stochastic effects, fatal cancer and birth defects
  - Severity not affected by dose
  - Likelihood of occurrence is related to dose
Radiographic imaging of the heart

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<tr>
<td>High temporal and spatial resolution possible</td>
<td>Limited in humans to acceptable patient radiation dose levels</td>
</tr>
<tr>
<td>Projection geometry</td>
<td>Projection information does not resolve 3D information directly, but requires less X-ray dose than cardiac CT.</td>
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<tr>
<td>Anatomy: accurate assessment of morphology</td>
<td>Aterial, veneous and ventrical lumen all possible. Morphological information of vessel lumen stenotic severity does not necessarily correlate with functional severity.</td>
</tr>
<tr>
<td>Function: assessment of blood flow / perfusion</td>
<td>Blood flow is normally measured via another device (e.g. intra-arterial doppler). Has been demonstrated directly from imaging, but is not routine (or straightforward). Assessment of perfusion currently rudimentary, but remains an area of active research.</td>
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Perfusion assessment

Pre intervention

Post intervention
Radiological Physics


Clinical Applications


Questions

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