# Basic scientific principles of dental CBCT imaging

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## Overview

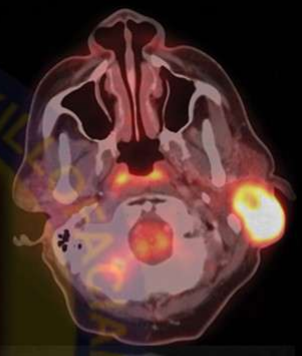
- Basic scientific principles…

- What is CBCT?
- How does it work?
- How is different to conventional medical CT?
- The imaging chain

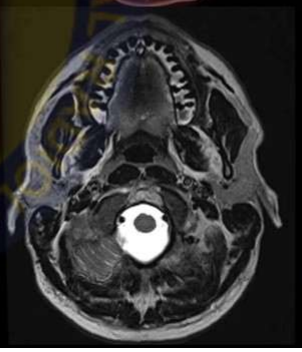
# CBCT?

- Cone Beam Computed Tomography
- *Digital Volumetric Tomography, 3D Dental Imaging, Flat Panel CT*

- Cross-sectional or three dimensional imaging modality
- Able to demonstrate anatomical structures within an imaged cylindrical volume within any plane



PET-CT



MRI







# CBCT

- Commercially available >20 years
- Most commonly used in dentistry

- Excellent hard tissue detail
- Lower dose than conventional (medical) CT

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# CBCT doses

| Radiographic technique | Effective dose (μSv) |
|---|---|
| Intraoral radiograph (bitewing/ periapical) | 0.3–21.6 |
| Panoramic radiograph | 2.7–38 |
| Lateral cephalometric radiograph | 2.2–14 |
| CBCT (small field of view*) | 11–214 |
| CBCT (medium field of view**) | 18–674 |
| CBCT (large field of view***) | 60–510.6 |
| CBCT (extended field of view****) | 30–1025 |
| CT scan (mandible) | 250–1410 |
| CT Scan (mandible and maxilla) | 430–860 |

FGDP Selection Criteria for Dental Radiography 2018

| AGE GROUP | Multiplication factor for risk |
|---|---|
| < 10 | x 3 |
| 10 – 20 | x 2 |
| 20 – 30 | x 1.5 |
| 30 – 50 | x 0.5 |
| 50 – 80 | x 0.3 |
| 80 + | Negligible |

**TABLE 3: Risks of cancer from diagnostic X-rays**

| X-RAY EXAMINATION | Estimated risk of fatal cancer |
|---|---|
| INTRA-ORAL PERIAPICAL/BITEWING USING 70KV, RECTANGULAR COLLIMATION, F SPEED FILM/DIGITAL RECEPTORS | 1 in 10,000,000 |
| PANORAMIC | 1 in 1,000,000 |
| UPPER STANDARD OCCLUSAL | 1 in 2,500,000 |
| LATERAL CEPHALOMETRIC | 1 in 5,000,000 |
| **COMPUTED TOMOGRAPHY** | **Range of risk** |
| CT MANDIBLE AND MAXILLA | 1 in 80,000 to 1 in 14,300 |
| DENTO-ALVEOLAR (small volume) CBCT | 1 in 2,000,000 to 1 in 30,000 |
| CRANIOFACIAL (large volume) CBCT | 1 in 670,000 to 1 in 18,200 |

BOS Guidelines for the Use of Radiographs in Clinical Orthodontics 2015

# Standing, seated and supine models…




DEXIS OP 3D



MORITA ACCUITOMO 170




NEWTOM 7G

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*CBCT / DPT FUNCTIONALITY*

*LATERAL CEPH COMPONENT*

CARESTREAM
CS 8100SC 3D

# Multi-modality / Combined units available

- CBCT +/-
  - Panoramic
  - Lateral ceph
  - 3D facial imaging

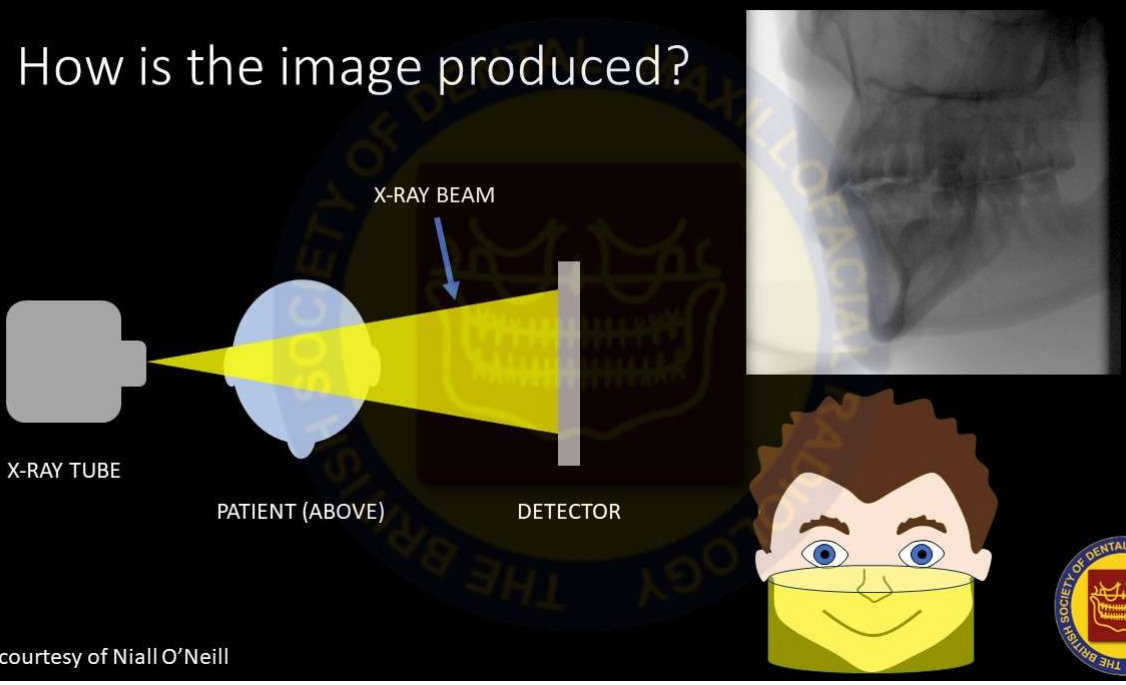


# How is the image produced?

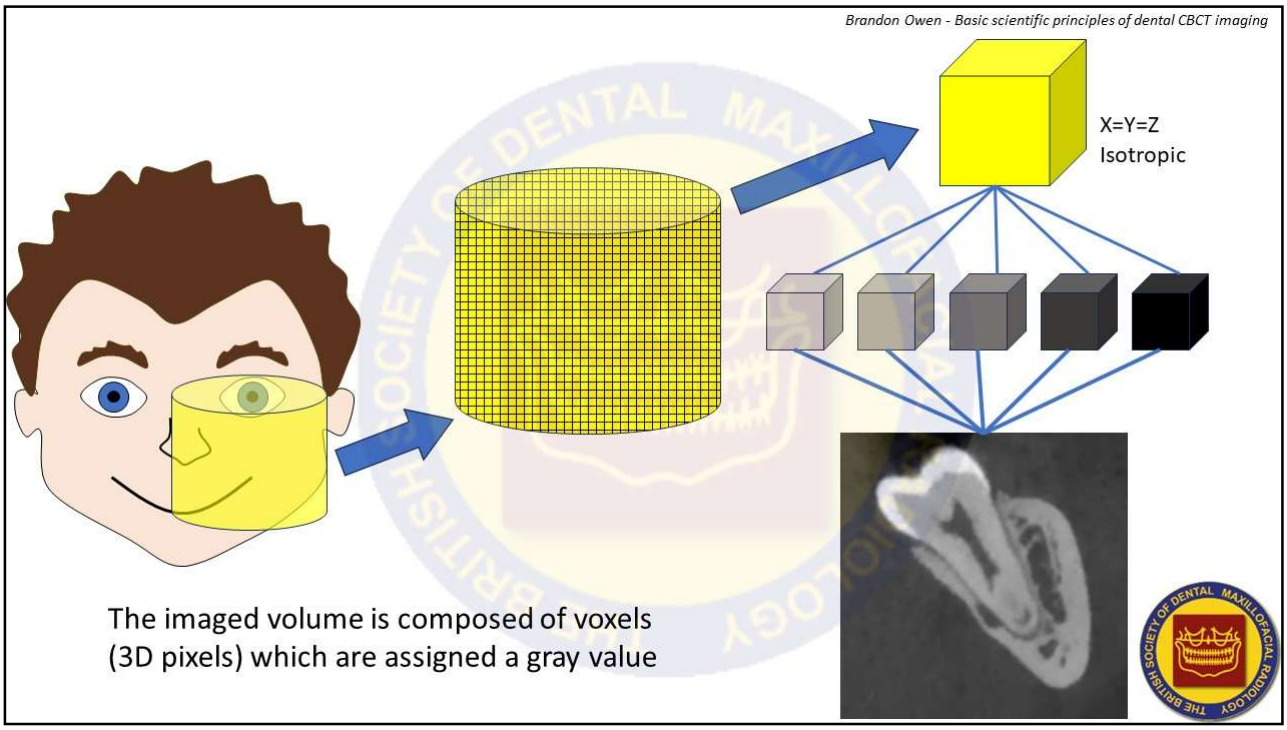
- Cone-shaped beam and single detector move synchronously around region of interest
- Acquires multiple two dimensional images in a single rotation (180-360 degrees) to form a single cylindrical or spherical volume
- The volume comprises a number of voxels (3D pixels) which are assigned a specific gray value to produce the image



# How is the image produced?




Video courtesy of Niall O'Neill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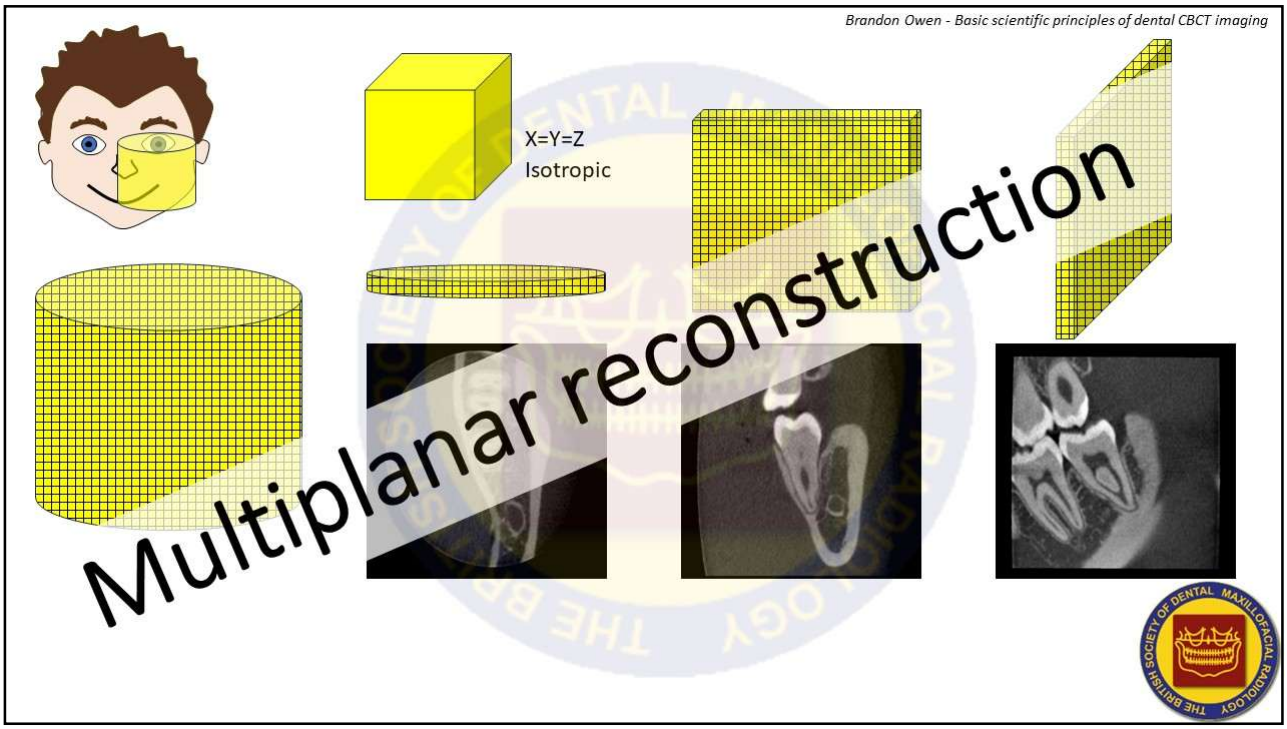
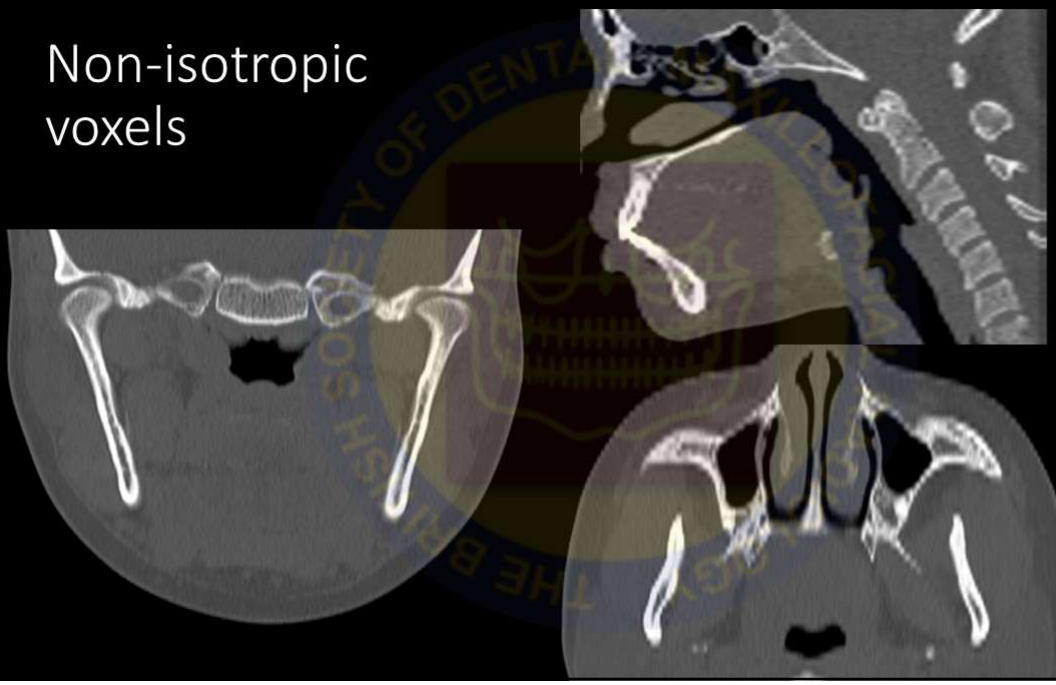
X=Y=Z
Isotropic
The imaged volume is composed of voxels
(3D pixels) which are assigned a gray value


Brandon Owen - Basic scientific principles of dental CBCT imaging
X=Y=Z
Isotropic
Multiplanar reconstruction

# Non-isotropic voxels





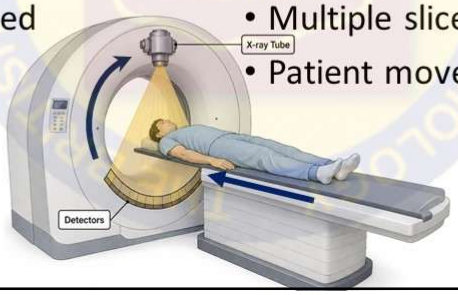
# How does image acquisition compare to conventional CT?

**Cone beam CT**

- Cone shaped beam
- Single detector
- Single rotation of x-ray tube
- Single volume imaged
- Patient static

**Conventional CT**

- Fan shaped beam
- Array of detectors
- Multiple rotations of x-ray tube
- Multiple slices imaged
- Patient moved through gantry



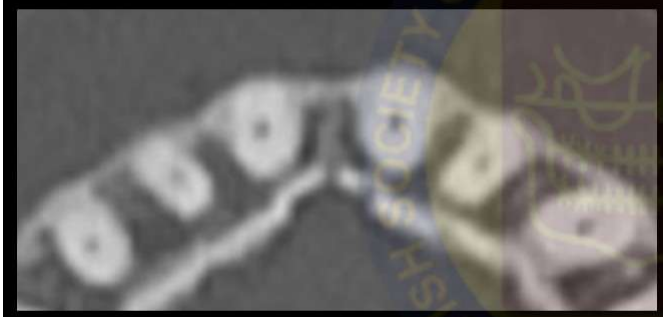
# Any other differences?

**Cone beam CT**
- Smaller footprint
- Lower cost
- Shorter scan time
- Limited applications
- Poor soft tissue contrast
- Lower radiation dose

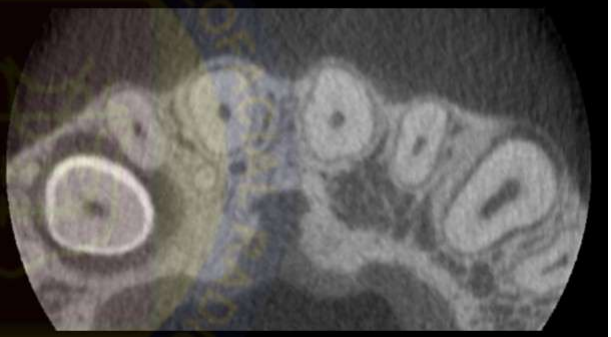
**Conventional CT**
- Larger footprint
- Higher cost
- Longer scan time
- Versatile – full body imaging
- Excellent soft tissue contrast
- Higher radiation dose



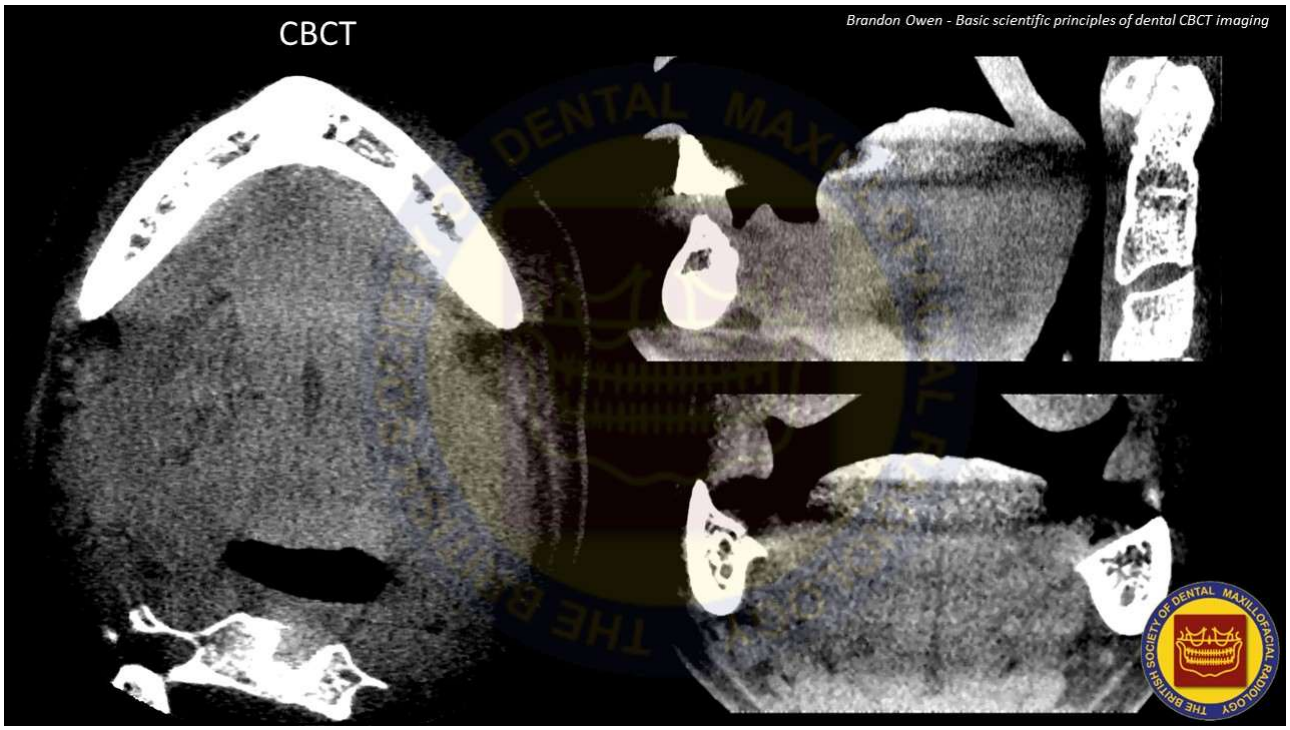
# Resolution



Conventional CT



CBCT


CBCT
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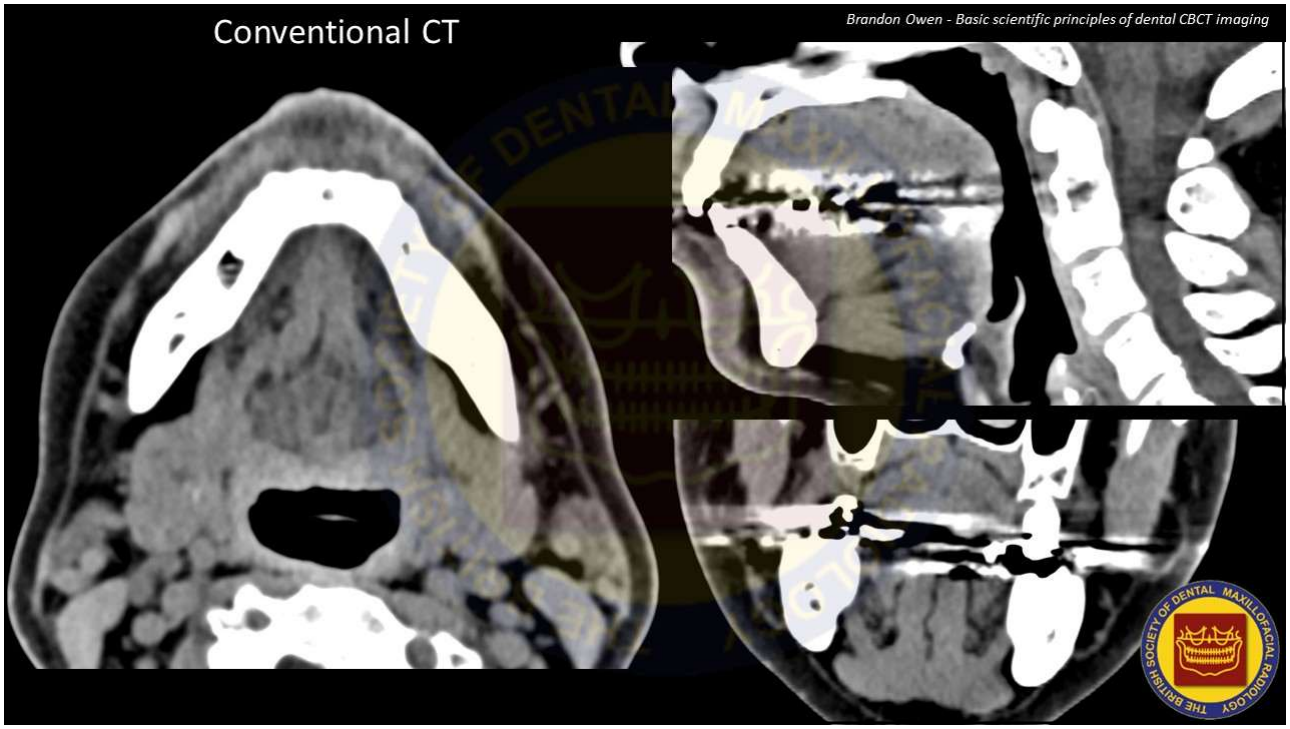
Conventional CT
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# The imaging chain

- The entire, interconnected sequence of components and processes required to create, process, store, and display an image
- Can be regarded as everything from patient preparation to interpreting the images

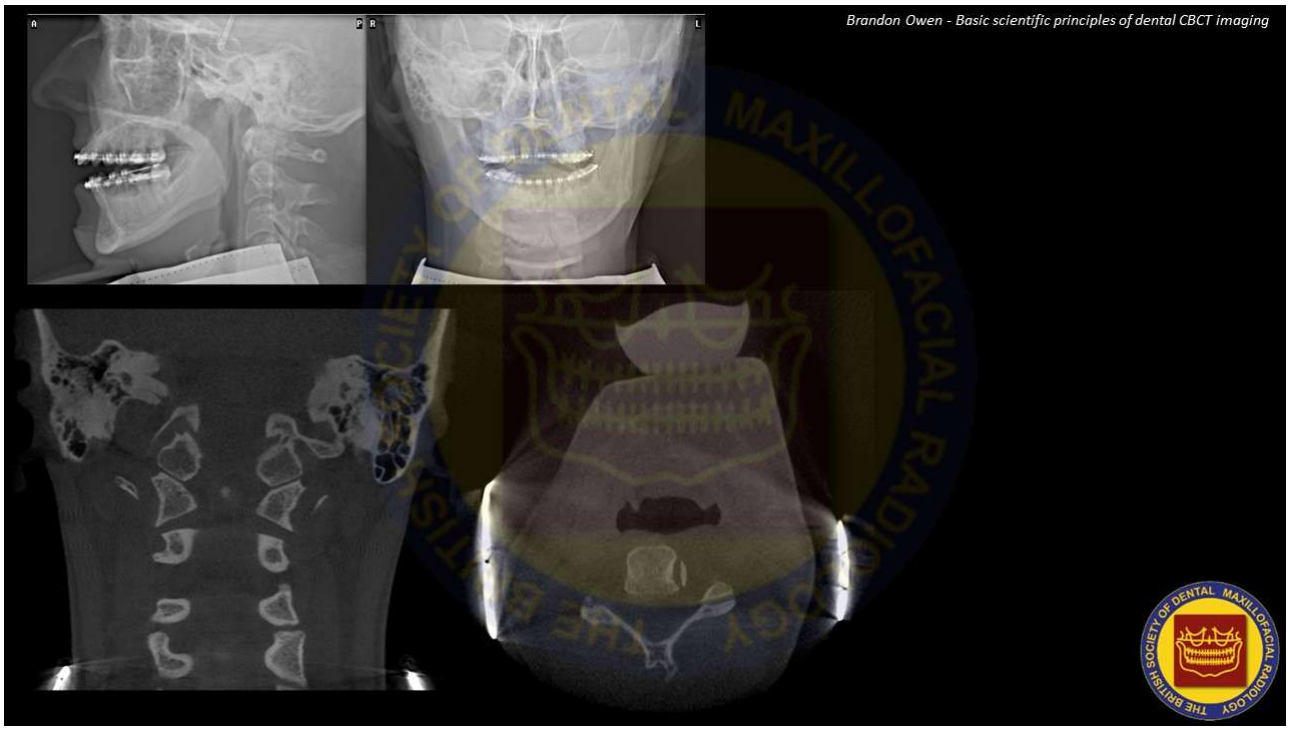
**Patient preparation** **Exposure factors** **Image detector**

**Data processing** **Image display and manipulation**



# Patient preparation

- Introduce machine
- Explain what will happen (consider test run)
- Remove metal objects **?thyroid collar**
- Place imaging stent / separate teeth if required
- Position patient in machine
- Immobilisation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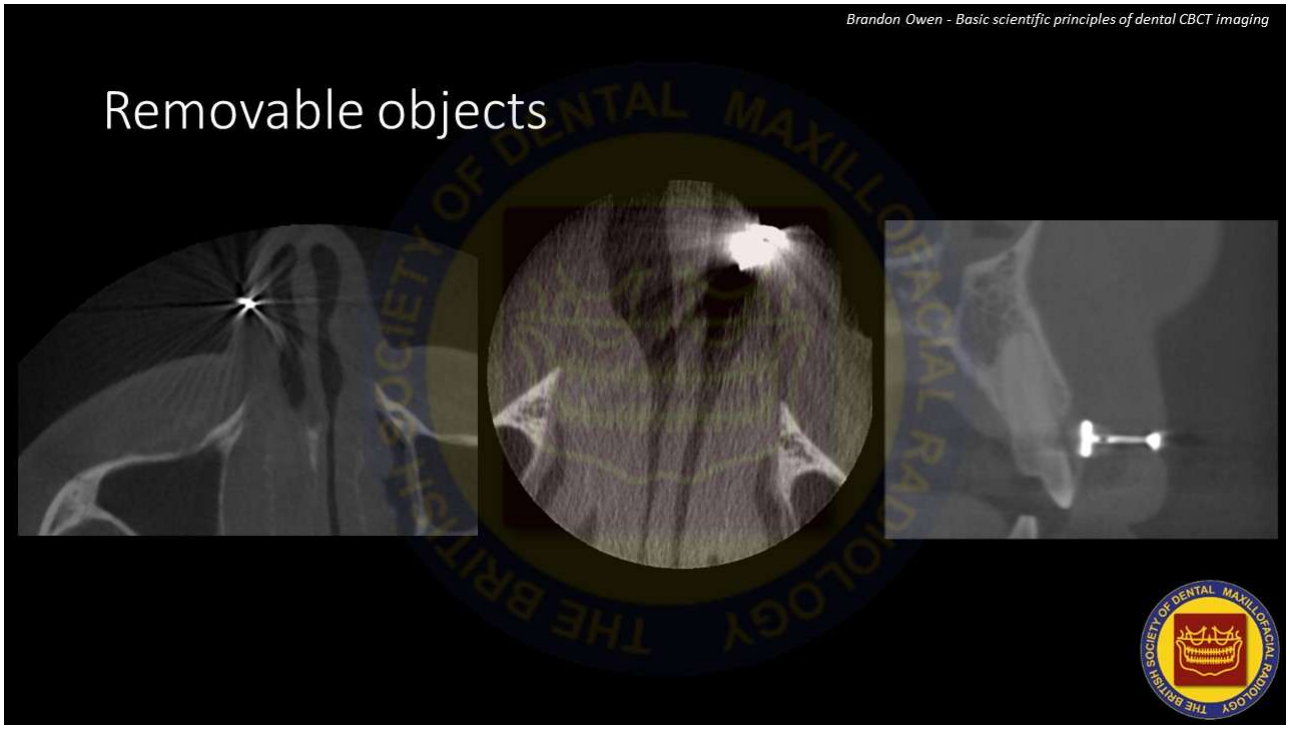
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Removable objects

## Not all metal objects can be removed



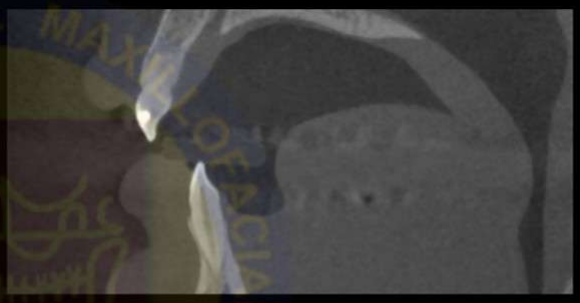


## Implant planning stent



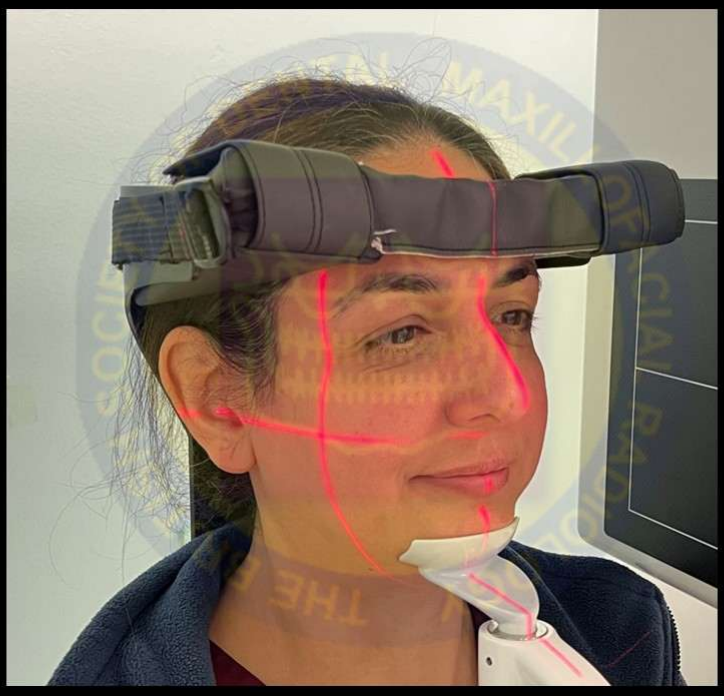
# Teeth together or apart?











# Scout views

- Important to ensure correct **position** and **size** of field of view
- Some units may adjust exposure parameters depending upon the amount of signal at the detector (AEC – more later).

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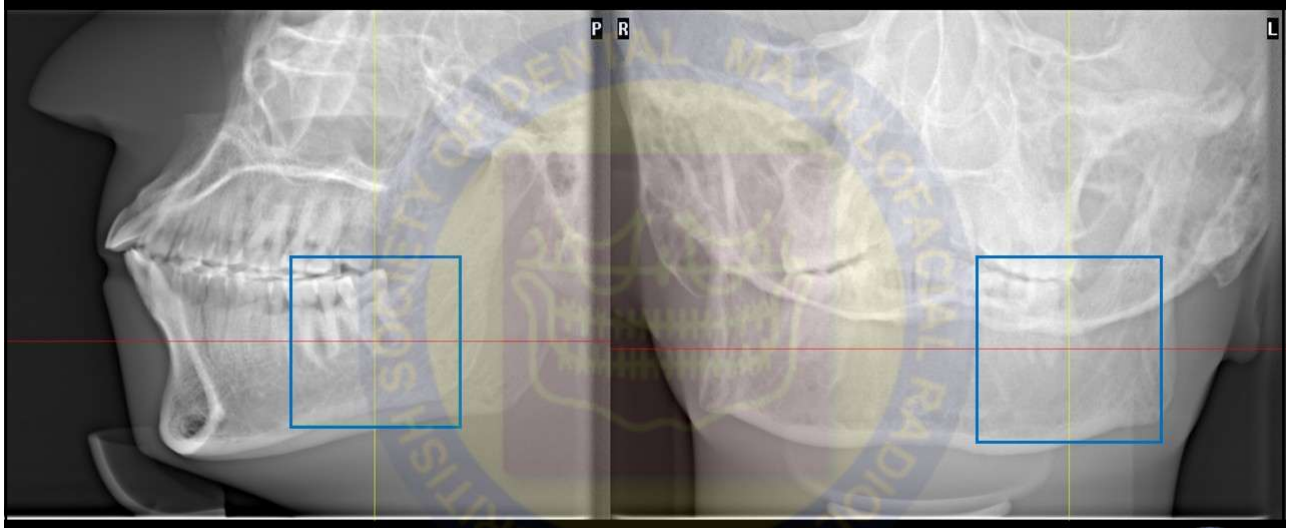
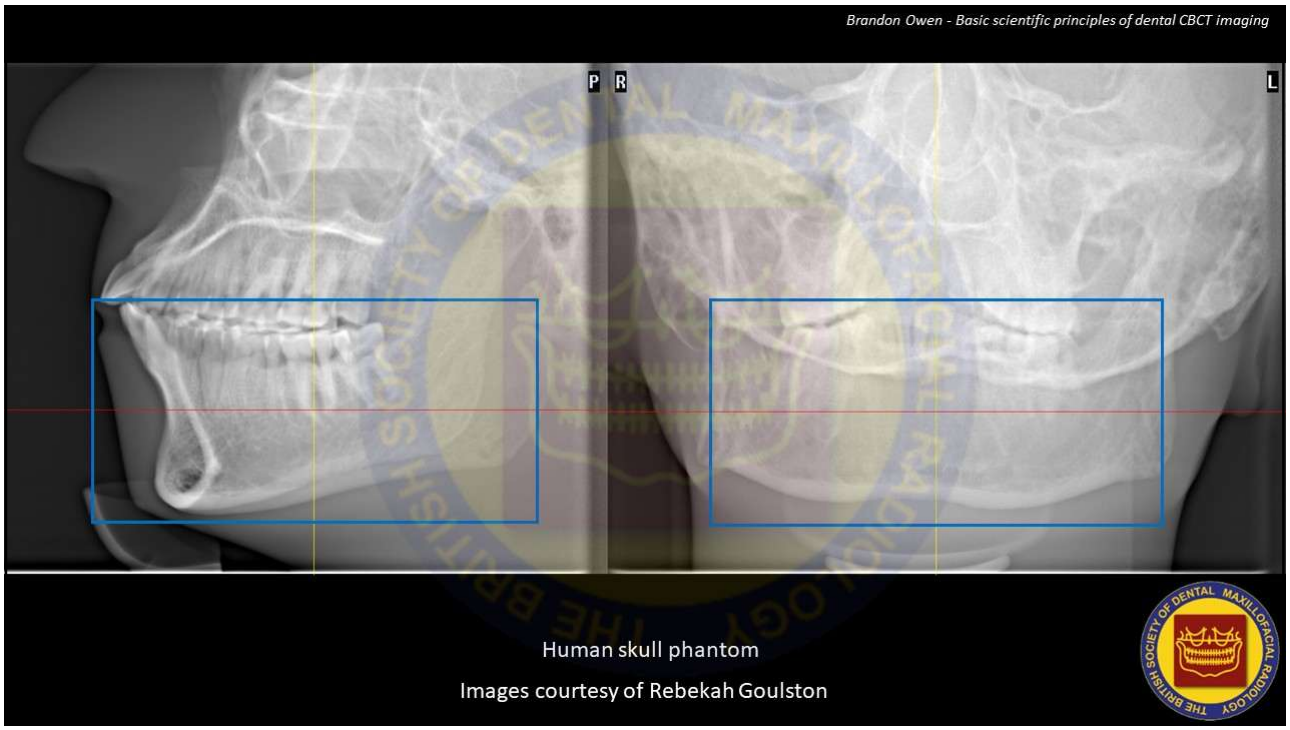



Human skull phantom

Images courtesy of Rebekah Goulston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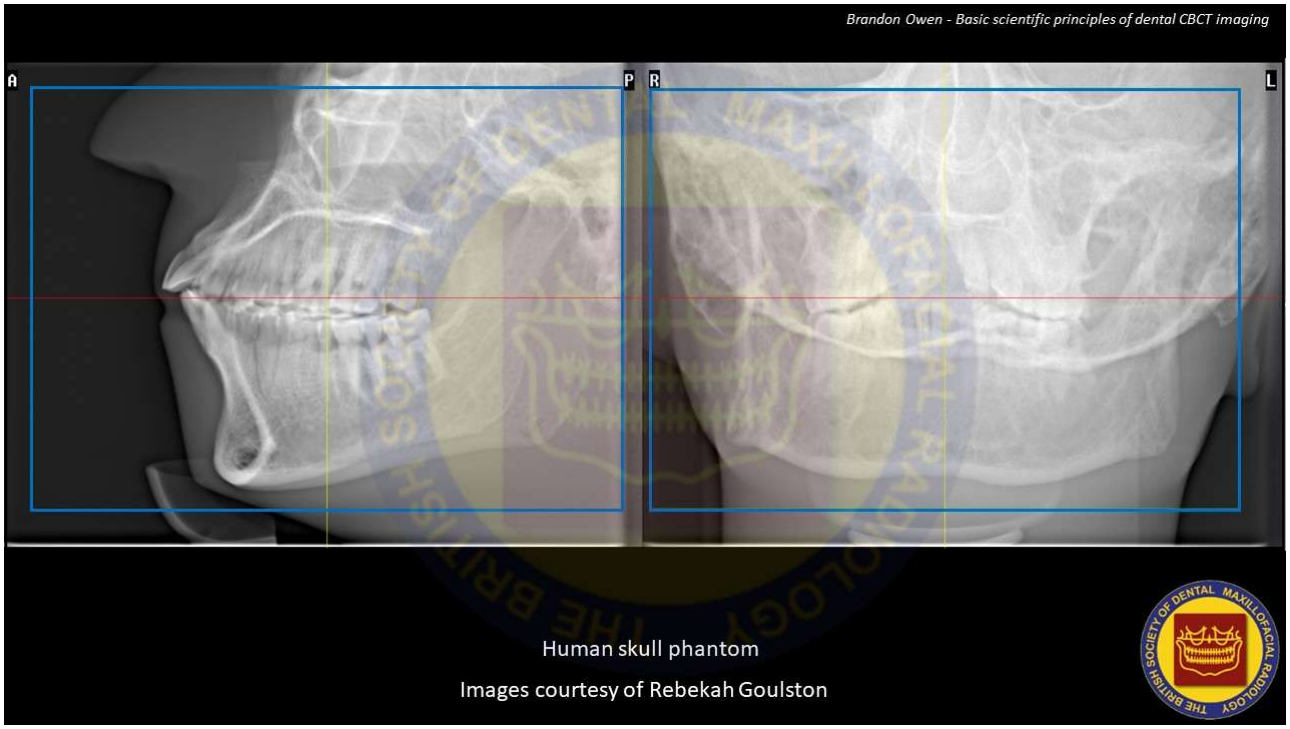
P
R
L
Human skull phantom
Images courtesy of Rebekah Goulston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A
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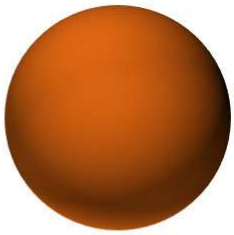
L
Human skull phantom
Images courtesy of Rebekah Goulston

# Image receptors

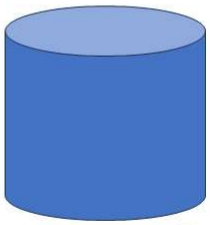
- Multiple types of image receptors

- Image intensifier - early generations
- **Flat panel detector**
  - Increased sensitivity
  - Better image quality / resolution
  - Lower doses
  - Distortion free
  - Less image degradation over time

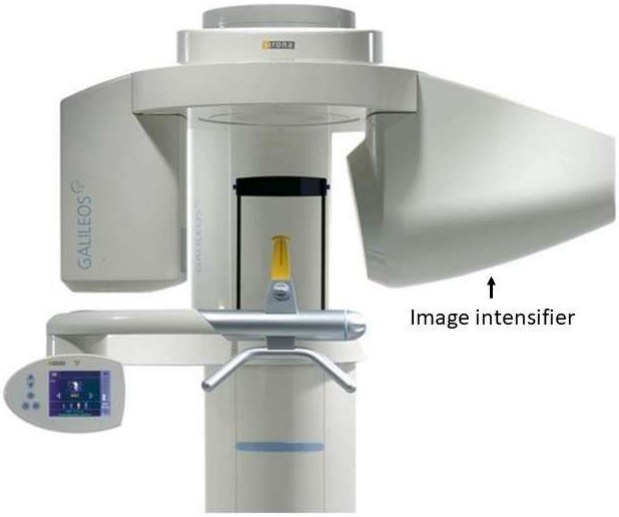
XRAY
↓
LIGHT
↓
ELECTRONS
↓
LIGHT
↓
DIGITAL SIGNAL



XRAY
↓
LIGHT
↓
DIGITAL SIGNAL








Sirona Galileos

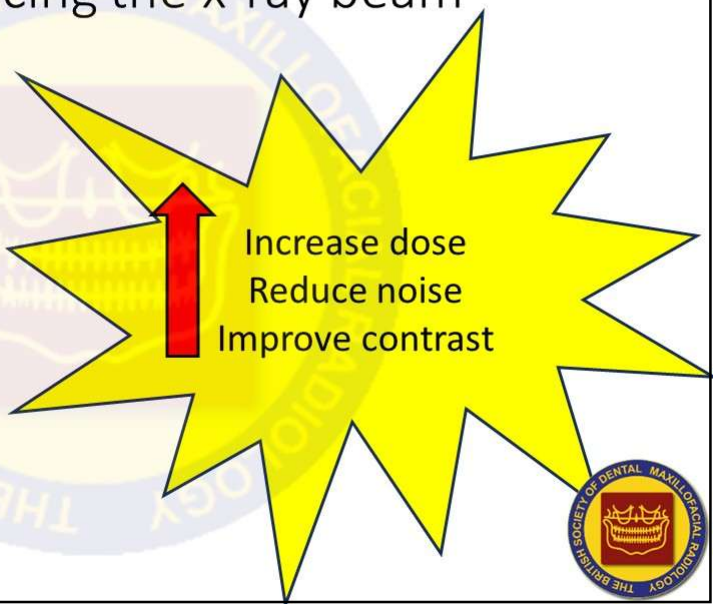



DEXIS OP 3D

# Basic factors influencing the x-ray beam

- **Exposure time (s)**
- **Tube current (mA)**
- May be combined (mAs)

- Influences number of x-rays produced
- Average and maximum energy unaffected

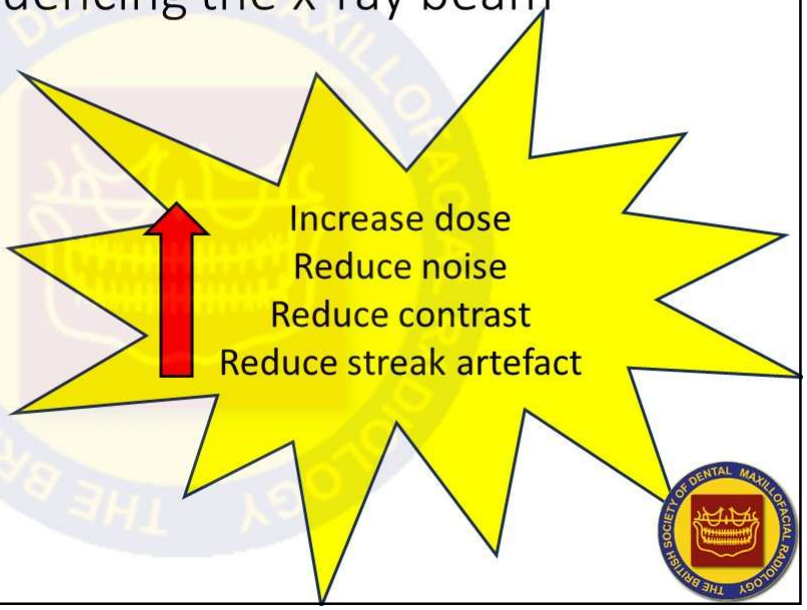





# Basic factors influencing the x-ray beam

- **Tube voltage (kV)**

- Influences average, maximum energy and number of x-rays produced



# Rotation

- Time variable ~10-40s
- High vs low speed protocols
- Variable arc of rotation 180-360°
  - Dose and image quality implications
- Note: may be able to reconstruct from smaller arc of rotation retrospectively – ie patient movement



# X-ray beam

- Continuous
  - Exposure time = rotation time
- *Pulsed*
  - X-ray beam coincides with detector sampling
  - Exposure time ≠ rotation time
  - Dose savings
- Modulated via automatic exposure control…

# Automatic exposure control

- Optimizes radiation doses by automatically modulating tube current, voltage, or exposure time based on patient size, attenuation, and anatomy.
- Improves image consistency

- May be 'pre-scan' or 'real-time'
- Pre-scan – scout view detector intensity
- Real-time – continuously adjusts parameters depending upon intensity at detector throughout exposure

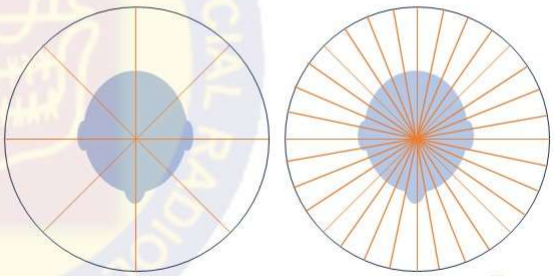
257
771
513
1026
263
257
257
266
513
263
527
767
523
256
377
511
264
265
257
261
365
264
261
257
665
257
262
257



# Basis projections

- More frames = higher image quality (↑SNR)
- But ↑ patient dose and scan time
  - Movement artefact

- May be fixed or variable within units
  - Fast scan protocols



# Field of view / Volume

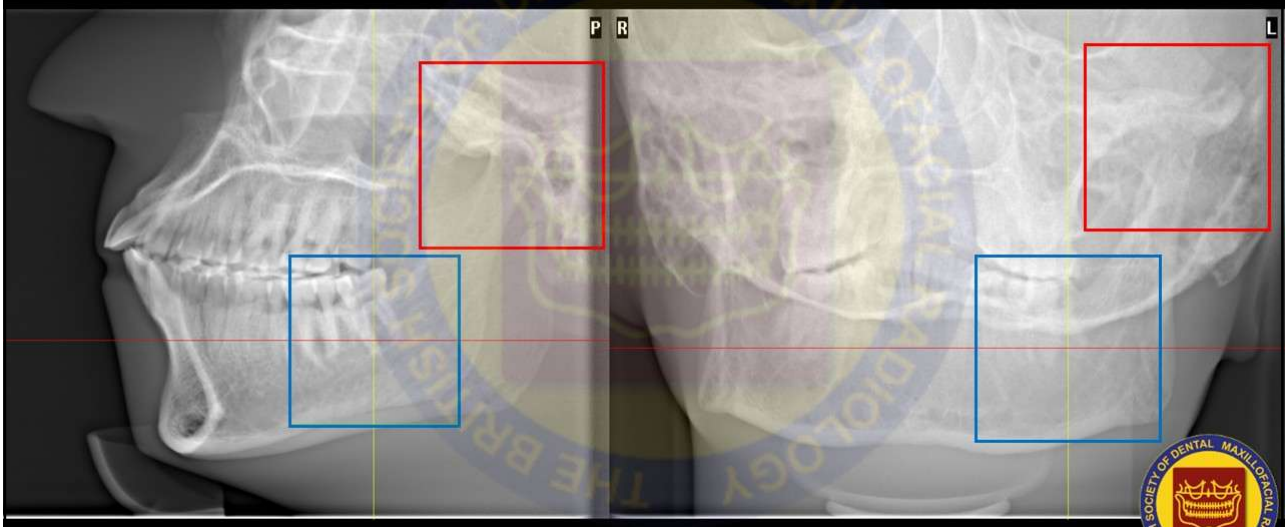
- Size can be varied, and centred on different regions of interest
- Volume sizes vary by manufacturer / model
- Degree of offset from the midline also varies
- Select the smallest volume to cover the region of interest



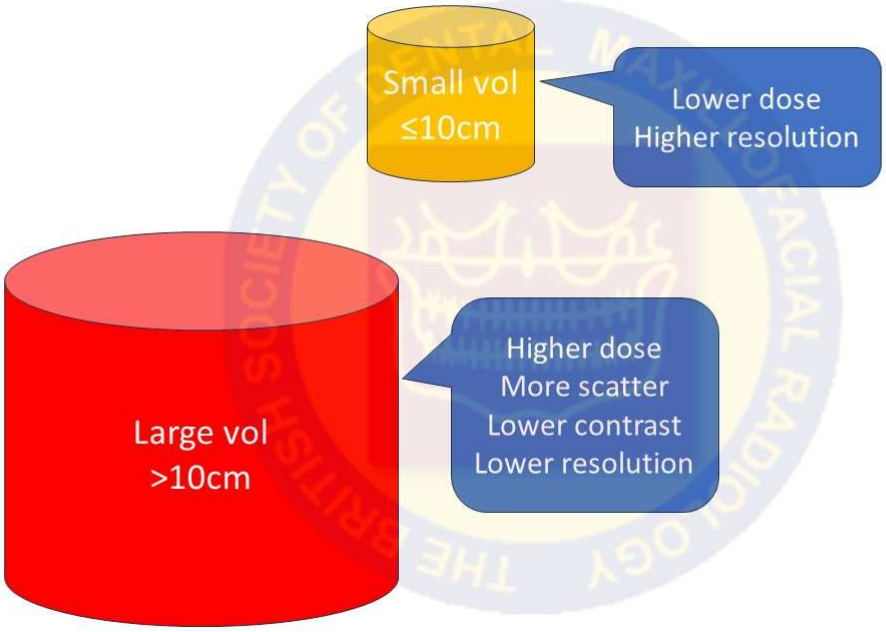




# Volume – degree of offset from midline varies




Human skull phantom  Images courtesy of Rebekah Goulston





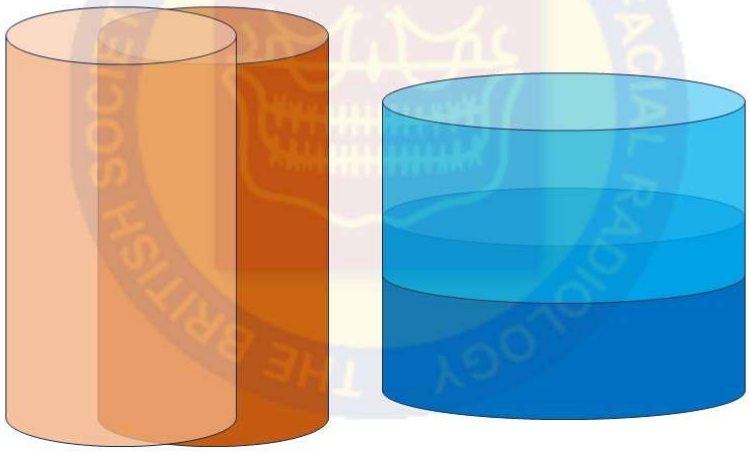

# Volume sizes vary by manufacturer

| | |
|---|---|
| **Image Volume Sizes (HxD)** | **5x5 cm, 6x9 cm, 8x8 cm, 10x10 cm, 10x11 cm, 10x15 cm (optional)**<br>**Volume height adjustable to offer a total of 66 customizable FOV options** |

| | | |
|---|---|---|
| Field of View<br>(Diameter × Height) | Ø 170 x120 mm Ø 170 x 50 mm<br>Ø 140 x100 mm Ø 140 x 50 mm<br>Ø 100 x100 mm Ø 100 x 50 mm<br>Ø 80 x 80 mm<br>Ø 60 x 60 mm<br>Ø 40 x 40 mm | **DENT** and **SIN****: 100 (diameter) x 100 (height)<br>100 (diameter) x 70 (height)<br>100 (diameter) x 60 (height)<br>80 (diameter) x 70 (height)<br>80 (diameter) x 60 (height)<br>80 (diameter) x 100 (height)<br>60 (diameter) x 70 (height)<br>60 (diameter) x 60 (height) |

The following FOV sizes are available for diagnostic needs: **5×5, 8×10, 13×10 and 18×10**.

## Multiple volumes may be 'stitched' to create larger volumes – overlap = ↑ dose





## 4x4cm

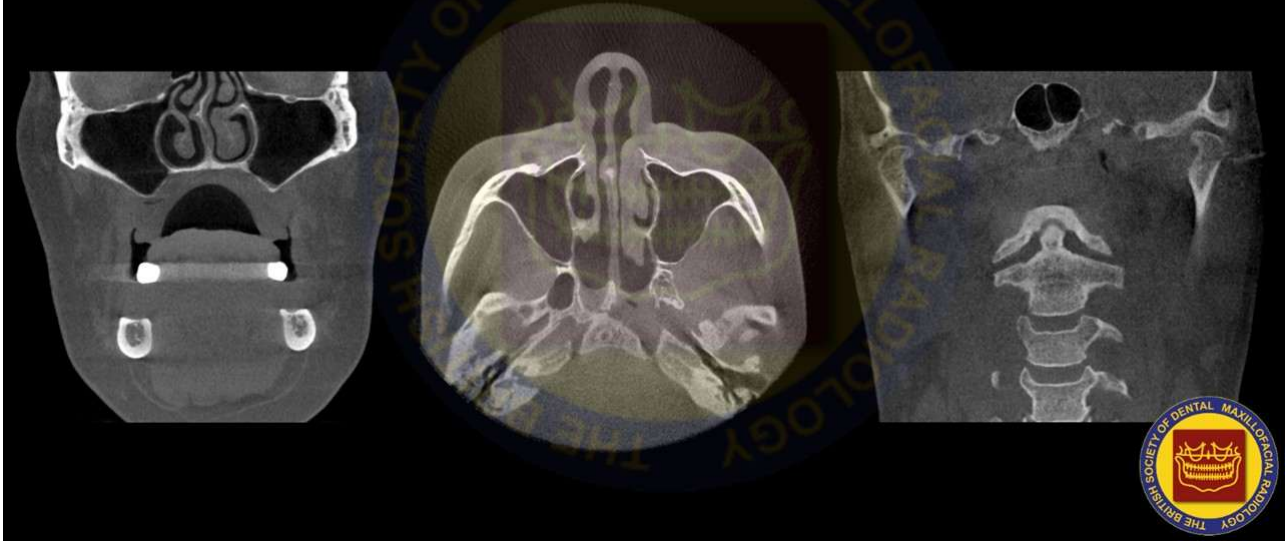


# 6x6cm

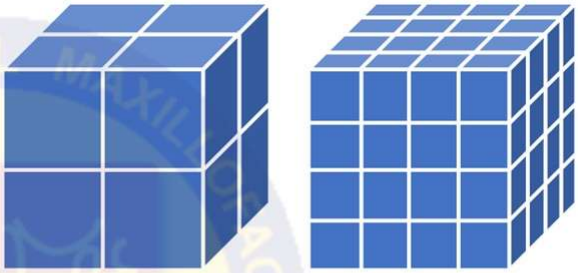




# 17x12 implant



# Voxel size

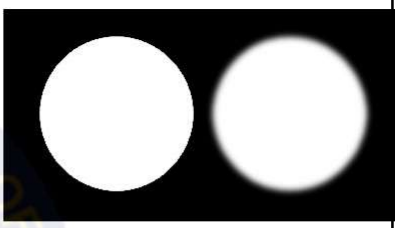


- 3D pixels
- 'Building blocks' of the image
- Smaller voxels
  ↑ resolution ↑ dose (for same SNR)
- Voxel size may be limited by FOV

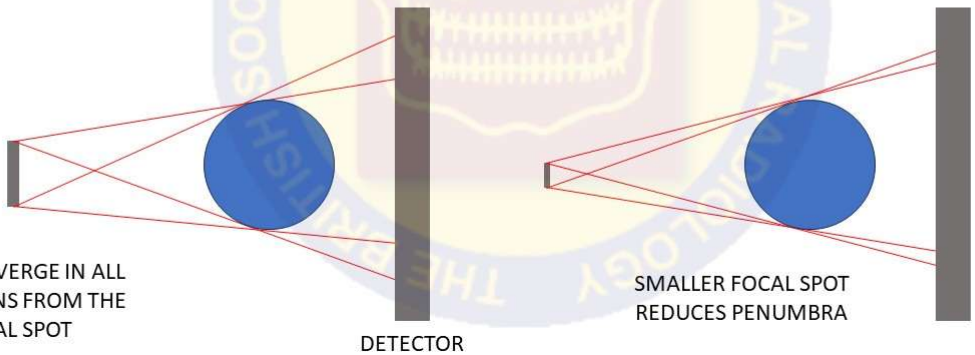




# Focal Spot

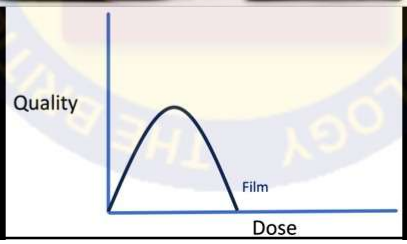


- Smaller focal spot = ↑ spatial resolution
- Penumbra / Geometric unsharpness "blurry edge"
- 0.5 mm common (0.2-0.7)



# Relationship between image quality and dose

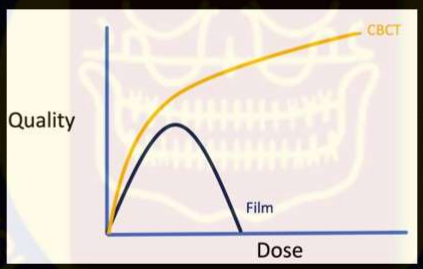







# Relationship between image quality and dose






# Reconstruction algorithm

- Trade secret
- Complex mathematical models

- Feldkamp
- Iterative reconstruction
- AI-based models

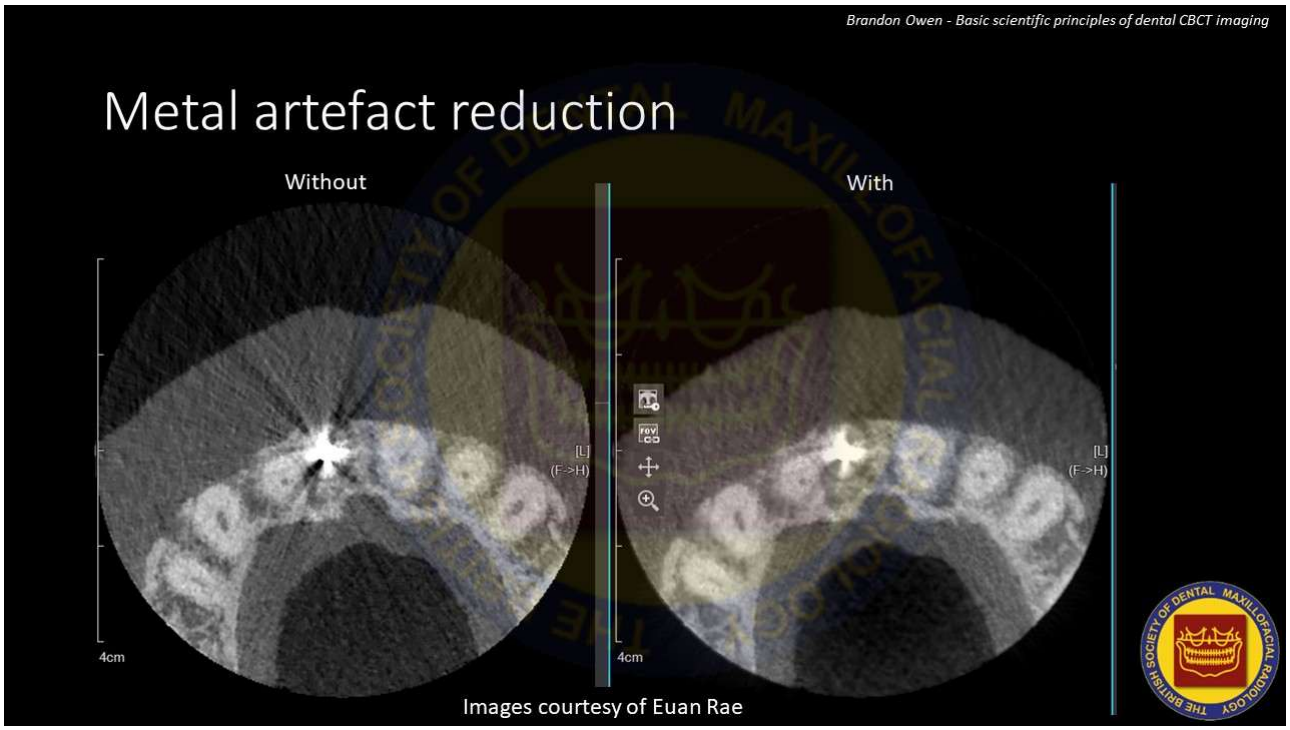


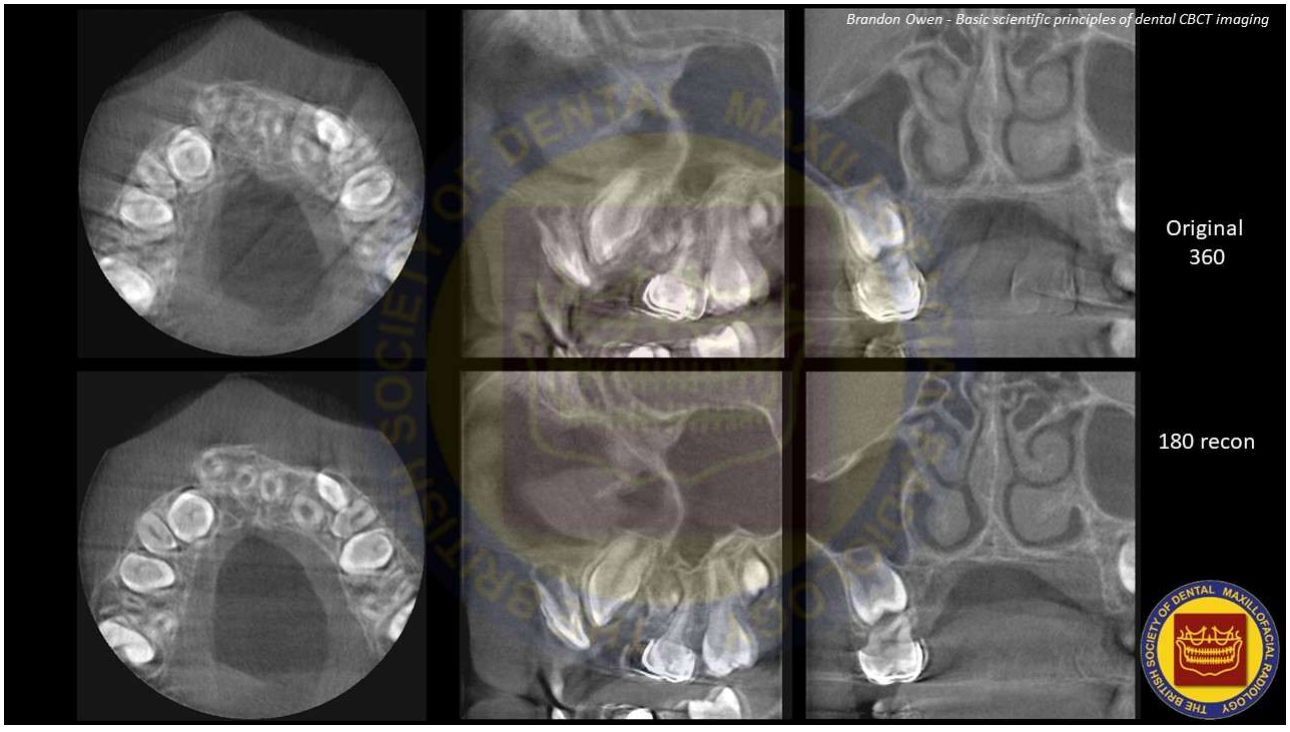


# Image processing

- Metal artefact reduction
- Motion artefact reduction
- Noise reduction

- Vary by manufacturer
- Variable impact on image quality


Brandon Owen - Basic scientific principles of dental CBCT imaging
Metal artefact reduction
Without
With
[L]
(F->H)
4cm
Images courtesy of Euan Rae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Original
360
180 recon

# Monitors

**Picture archiving and communication systems (PACS) and guidelines on diagnostic display devices**
**Third edition**

**Table 1: Recommendations for display standards in primary diagnostic work**

| Feature | Plain film X-ray | CT scan | MRI scan | Ultrasound scan | Fluoroscopy | Nuclear medicine |
|---|---|---|---|---|---|---|
| Minimum resolution (Megapixels) | 2048 x 1536 (3 MP) | 1600 x 1200 (2 MP) | 1600 x 1200 (2 MP) | 1600 x 1200 (2 MP) | 1600 x 1200 (2 MP) | 1600 x 1200 (2 MP) |
| Megapixel resolution | 3 MP | 2 MP | 2 MP | 2 MP | 2 MP | 2 MP |
| Maximum pixel pitch | 0.21 mm | 0.21 mm | 0.21 mm | 0.25 mm | 0.25 mm | 0.25 mm |
| Orientation | Portrait format | Portrait/ landscape | Portrait/ landscape | Portrait/ landscape | Portrait/ landscape | Portrait/landscape |
| Calibration | DICOM GSDF ≤10% | DICOM GSDF ≤10% | DICOM GSDF ≤10% | DICOM GSDF or sRGB ≤20% | DICOM GSDF or sRGB ≤20% | DICOM GSDF or sRGB ≤20% |
| Luminance (min/max) | 1/350 cd/m² | 1/350 cd/m² | 1/350 cd/m2 | 0.8/250 cd/m² | 0.8/250 cd/m² | 0.8/250 cd/m² |

https://www.rcr.ac.uk/our-services/all-our-publications/clinical-radiology-publications/picture-archiving-and-communication-systems-pacs-and-guidelines-on-diagnostic-display-devices-third-edition/

*Brandon Owen - Basic scientific principles of dental CBCT imaging*

# Monitors

**Picture archiving and communication systems (PACS) and guidelines on diagnostic display devices**
**Third edition**

**Table 2: Clinical and mobile review display standards**

| Feature | All |
|---|---|
| Minimum resolution (Megapixels) | 1600 x 1200 (2 MP) |
| Megapixel resolution | 2 MP |
| Maximum pixel pitch | 0.25 mm |
| Colour/monochrome | Colour |
| Orientation | Landscape or portrait format |
| Calibration | DICOM GSDF ≤20% or using TG18 test pattern |
| Luminance (min/max) | 1/250 cd/m² |

https://www.rcr.ac.uk/our-services/all-our-publications/clinical-radiology-publications/picture-archiving-and-communication-systems-pacs-and-guidelines-on-diagnostic-display-devices-third-edition/

# Viewing conditions

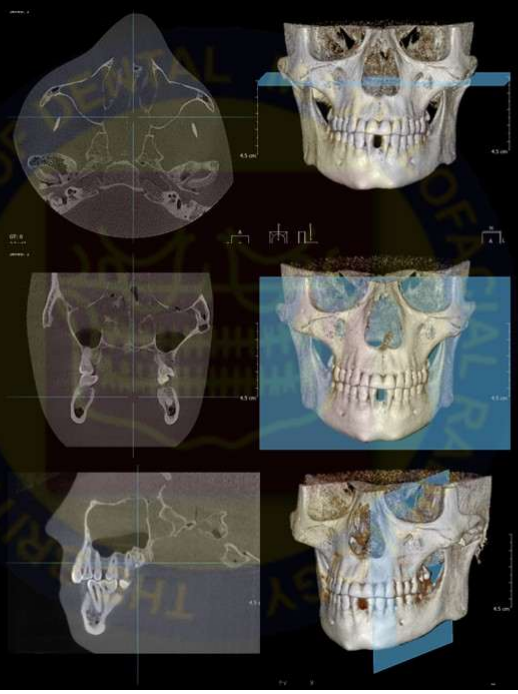




# Image manipulation

- Multiplanar reconstruction
- Pseudo-panoramic reconstruction
- Cross-sections
- 3D volume rendering
- Segmentation and mapping of anatomical structures
- Fusion with surface scan data

# Multiplanar reconstruction



Axial

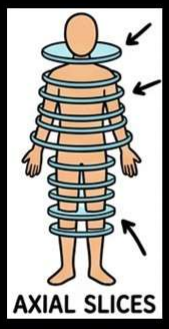
Coronal

Sagittal

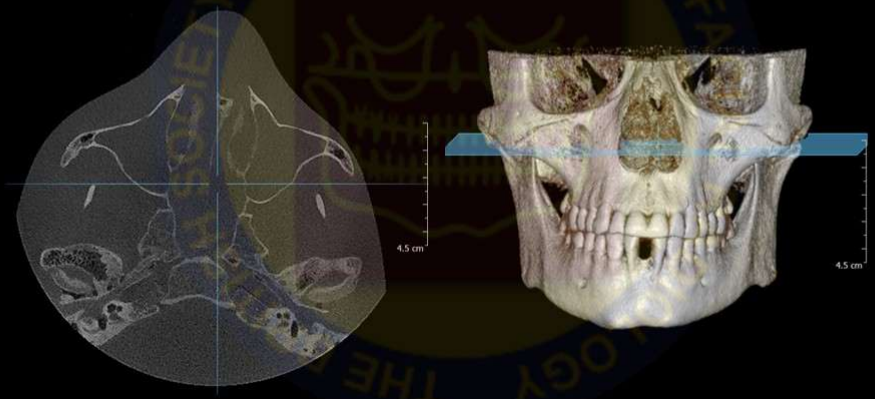
Images of human skull phantom courtesy of Rosalyn Clarkson



# Multiplanar Reconstruction: Axial Plane

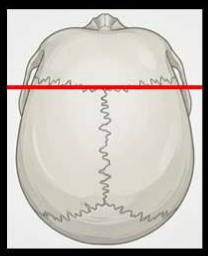


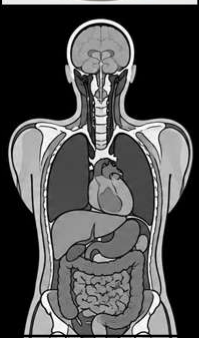


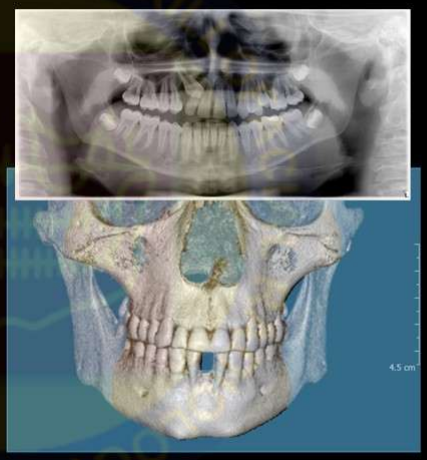

Images of human skull phantom courtesy of Rosalyn Clarkson

# Multiplanar Reconstruction: Coronal Plane





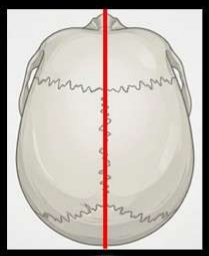


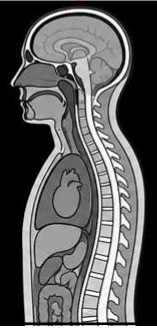


Images of human skull phantom courtesy of Rosalyn Clarkson

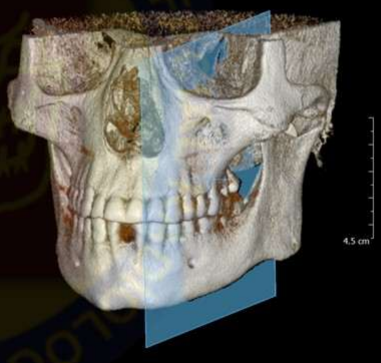
Brandon Owen - Basic scientific principles of dental CBCT imaging

# Multiplanar Reconstruction: Sagittal Plane





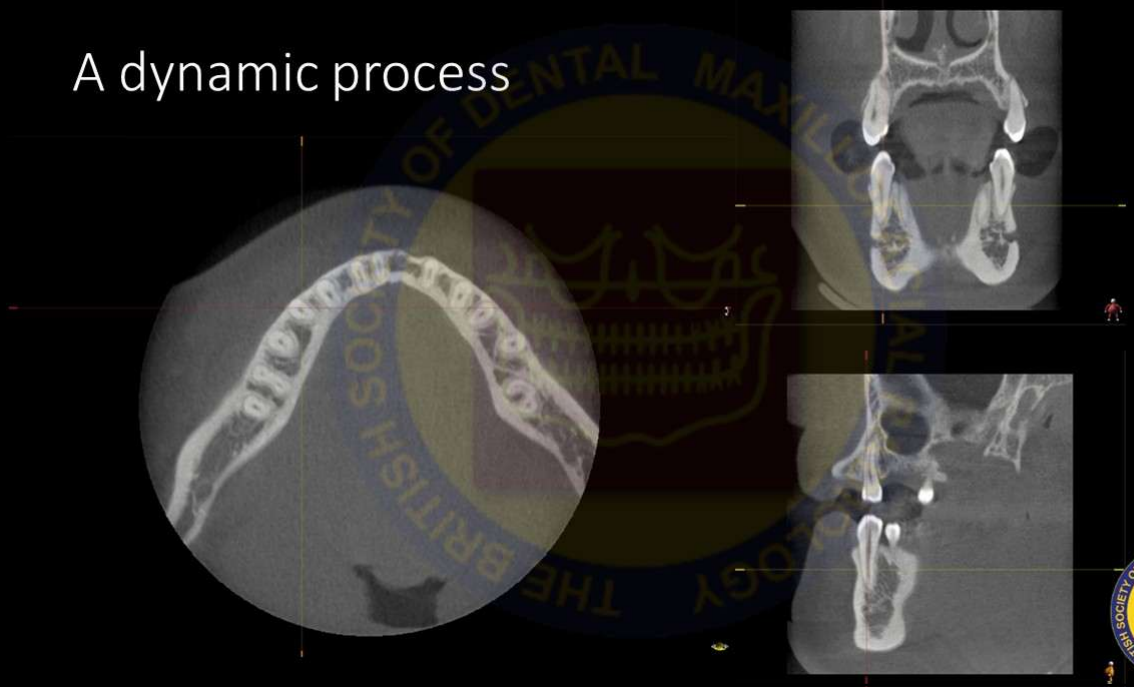




Images of human skull phantom courtesy of Rosalyn Clarkson

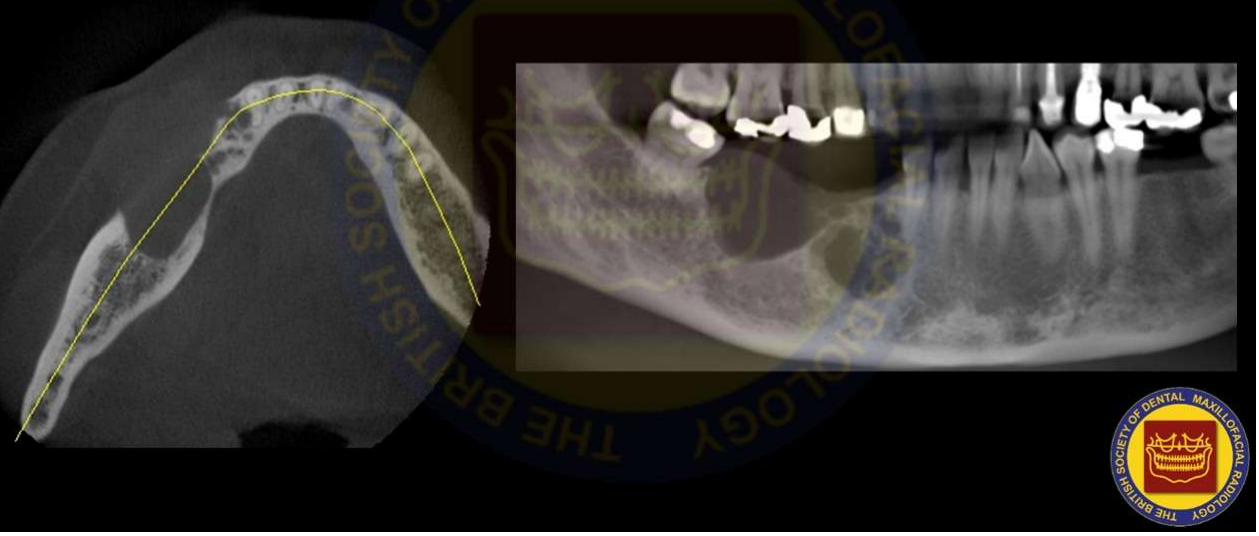
"Sagittal sides"

# A dynamic process





# Pseudopanoramic reconstruction

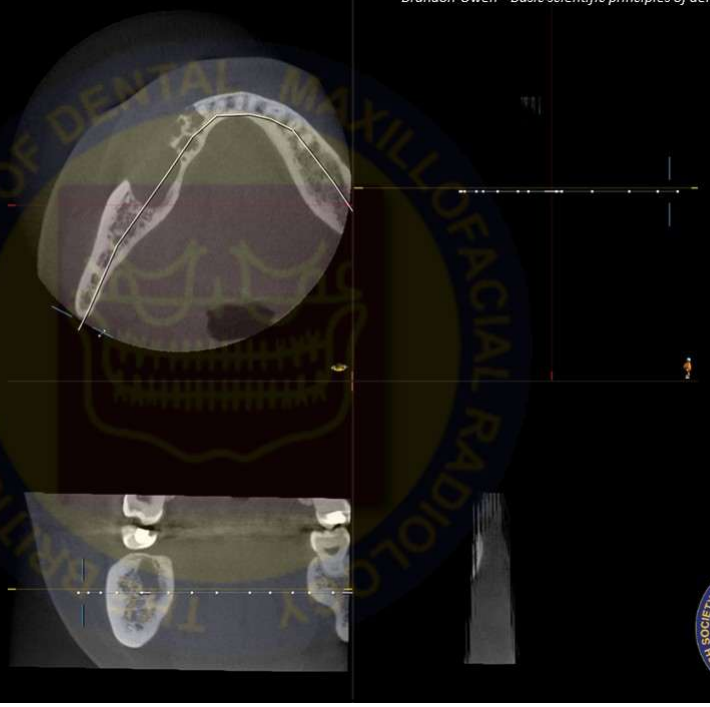


# Pseudopanoramic reconstruction

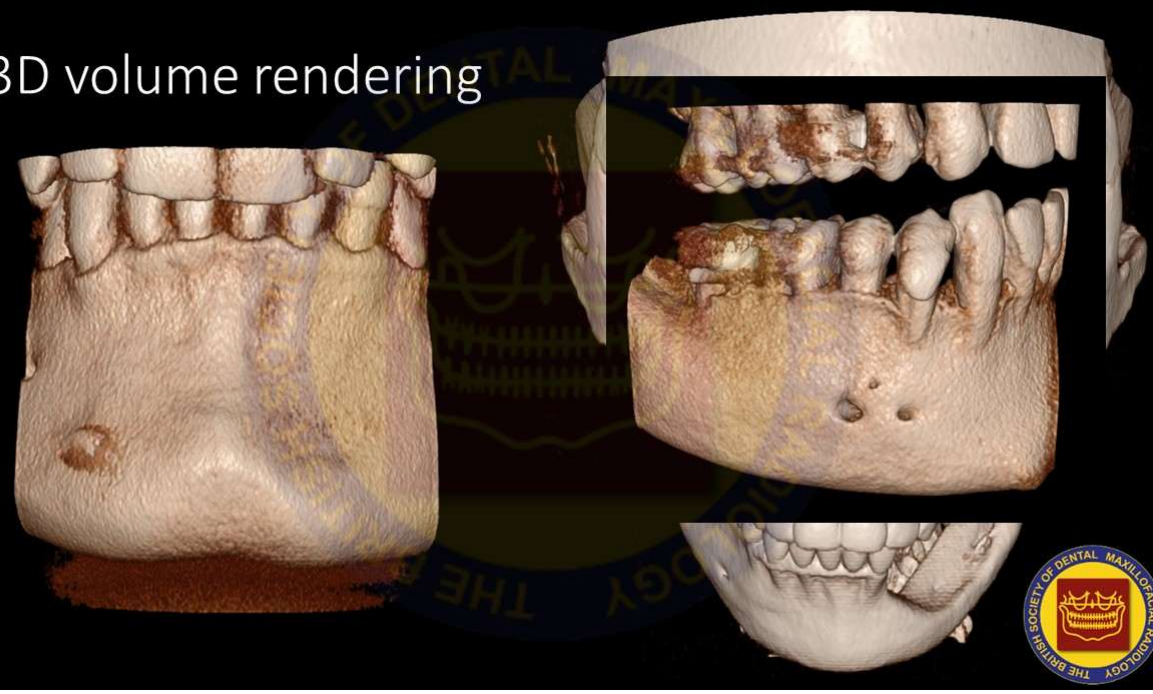




# Cross-sections



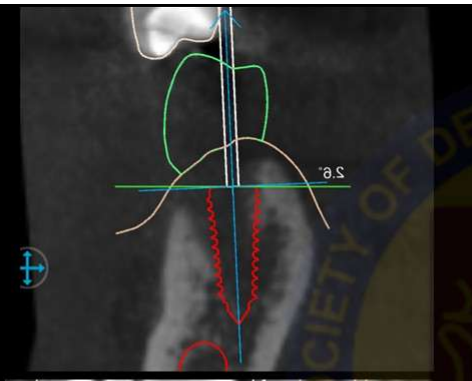
## 3D volume rendering

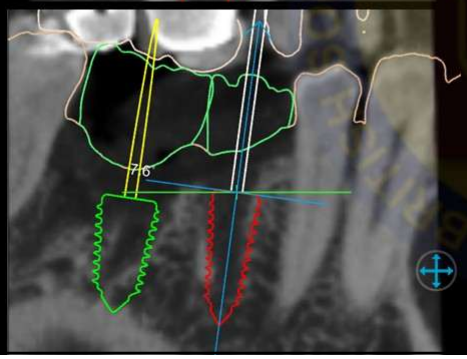


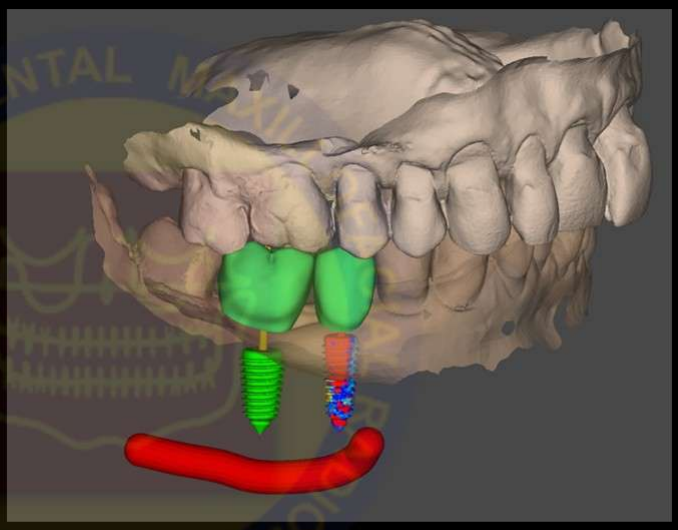


## Mapping of inferior alveolar canal









## Digital workflow



## Conclusion

- CBCT is a cross-sectional or three dimensional imaging modality
- Excellent hard tissue detail
- Greater doses than plain dental radiographs
- Carefully consider components of the imaging chain to optimise images
- Quality vs dose