• Godfrey Hounsfield, inventor of clinical CT, 1971
  - 1979 Nobel prize
  - 1\textsuperscript{st} Oct 1971 – 1\textsuperscript{st} patient scanned
“Third generation” CT scanners

- Tube & detectors
  - rotate around patient gathering x-ray projections
- Projection data used to form slice images
  - filtered back projection
Helical/Spiral:
Helical CT

- Continuous gantry rotation + continuous table feed
- Scan data traces a helical path - or ‘spiral’ - around patient
  - data used to form axial images
Helical Single-Section Mode

Translation

Helical Trajectory

Interpolation using samples from single row detector ring
Decrease scan time

Large tissue volumes scanned in short times

Inter-scan delay eliminated

Capabilities of Single Row Detector CT (SDCT)
Limitations of SDCT

- Large volume scan in short duration is limited
- Near isotropic resolution only over small volume
- Poor utilization of X-ray tube

- Multiple row detector CT (MDCT) offers substantial improvement in volume coverage, scan speed with efficient use of X-ray tube
Detector banks

- Array extends in 2 directions
  - xy-plane
    - arc to collect many samples for each projection
  - z-axis
    - along the patient length

- SSCT
  - z-axis coverage: one element

- MSCT
  - many z-axis elements
Cone Beam Geometry

- In MDCT, widening beam aperture in z-direction increases cone angle, that results in significant cone beam artifacts.
Single Row Detectors

Multiple Row Detectors
Multi-Slice CT

- Wider beam widths

Beam widths up to 40 mm
Multi-Slice CT

- Wider beam widths

10 mm  
20, 24, 32 mm  
29, 32, 40 mm

single slice  
4 - 16 slice  
64 slice
Issues in Multi-Slice CT

- Thin slice data acquisition
  - 4, 16, 32, 40, 64 simultaneous slices
    - Eg
      - $4 \times 0.5 \text{ or } 5 \text{ mm}$
      - $16 \times 0.625 \text{ or } 1.25 \text{ mm}$,
      - $64 \times 0.5 \text{ or } 0.625 \text{ mm}$

beam widths up to 40 mm

number of slices

Z-axis
Multi-Slice CT

- Thinner slices and more of them

- 64 x 0.5 = 32 mm
- 16 x 0.5 = 8 mm
- 4 x 0.5 = 2 mm

Toshiba Aquilion series
The scanner

Typical detector length $\sim 40$ mm
Depending on scanner:
4, 16, 64, 128, 320 rows (slices of data)
min size of detector element ~ 0.5, 0.6 mm
Multi-Slice CT

- Rotating tube and detectors – same as single slice
- Many axial images
- Helical scanning – many data sets
Beam width, detectors and slices

- GE LightSpeed 64
  - 64 x 0.625 mm detectors
  - Beam = 40 mm
  - 64 x 0.63 mm
  - 32 x 1.25 mm
  - 16 x 2.5 mm

40 mm

64 x 0.625 mm

z-axis
Multi-slice CT scanning

- Many features in common with single slice (SSCT)
  - multiple parallel detector banks along z-axis
  - enables a number of projections to be acquired simultaneously
DAS:
Data acquisition system
Axial scanning – ‘step and shoot’

– Also known as sequential scanning
Detector array:

- Uniform
- Non-uniform
- Hybrid
Uniform Element Arrays

Possible section widths

- 2 x 0.63 mm
- 4 x 1.25 mm
- 4 x 2.5 mm
- 4 x 3.75 mm
- 4 x 5 mm
- 2 x 7.5 mm
- 2 x 10 mm

Lightspeed, GE Medical Systems
Non-Uniform Element Arrays

Possible section widths:

- 2 x 0.5 mm
- 4 x 1.0 mm
- 4 x 2.5 mm
- 4 x 5.0 mm
- 2 x 8.0 mm
- 2 x 10.0 mm

Volume Zoom, Siemens Medical Systems
Hybrid Element Arrays

Possible section widths

- 4 x 0.5 mm
- 4 x 1 mm
- 4 x 2 mm
- 4 x 3 mm
- 4 x 5 mm
- 4 x 8 mm
- 2 x 10 mm

Acquilion, Toshiba Medical Systems
MDCT: Detector Element Arrays

- GE: 16 x 1.25 mm
- Siemens & Philips: 20 mm
- Toshiba: 15 mm, 32 mm Z-axis
How are detector elements used in MDCT?

4-section scanners collect four simultaneous channels of data.
Detector Configuration: For 4 x 1.25 mm
Detector Configuration: For 4 x 2.5 mm
Helical Multiple Section Mode

4 helical trajectories

Translation

Interpolation using samples of ALL detector rings
Helical Single-Section Mode

Helical Trajectory

Translation

z (mm)

t (s)

Interpolation using samples from single row detector ring

Helical Multiple Section Mode

Helical Trajectory

Translation

z

t

Interpolation using samples of ALL detector rings

4 helical trajectories
The Detector’s Evolution...
Slices & detectors

- Just 4 detectors reduces options for scanning
- Narrow coverage
  - e.g., 5 mm for \(d=1.25\) mm

Heart hospital
Slice width selection: 4 slice

- For more flexibility
  AND
  greater coverage
  need more detectors
- Can collect data from groupings of detectors
  - individual detectors
    - 4 x d
  - pairs
    - 4 x 2d
  - triples
    - 4 x 3d

4 output slices
Slice options: real example

- GE LightSpeed
  - 4 slices
  - 16 detectors
- Detector output combined to define data acquisition width
- Coverage up to 20 mm
Adaptive arrays

- Detector elements not all same size
  - e.g. Toshiba Aquillion series

Aquilion 4
34 detectors

Aquilion 16
40 detectors
More “thinnest-slice” coverage

Aquilion series

Detector mock-ups courtesy of Toshiba
64 slice scanners

- Toshiba Aquilion 64
  - 64 x 0.5
- GE LightSpeed VCT
  - 64 x 0.625 mm
- Philips Brilliance CT64
- Siemens Sensation 64
  - 4 x 1.2
  - 32 x 0.6
  - 4 x 1.2

z-axis
DAS channels: Four versus Eight

Detector

Switching Array

4 x 1.25 mm

20 mm

8 x 1.25 mm

GE Medical Systems
Detector Evolution: 4 vs 16 sections per rotation

Siemens & Philips Medical Systems
Detector Evolution: 4 vs. 16 sections per rotation

4x0.5, 4X1, 4x2, 4x3 up to 4x8

16x0.5, 16X1, 16x2, up to 8x4

Toshiba Medical Systems
Channels (or data channels)
collimated x-ray beam width using four 5.0 mm detectors

2 detectors binned

4 x 1.25 mm

collimated x-ray beam width using four 1.25 mm detectors

detector configurations
collimated x-ray beam width using four 5.0 mm detectors

2 detectors binned

4 x 2.5 mm

collimated x-ray beam width using four 1.25 mm detectors

Configurations
4 x 5 mm
MDCT Episode II: Attack of the Cones
Cone Beam Geometry

- In MDCT, widening beam aperture in z-direction increases cone angle, that results in significant cone beam artifacts
Single-slice detector

Sixteen-slice detector

X-ray tube
Tube rotates around patient and moves along z-axis during helical acquisition.
16+ slice reconstruction

Distortion
Key Problem: Cone Angle

- What happens, if the cone angle of the rays is neglected?

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Pitch</th>
<th>Scan Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mm</td>
<td>1.6</td>
<td>12 mm/sec</td>
</tr>
<tr>
<td>8 mm</td>
<td>1.6</td>
<td>24 mm/sec</td>
</tr>
<tr>
<td>12 mm</td>
<td>1.6</td>
<td>38 mm/sec</td>
</tr>
<tr>
<td>16 mm</td>
<td>1.6</td>
<td>48 mm/sec</td>
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</tbody>
</table>

- Image results for > 4 sections are clinically unacceptable!
## MSCT Faster Scanning

<table>
<thead>
<tr>
<th>Detector</th>
<th>Beam Thick. (mm)</th>
<th># rotations</th>
<th>Total scan time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 x 1.25</td>
<td>1.25</td>
<td>160</td>
<td>128</td>
</tr>
<tr>
<td>4 x 1.25</td>
<td>5</td>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>8 x 1.25</td>
<td>10</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>16 x 1.25</td>
<td>20</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>64 x .625</td>
<td>40</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

1.25mm images and 20cm scan length at 0.8sec rotation and 1.0 pitch
The 3 Fs of CT

- Faster
- Further
- Finer
Benefits of multi-slice

- Faster
  - Same scan in shorter time
- Thinner
  - Thinner slices give excellent z-axis resolution
- Further
  - Wider collimations allow large scan volumes
- Multi-slice CT: MSCT
- Multi-detector CT: MDCT
- Multi-channel CT: MCCT
- Multi-row CT: (MRCT less common as abbreviation)

All effectively the same thing

Note: care when using “SSCT”
- normally used for single slice
- can sometimes refer to single source
  - check the context
Question:
Thank you for your attention!