Image Diagnostic Technology Ltd
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Diagnostic Imaging in Implant Dentistry

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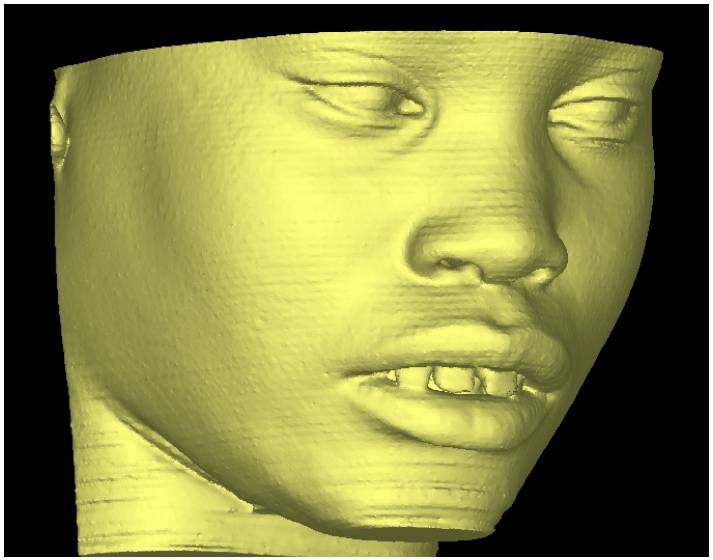
Registered Clinical Scientist CS03469

Image Diagnostic Technology Ltd.

Who or what is IDT?

Image Diagnostic Technology Ltd aka "IDT Scans"



Specialises in:

- **arranging dental CT/CBCT scans**
- **prepare datasets for implant planning**
- **radiology reports**
- **implant simulation & treatment planning**
- **3D models**
- **surgical drill guides**

33,000 scans processed since 1991

What can IDT do with my images?

- **Prepare datasets for planning implants**
- **Radiology Reports**
- **Treatment Plans**
- **3D Models**
- **Surgical Drill Guides**

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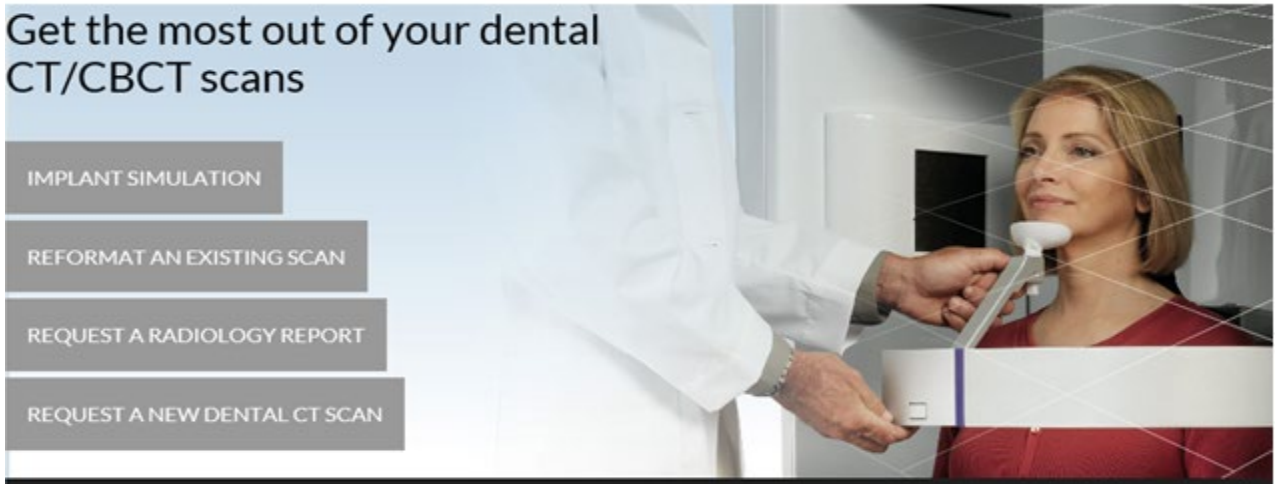

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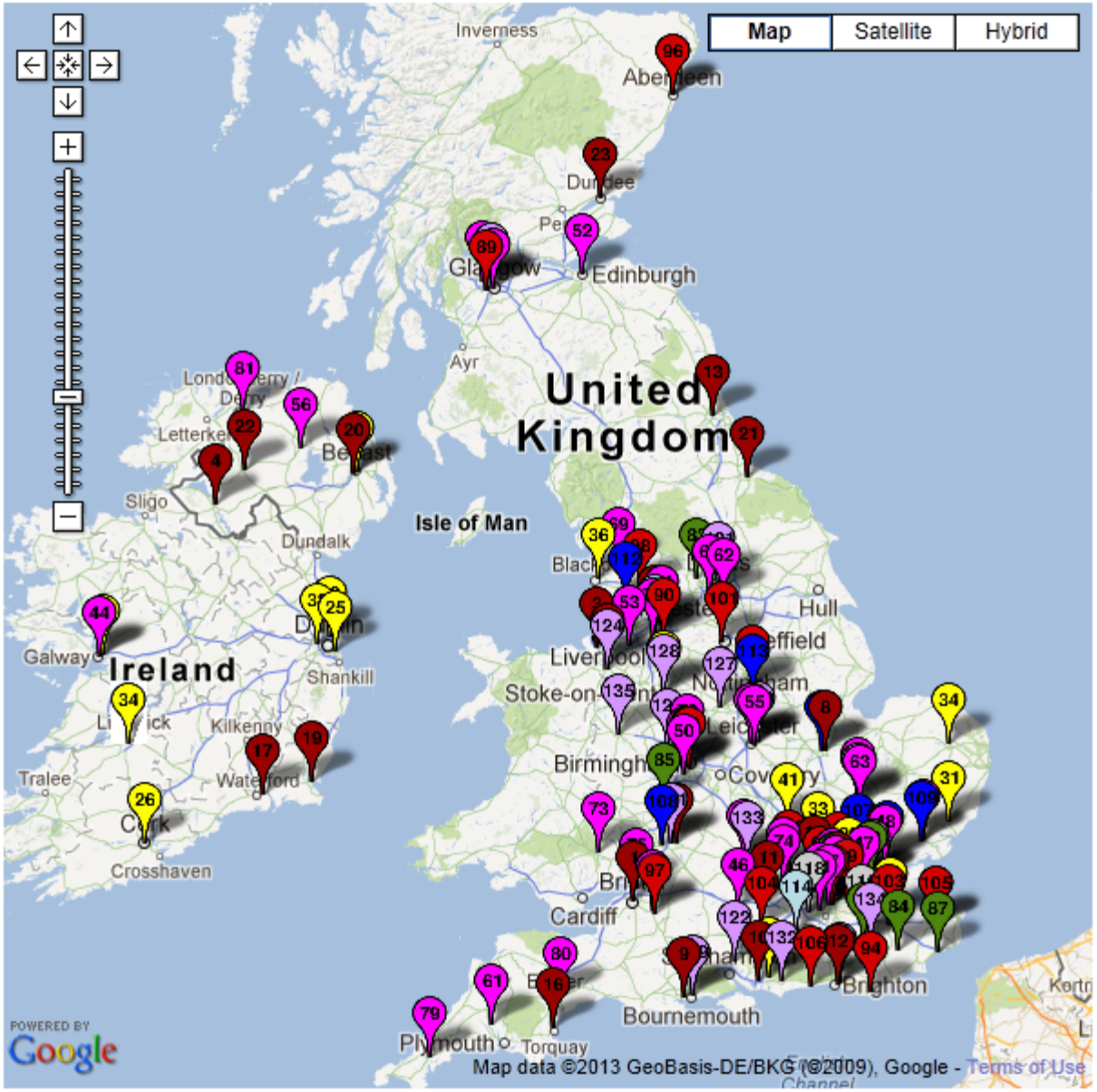

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Scan Site Search

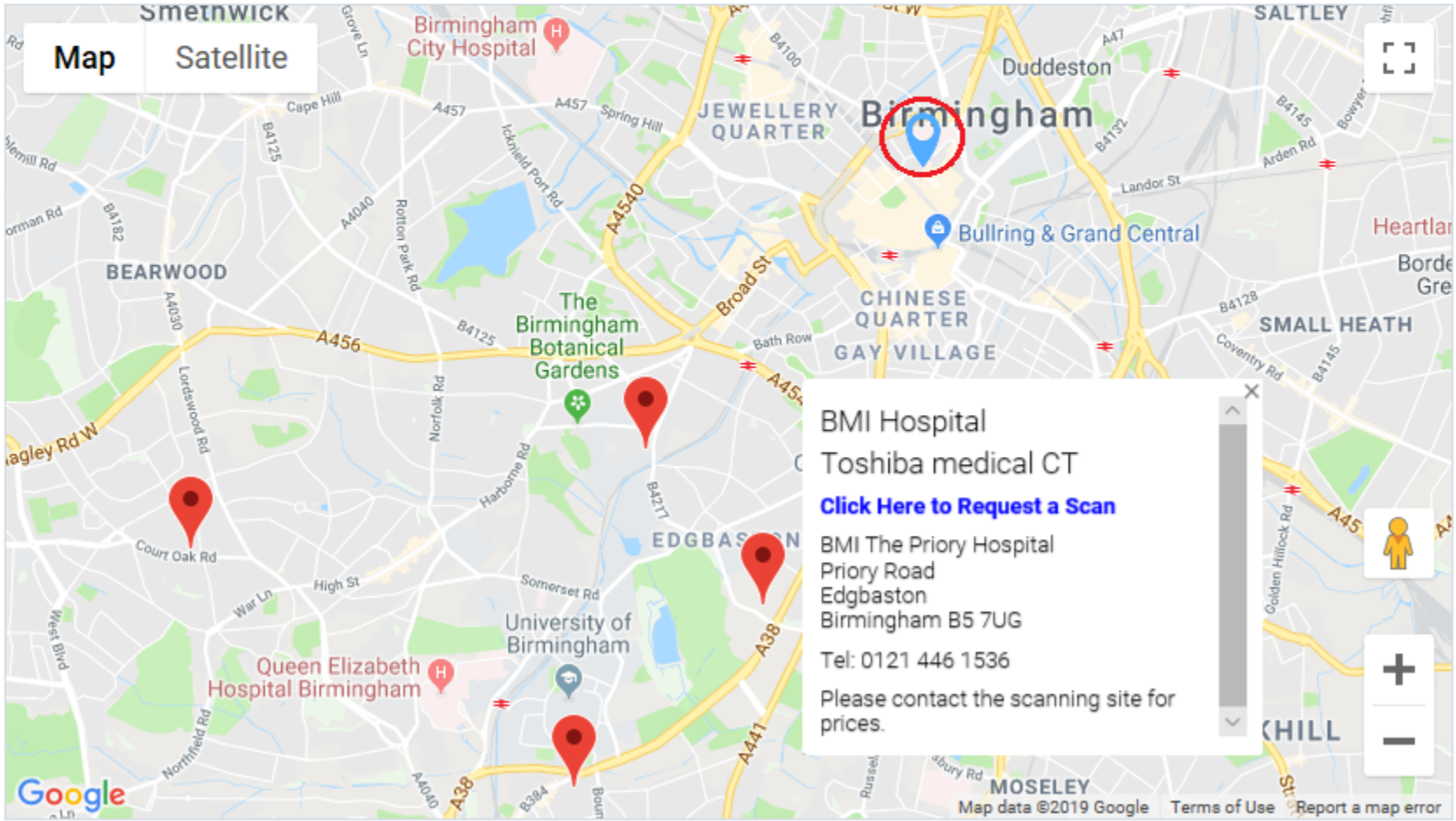
Location Keyword A-Z List

United Kingdom ◉ Ireland ○

B4 6BN | 10 miles | Search

Found 6 sites. Please click the icons for more information.

Name	Distance
Cavendish Imaging Birmingham	1.6 miles
BMI The Priory Hospital	1.9 miles
CT Dent Birmingham	2.9 miles
The Birmingham Periodontal and Implant Centre	3.4 miles
Scott Arms Dental Practice	4.5 miles
Central England Specialist Referral Centre	6.8 miles



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Outline of Lectures

- ✔ **Introduction / Disclosures**
- **Diagnostic Imaging in Dentistry**
  - **Conventional Radiography**
  - **CT / CBCT Scans**
- **Computer software for planning dental implants**
- **Radiation Safety**
- **3D models and surgical drill guides**

Introduction to Dental Imaging

Anthony Reynolds BA MSc PhD

Image Diagnostic Technology Ltd.

What do we use dental imaging for?

Review patient anatomy and pathology

- **requires diagnostic quality images**
- **at a low radiation dose**

Answer specific clinical questions

- **is caries present**
- **how many teeth are present**
- **quality and quantity of bone**
- **pain or inflamation that requires investigation**

Imaging for specific dental applications

- **Planning dental implants**
- **Endodontics**
- **Orthodontics**
- **Othognathic Surgery**
- **TMJ and Airway Analysis**

These have their own specific imaging requirements.

Imaging for Dental Implants

Need to be able to:

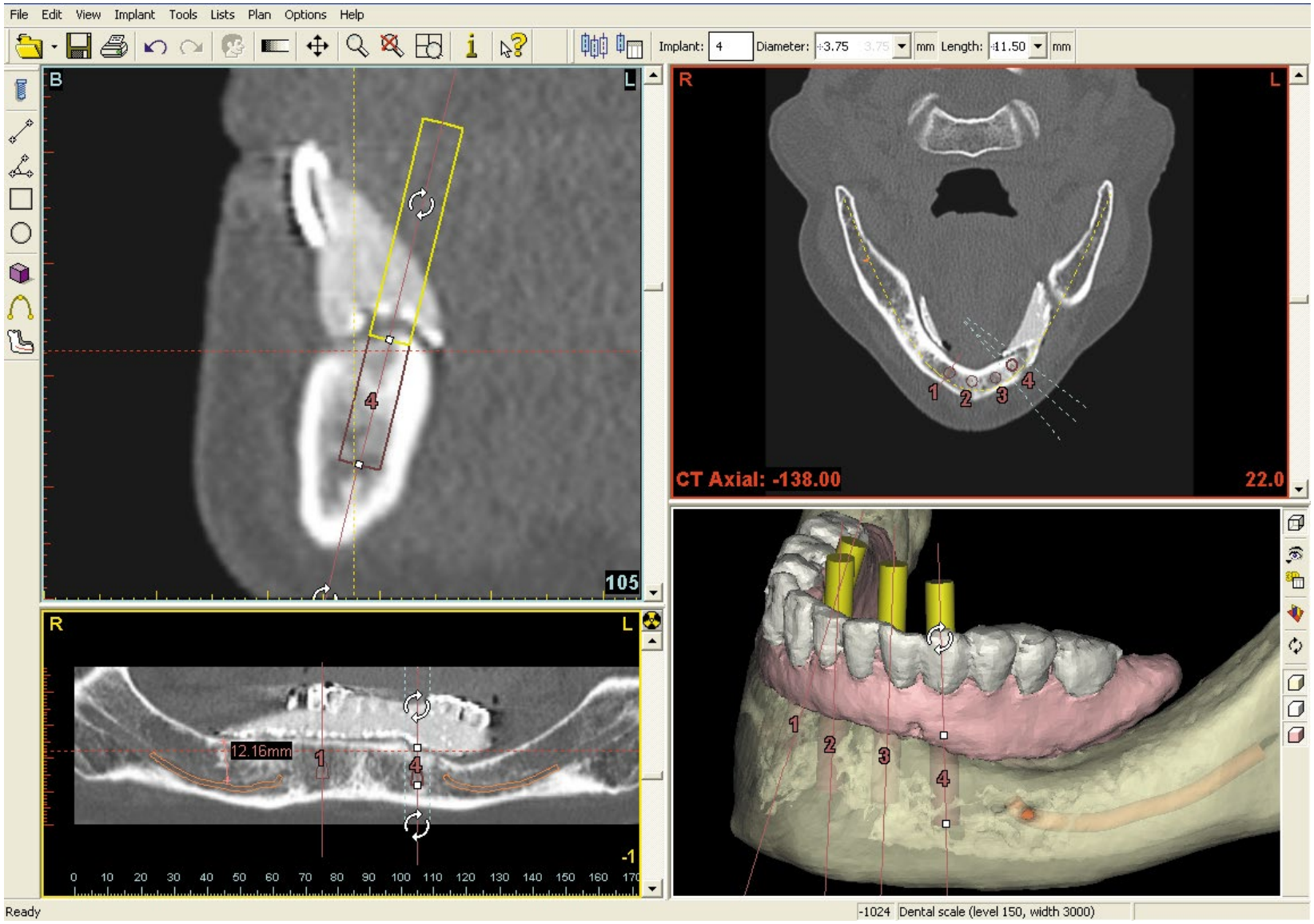
- **Review patient anatomy and pathology**
  - **diagnostic quality images**
- **Assess bone quantity and quality**
  - **quantitative assessment**
- **Decide where implants should go**
  - **accurate 3D measurements**
  - **avoid sensitive structures**
  - **must work mechanically and aesthetically**

Restoration-Driven Implant Planning

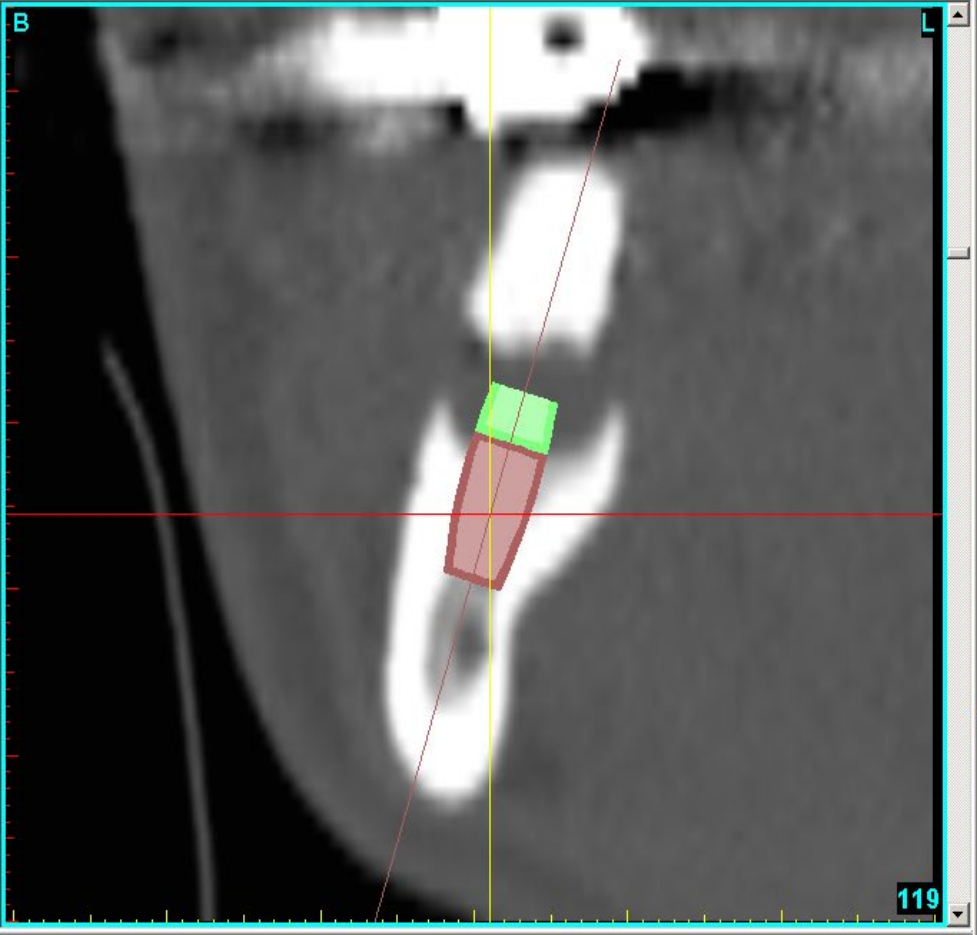
"Create a model of the desired result, then work backwards to determine how it can be achieved"

- ***3D Treatment Planning Software***
- ***Radio-Opaque Scanning Stents***
- ***Surgical Drill Guides***

SimPlant Computer Guided Implantology — *interactive implant planning software*



Simplant™ is a trademark of Dentsply Sirona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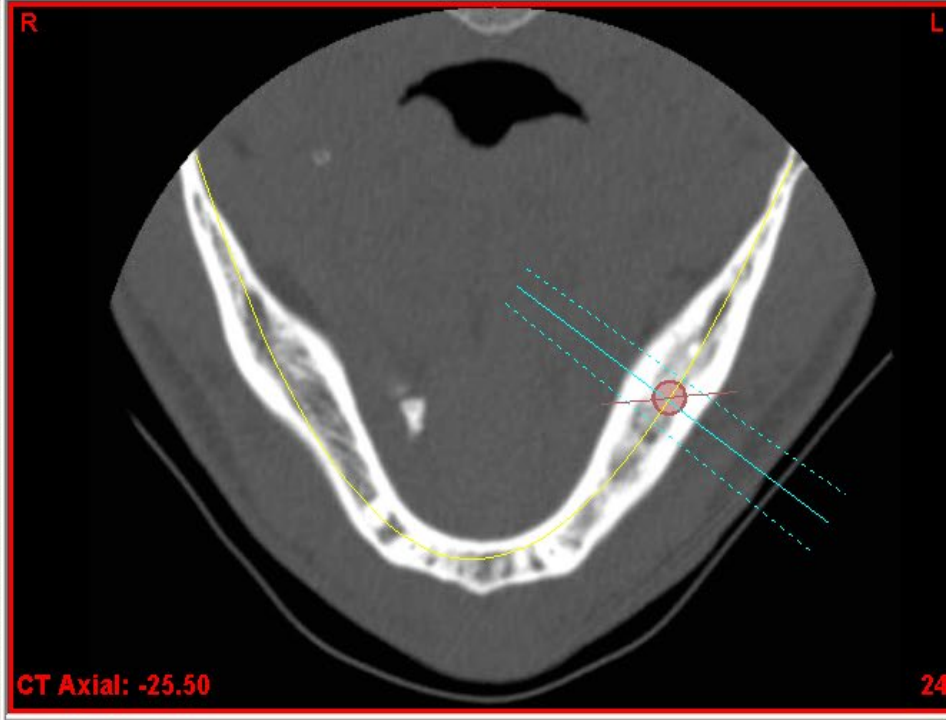
119


R
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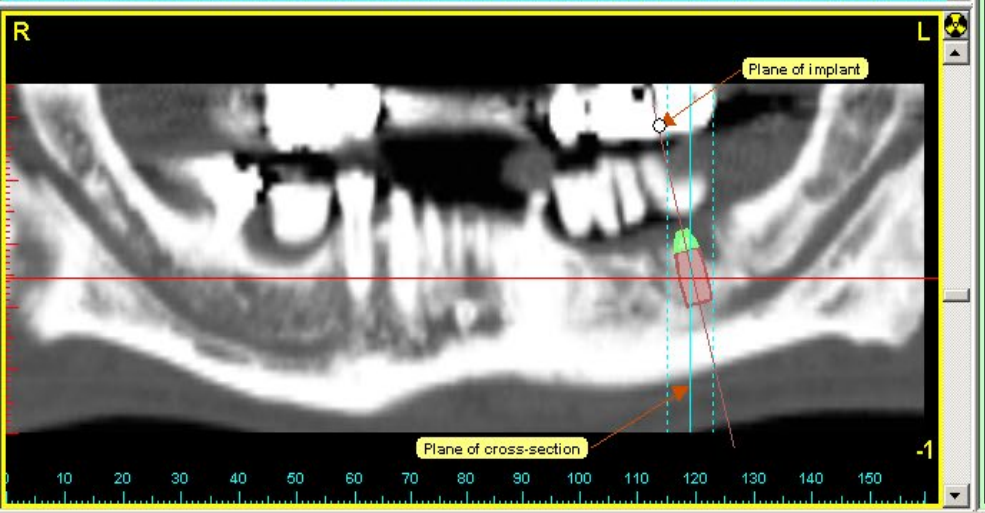
CT Axial: -25.50
24


R
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Plane of implant
Plane of cross-section
-1
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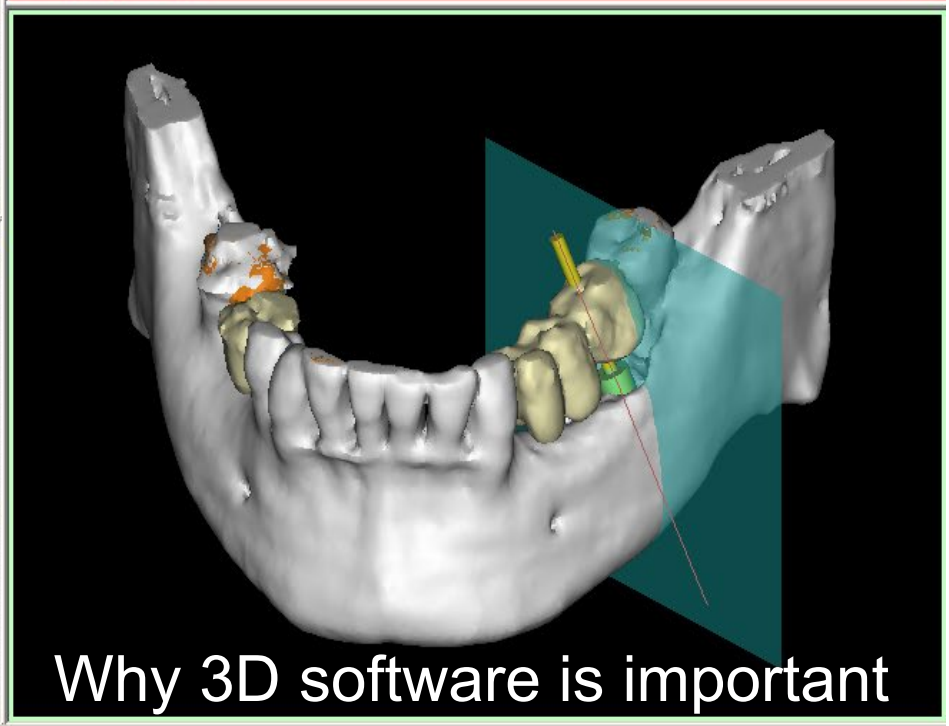
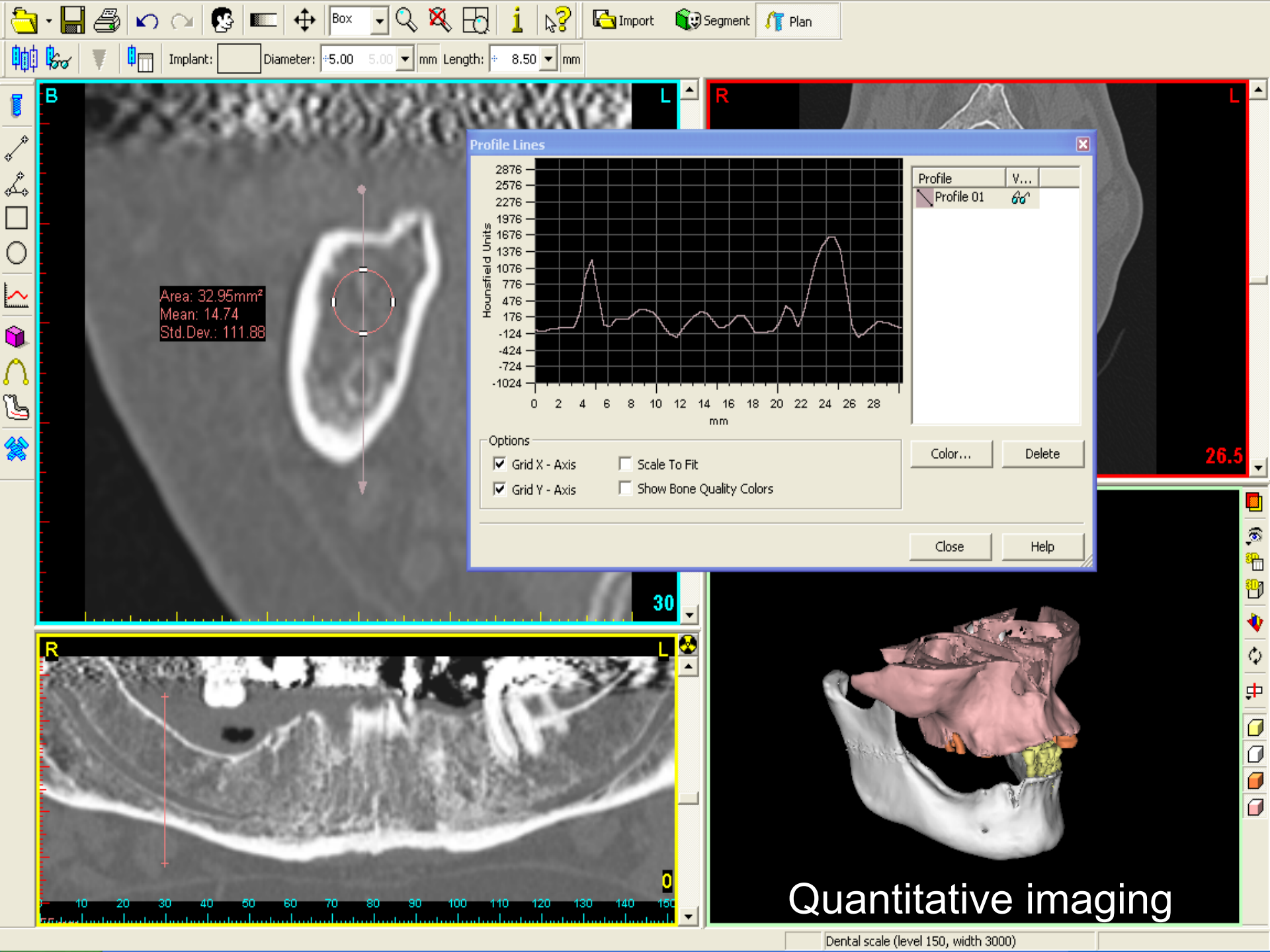
150


Why 3D software is important


Box
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Plan
Implant:
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mm
Length:
8.50
mm
B
L
Area: 32.95mm²
Mean: 14.74
Std.Dev.: 111.88
30
R
L
26.5
Profile Lines
Hounsfield Units
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2576
2276
1976
1676
1376
1076
776
476
176
-124
-424
-724
-1024
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
mm
Profile
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Profile 01
Options
Grid X - Axis
Grid Y - Axis
Scale To Fit
Show Bone Quality Colors
Color...
Delete
Close
Help
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0
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Quantitative imaging
Dental scale (level 150, width 3000)

Software for planning Dental Implants

- **Simplant (Dentsply Sirona)**
- **Blue Sky Plan (Blue Sky Bio)**
- **Osirix (with Dental3D plugin)**
- **In Vivo Dental (Anatomage)**
- **Nobel Clinician (Nobel Biocare)**
- **coDiagnostiX (Dental Wings)**
- **Carestream CS3D**
- **etc etc**

Simplant Pro

(Windows only)

- **Costs around £5500+VAT from Dentsply Sirona**
- **Can be used with any implant system**
- **Very realistic implants, abutments, crowns**
- **Can import DICOM CT/CBCT data**
- **Can import STL files from optical scanners**
- **Can be used to design surgical drill guides**
  (but they must be manufactured by Dentsply Sirona)
- **Extensive support available at Simplant Academy**

Blue Sky Plan

(Macintosh or PC)

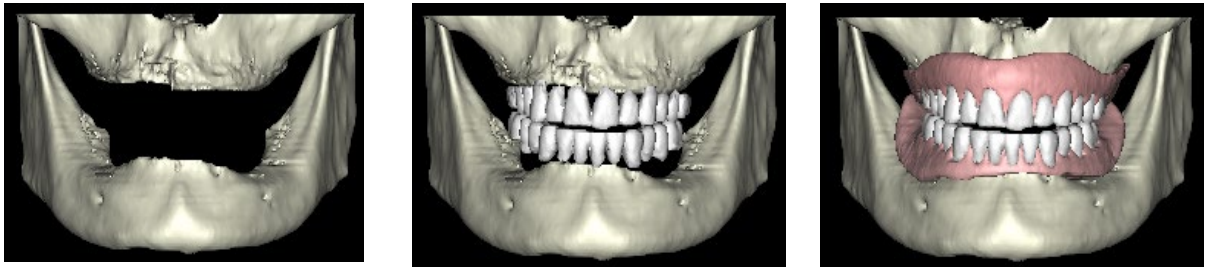
- **Free Software produced by Blue Sky Bio**
- **Can be used with any implant system**
  (but only Blue Sky Bio implants are realistic)
- **Can import DICOM CT or CBCT data**
- **Can import STL files from optical scanners**
- **Can be used to design surgical drill guides**
  (but there is a charge to export the STL file)
- **Can be used to design dentures, orthodontic aligners etc**
- **Extensive videos available on YouTube**

Restoration-Driven Implant Planning

"Create a model of the desired result, then work backwards to determine how it can be achieved"

- ✔ ***3D Treatment Planning Software***
- ***Radio-Opaque Scanning Stents***
- ***Surgical Drill Guides***

Advantages of using a Scanning Stent

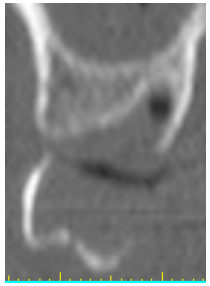


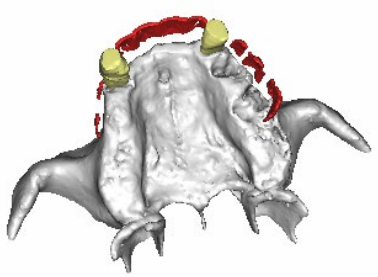
- **Gives inter-arch stability for the patient during the scan**
- **Opens the bite slightly (a few mm) using occlusal stops**
- **Shows position and size of the desired restorations**
- **Shows inter-arch relationship**
- **If you want a mucosa-supported surgical guide, edentulous patients MUST be scanned wearing a stent**

Making a Scanning Stent

- **Plastic and clear acrylic does not show up on a CT scan.**

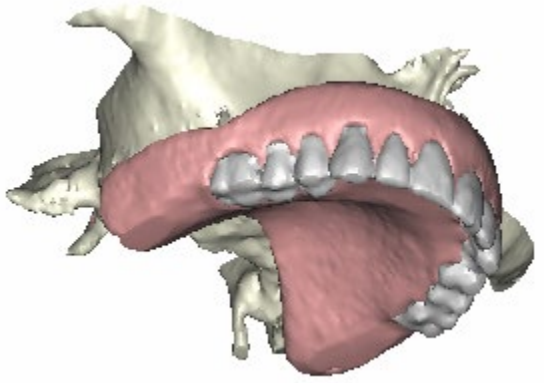
- **To make it show up, you can:**



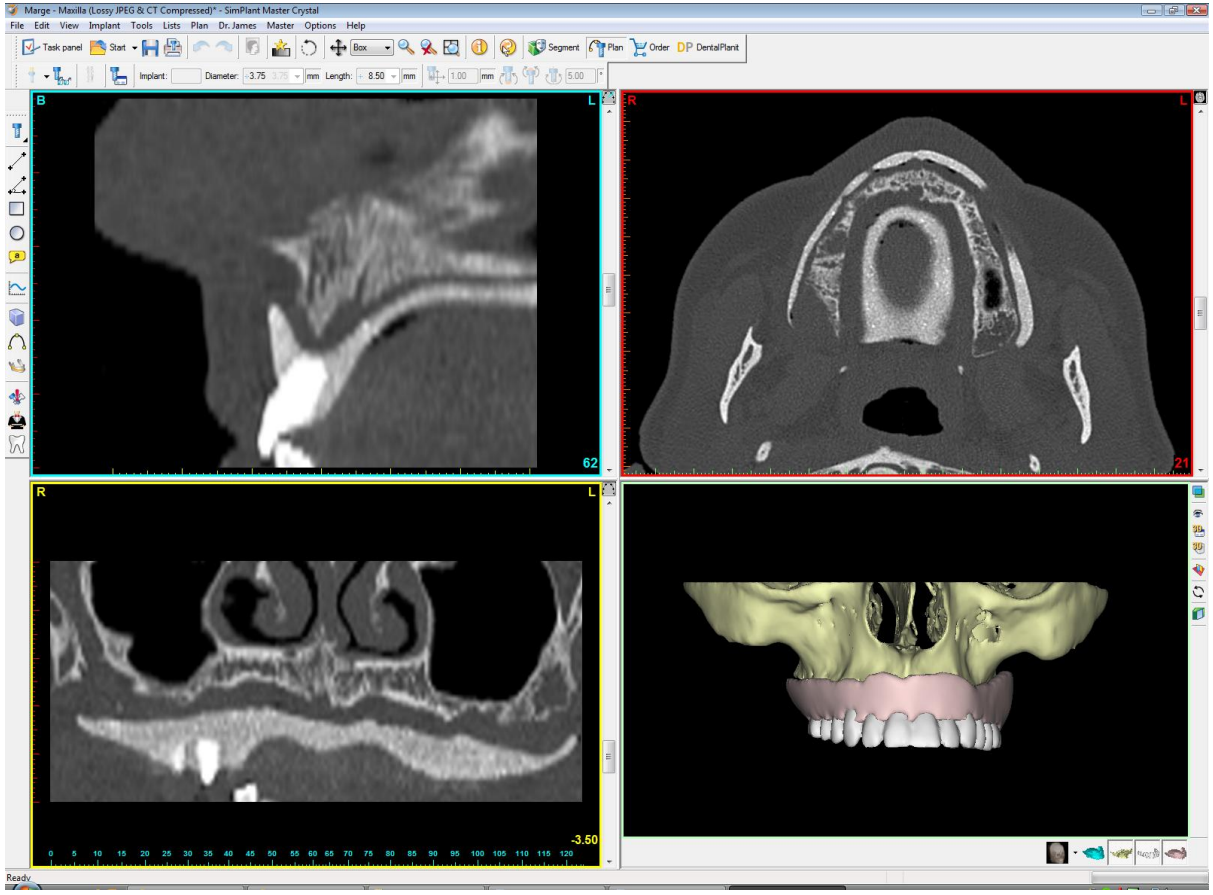


- **mix barium sulphate with the acrylic**
- **paint barium sulphate on the surface**
- **use radio-opaque teeth**
- **use markers made from a radio-opaque material**
  - **lab putty**
  - **gutta percha**
  - **glass ionomer**
- **use a dual-scan technique.**

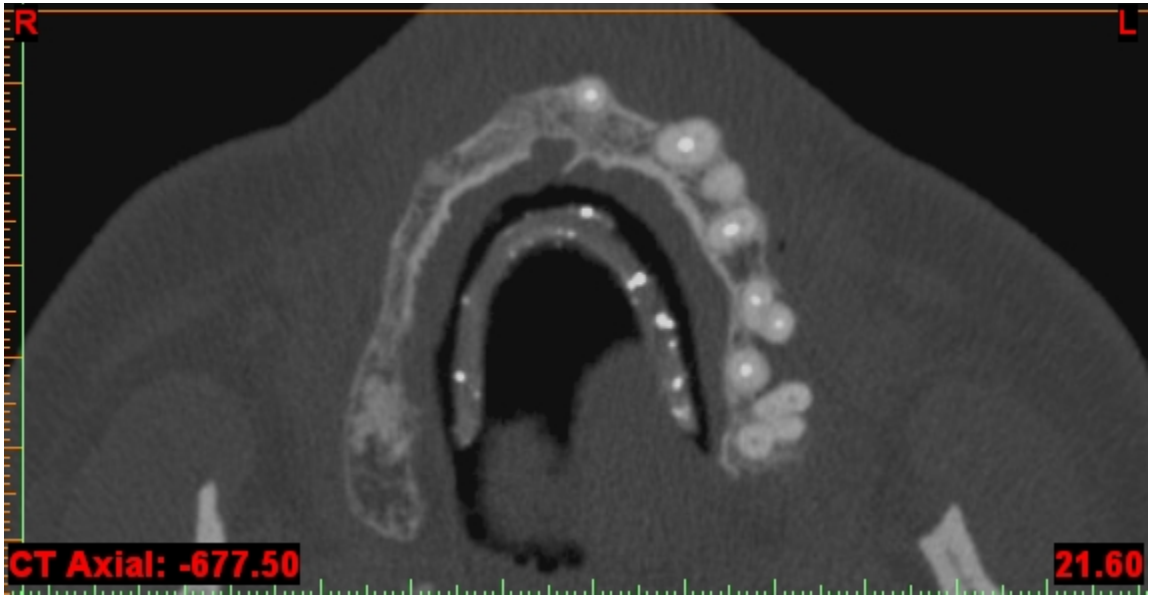
- **We recommend using a barium sulphate-acrylic mix for both the radio-opaque teeth and the baseplate.**
- **Use 15% barium sulphate in the teeth and 10% barium sulphate in the baseplate. This allows the teeth to be picked out separately.**
- **Do not use too much Barium Sulphate as it will cause an artefact.**
- **An accurate fitting stent with radio-opaque baseplate is usually the best option for mucosa-supported surgical drill guides.**



Good Stent


Marge - Maxilla (Lossy JPEG & CT Compressed)* - SimPlant Master Crystal
File Edit View Implant Tools Lists Plan Dr. James Master Options Help
Task panel Start
Segment Plan Order DP DentalPlant
Implant: Diameter: 3.75 mm Length: 8.50 mm
B L
62
R L
21
R L
-3.50
Ready

Bad Stent




B
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Terrible Stent
63


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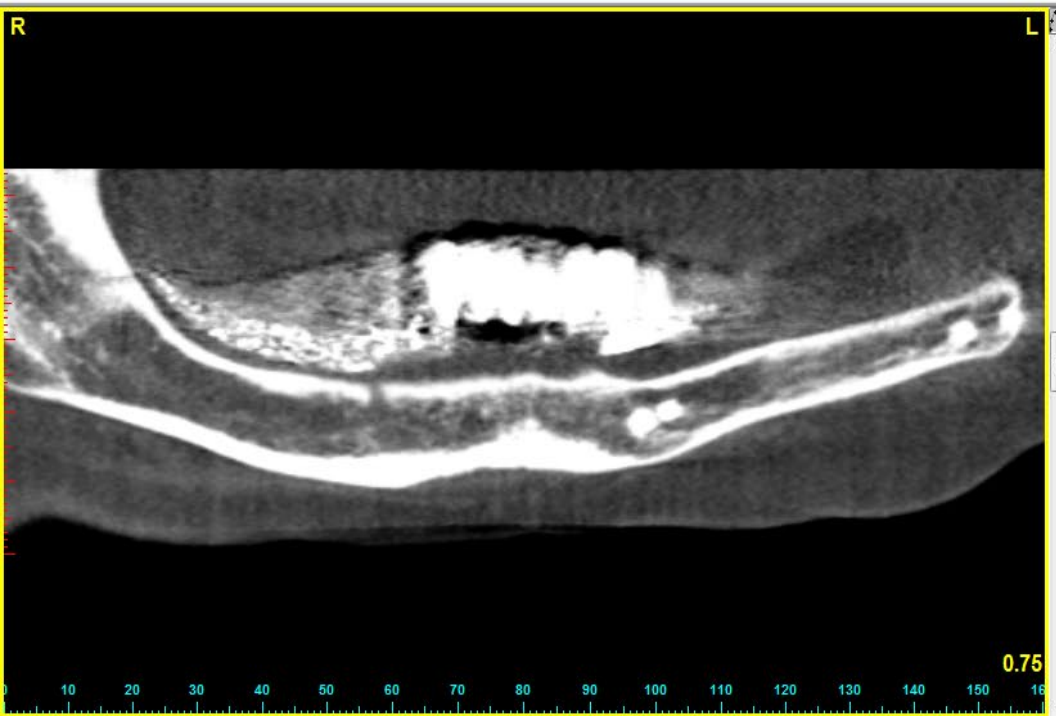
CT Axial: -25.38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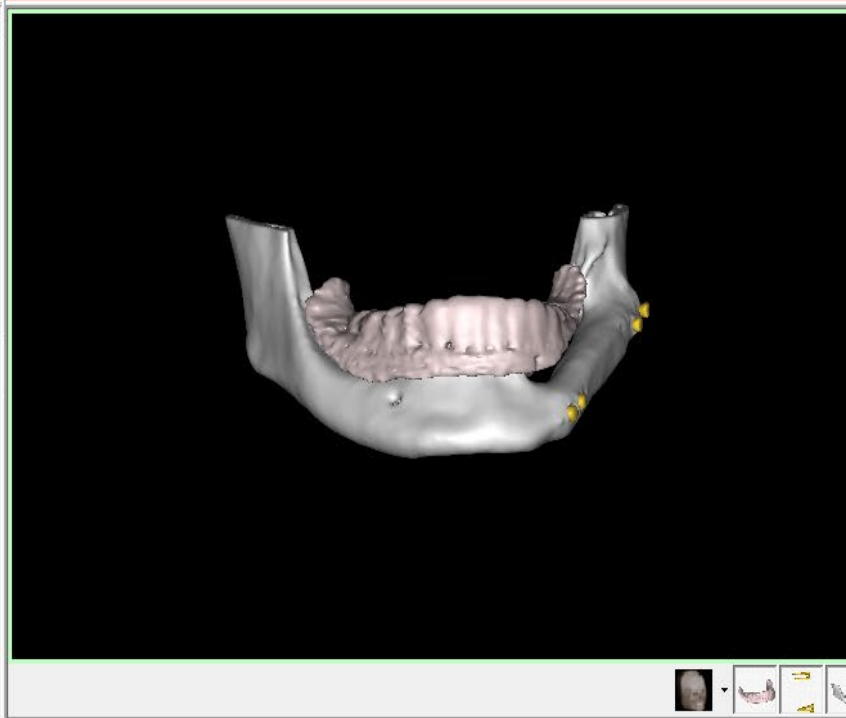
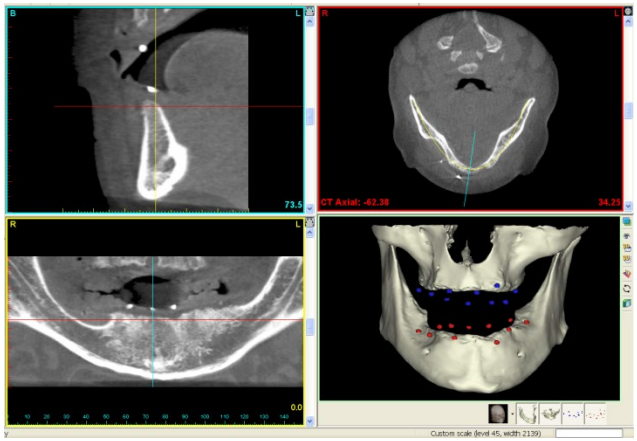


Dual Scan Technique



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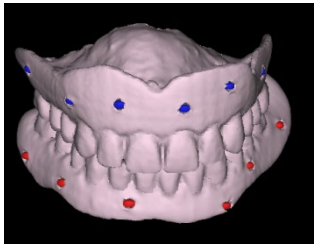

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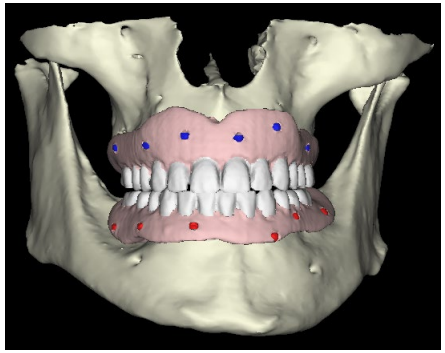

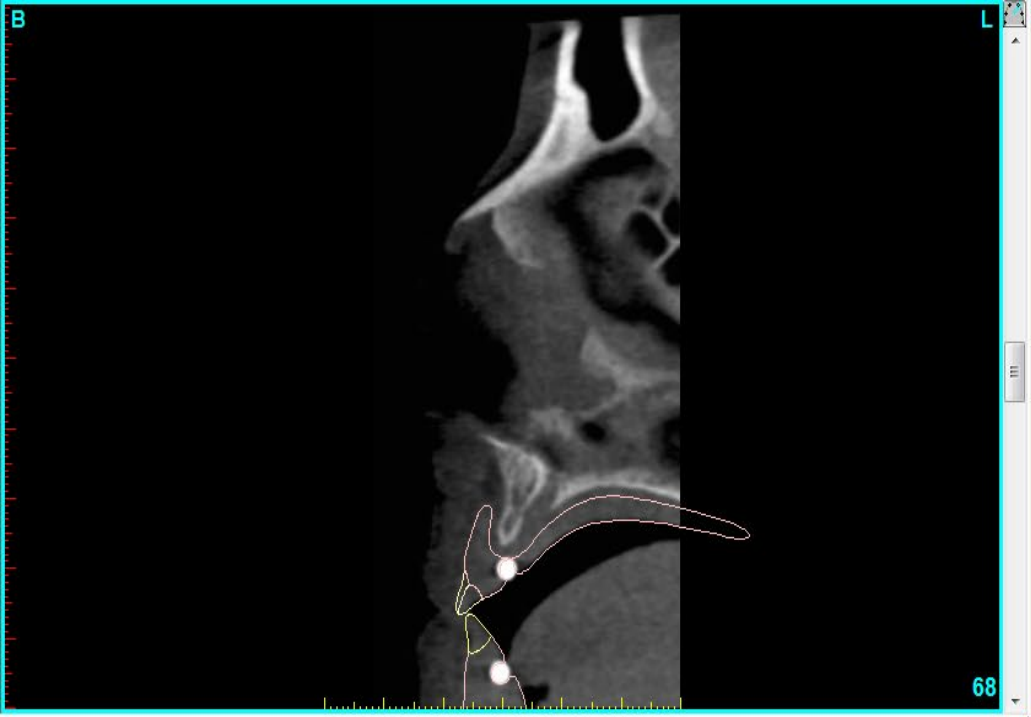
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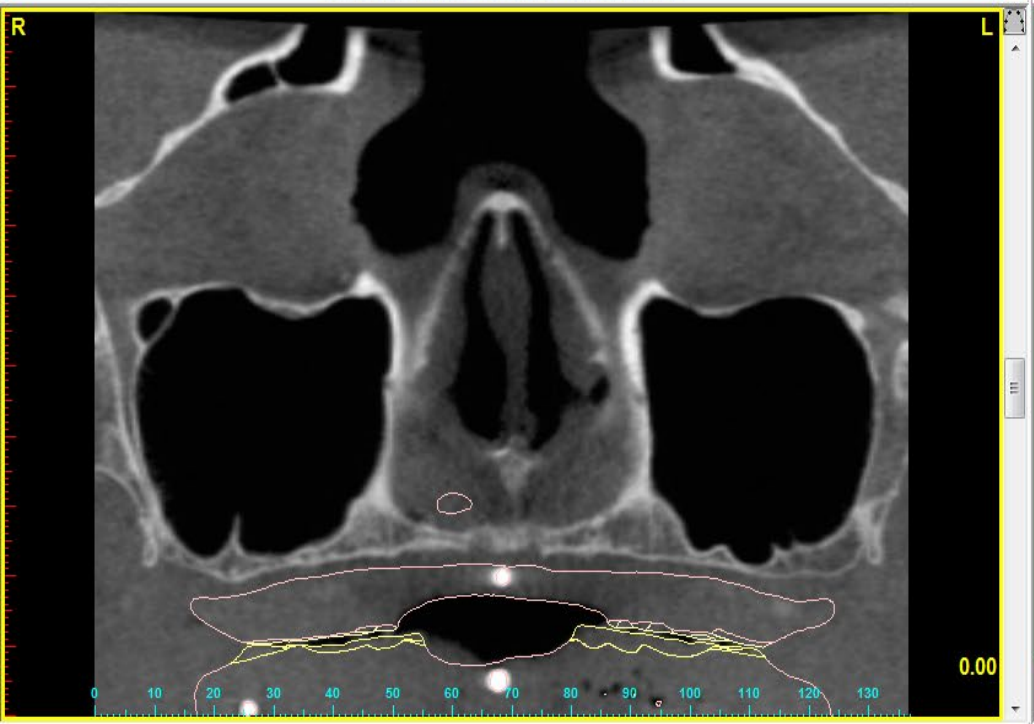
68


R
L
CT Axial: -50.25
50.10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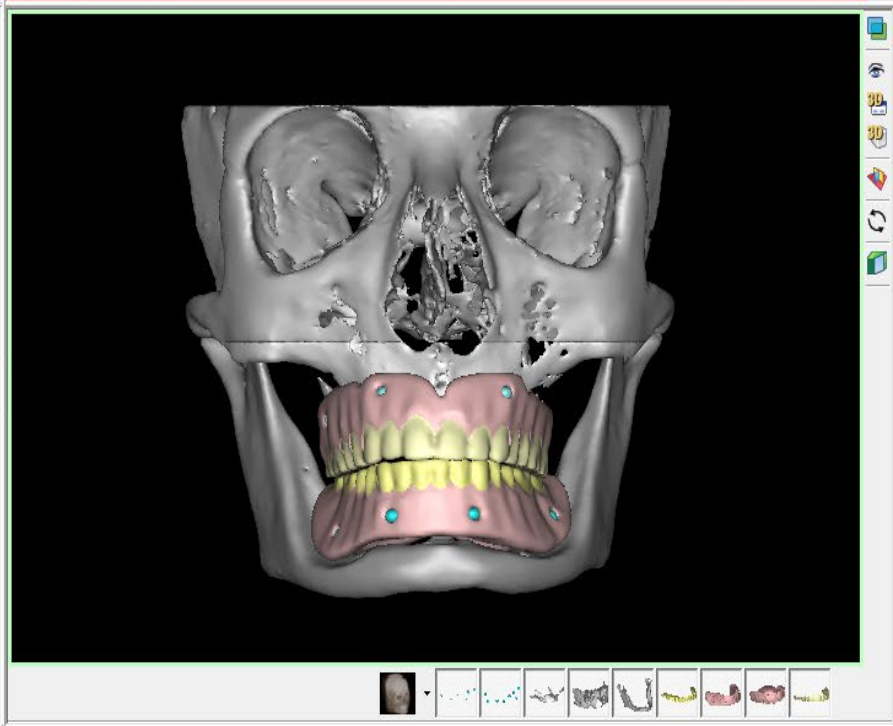
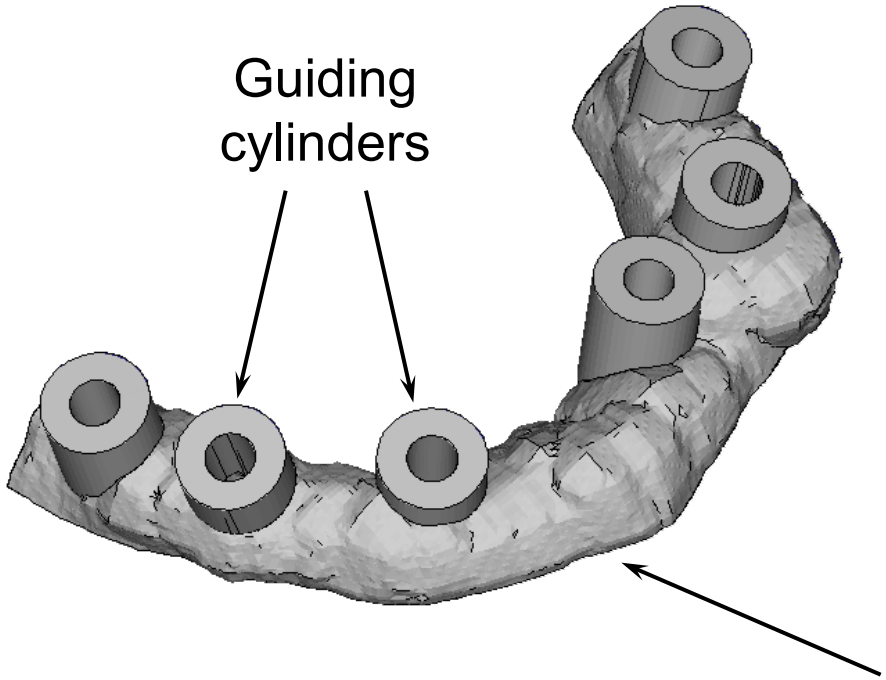


Restoration-Driven Implant Planning

"Create a model of the desired result, then work backwards to determine how it can be achieved"

- ✔ *3D Treatment Planning Software*
- ✔ *Radio-Opaque Scanning Stents*
- *Surgical Drill Guides*

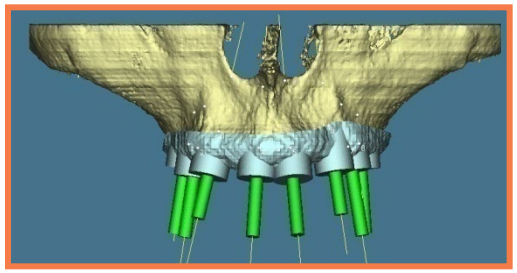
Surgical Drill Guides



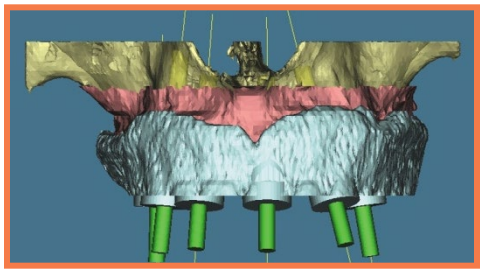
The guide controls:
- Position
- Orientation
- Depth

Guide can rest on:
- Bone
- Mucosa
- Teeth

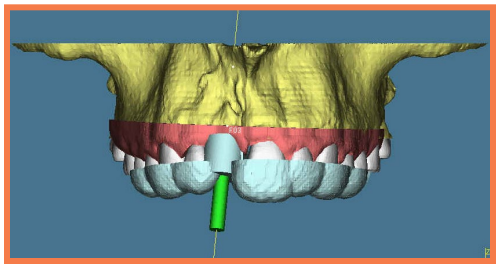
Drill Guides can be supported on



Bone



Mucosa



Teeth

Bone Supported Guides:

- Bone crest must be clearly visible in the CBCT images and ≥ 3cm long

Mucosa Supported Guides:

- Patient must be scanned with a radio-opaque scanning stent in place

Tooth Supported Guides:

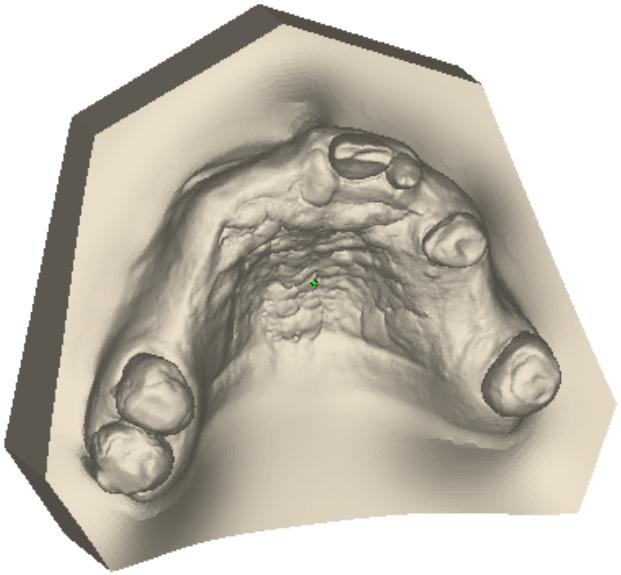
- Tips of teeth must be clearly visible in the CBCT images
- A recent and accurate plaster cast will be required

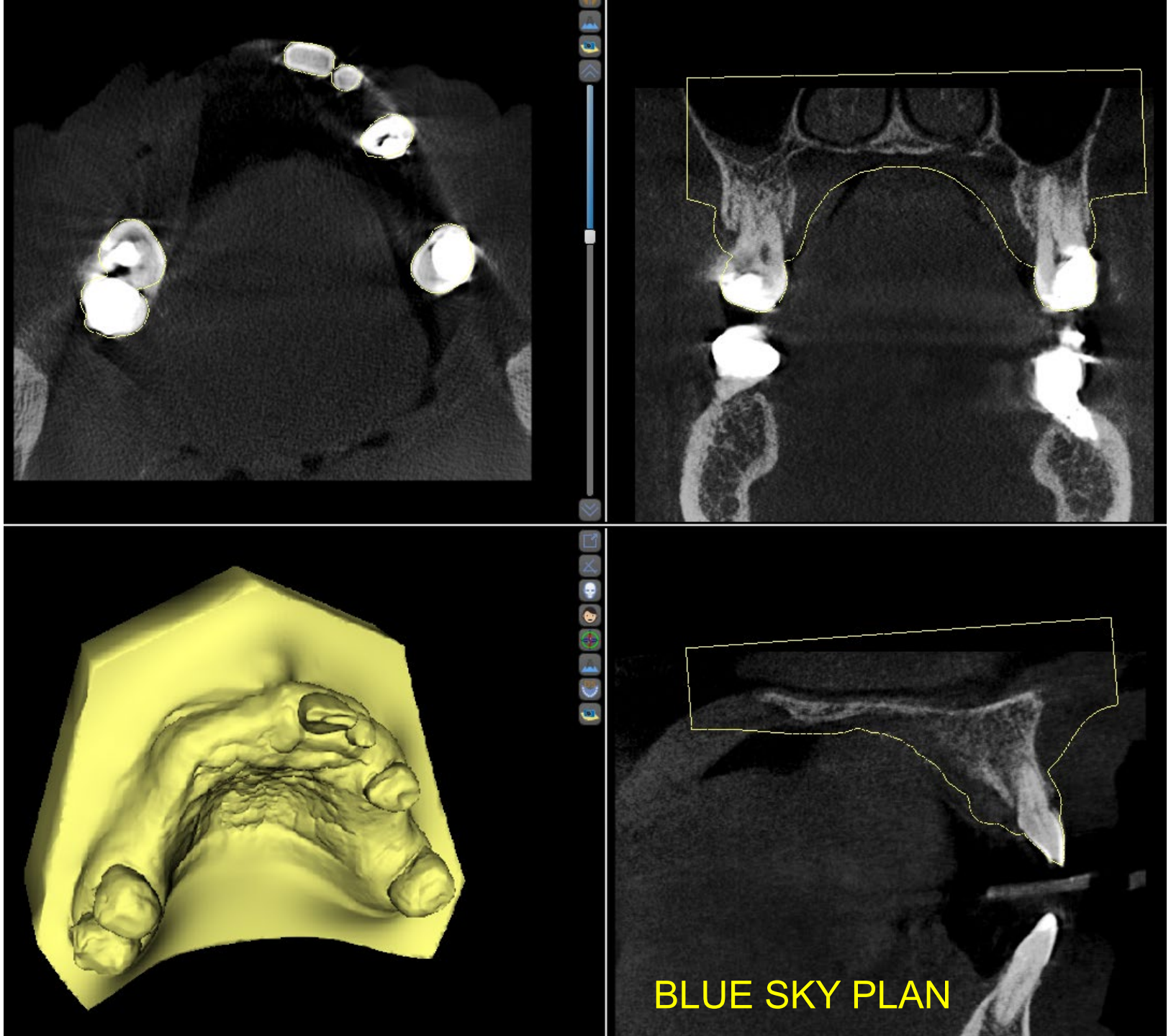
Need to think about the Guide before you request the CBCT Scan!

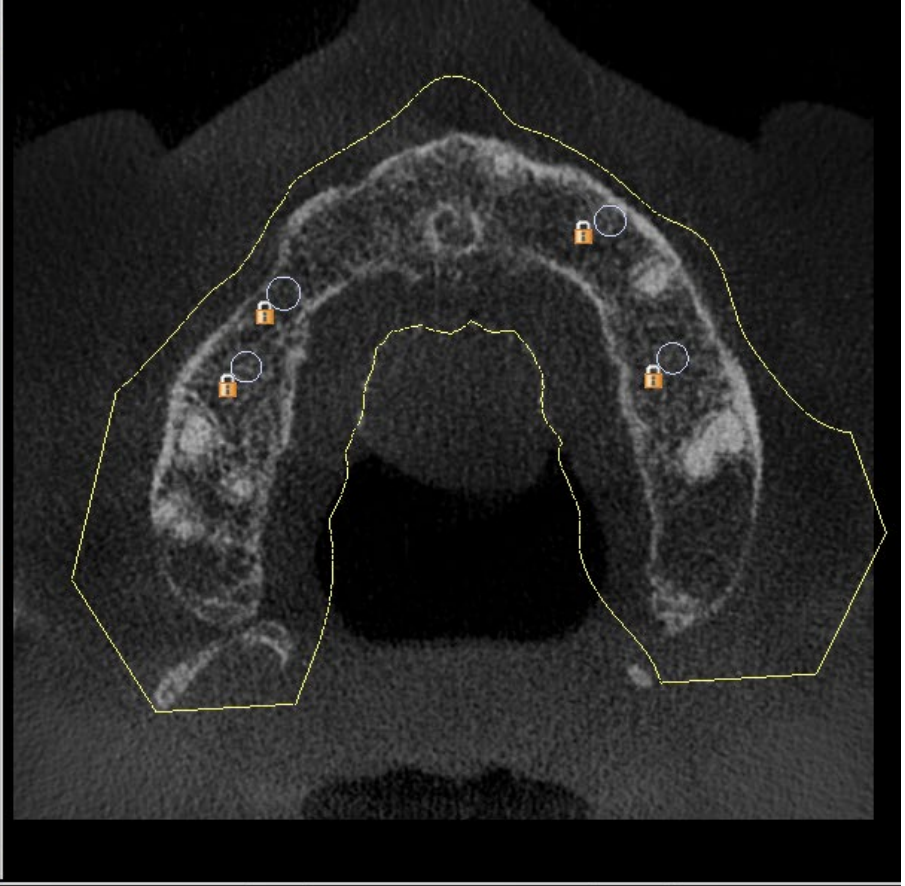
Tooth Supported Guides

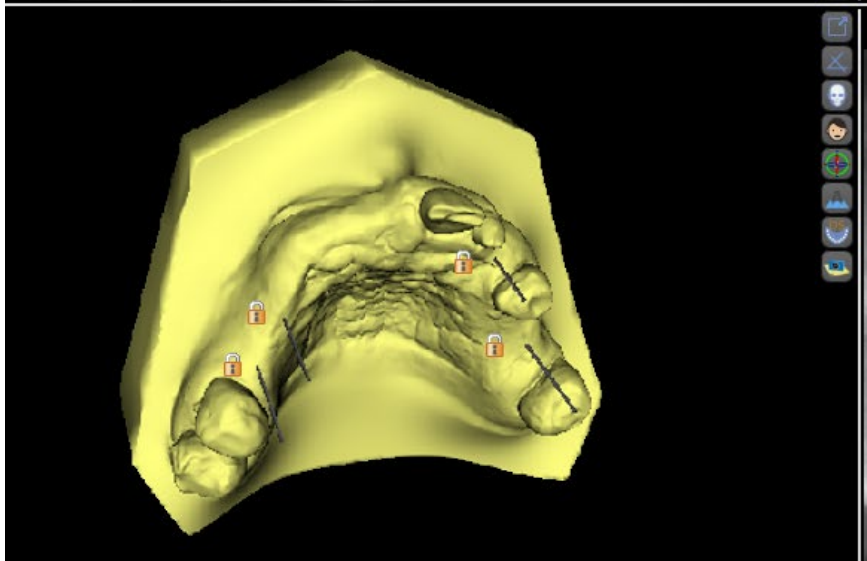
- **Drill Guide will be supported on patient's existing teeth**
- **Need a recent and accurate impression or plaster cast**
- **Optical (laser) scan of plaster cast (or intra-oral scan)**
- **Import optical scan into the implant planning software**
- **Guide will be designed to fit the plaster cast.**

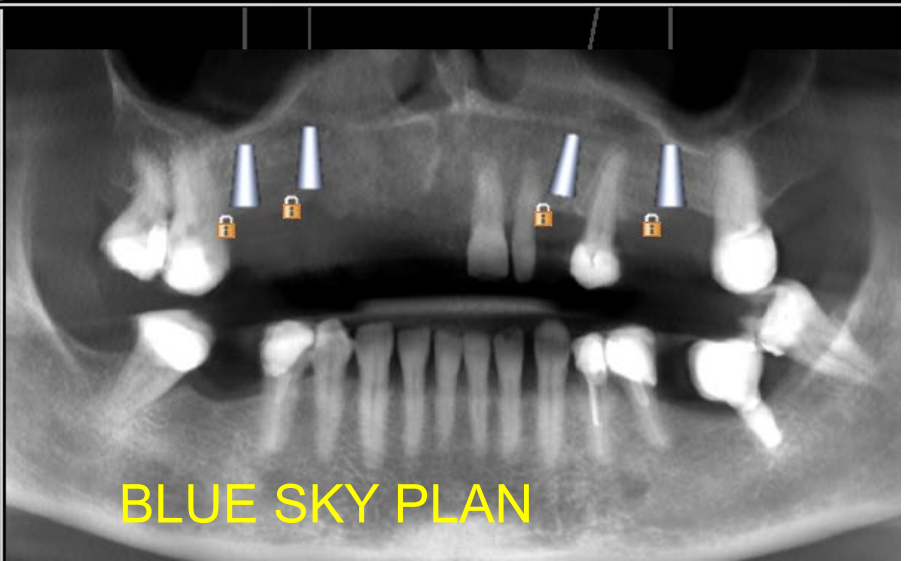
Optical Scan of Plaster Cast



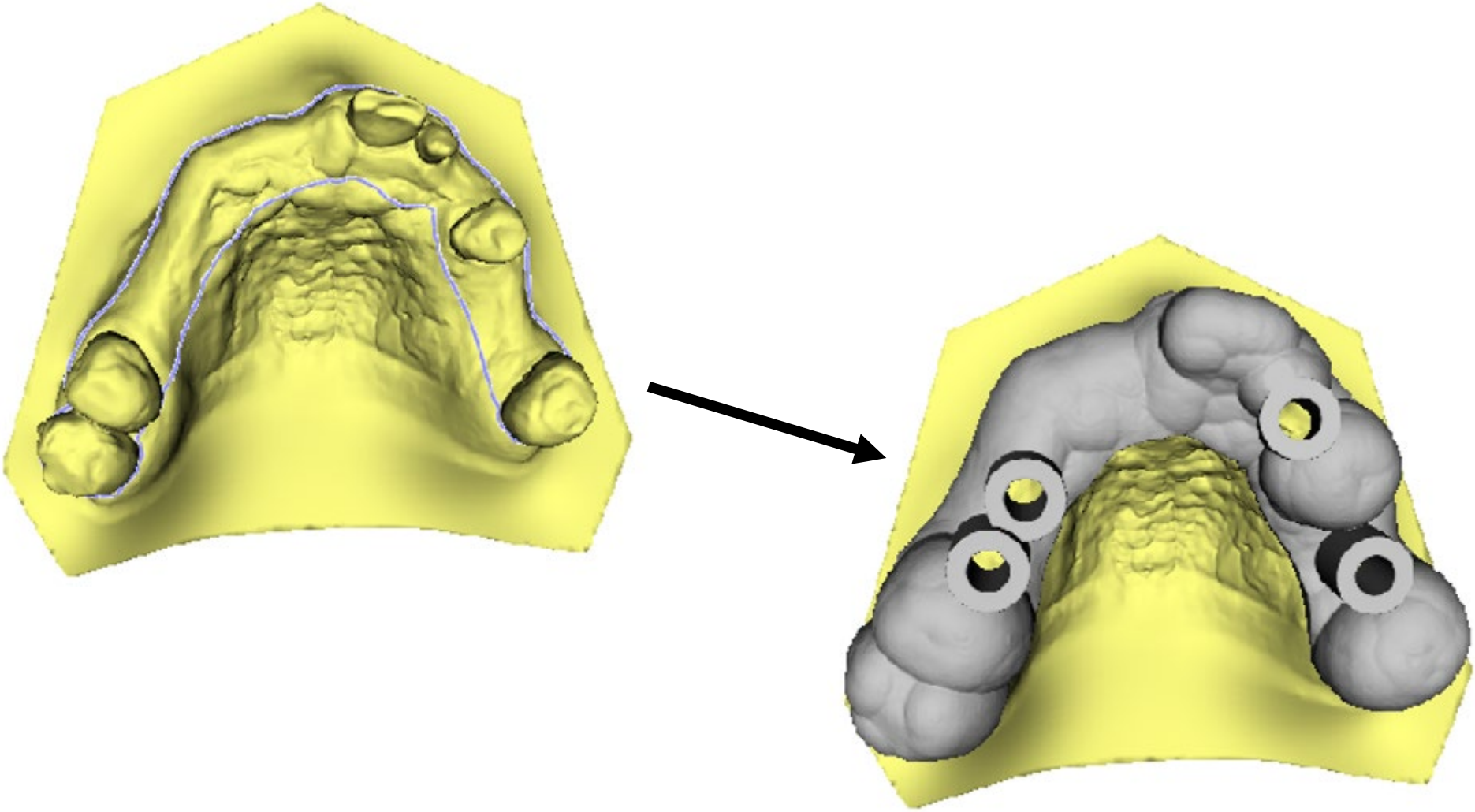

BLUE SKY PLAN





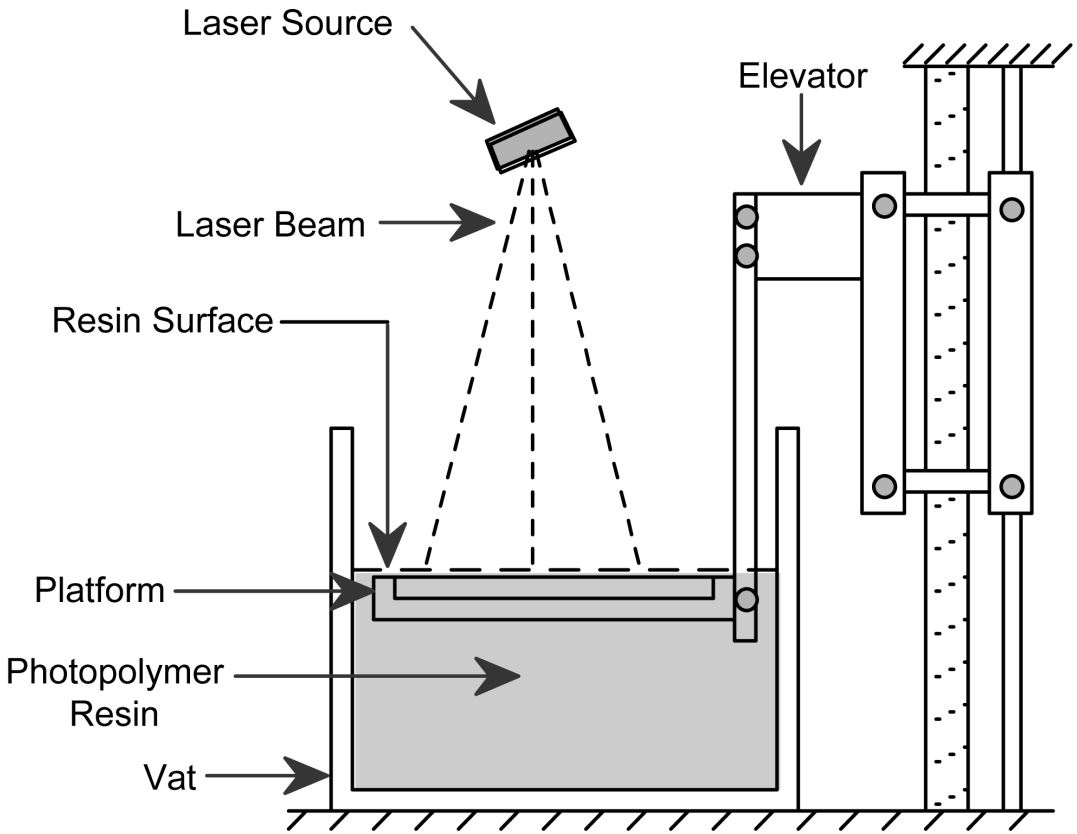

BLUE SKY PLAN

Design the Guide



Print it on a 3D Printer

Stereolithography



Zhang et al, (2000) "Reconstruction of the Homunculus skull using a combined scanning and stereolithography process", Rapid Prototyping Journal, Vol. 6 Iss: 4, pp.267 - 275


2.3

The Ultimate Goal

Place implants so accurately that a (temporary) restoration can be fabricated before the surgery takes place

"The Immediate Smile" *– Dentply Sirona*
"Teeth in an Hour" *- Nobel Biocare*
"Smart Implants" *– Limplant Ltd*

The Ultimate Goal

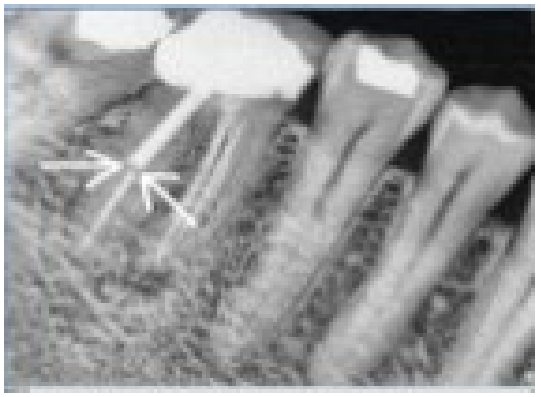
Place implants so accurately that a (temporary) restoration can be fabricated before the surgery takes place

- To do this you have to rely on your imaging!

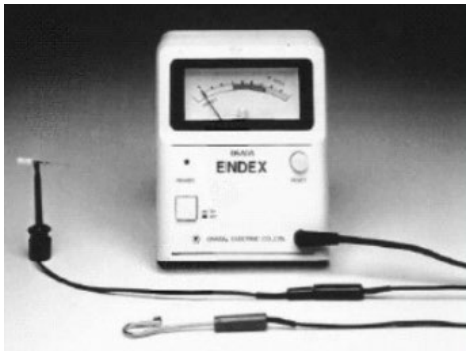
What Imaging Modalities are available?

- **Intra-oral radiography**
  - **Periapicals, bitewings, ~~occlusal views~~**
- **Extra-oral radiography**
  - **AP and Lateral cephs**
- **Dental Panoramic Tomography (DPT or OPG)**
- **Cone Beam Computed Tomography (CBCT)**

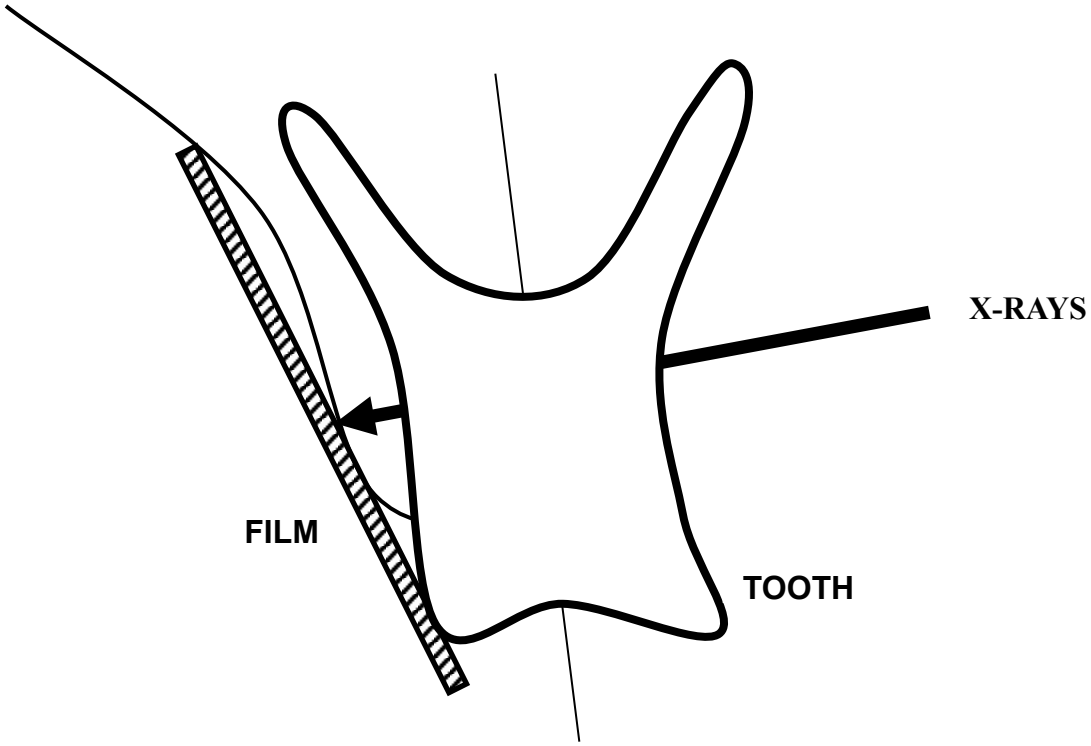
Intra-oral Imaging



+ Very high resolution (20 lp/mm)
+ Fast, convenient, low dose
– Magnification / Distortion
– No (quantitative) bone quality
– Distance measurements not reliable



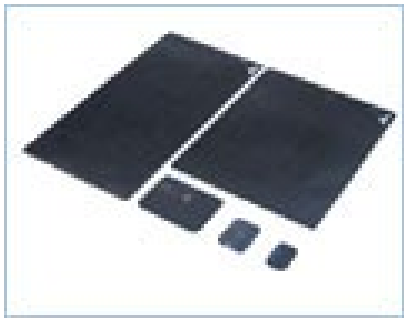
Distortion in intra-orals



Solutions:

- bisecting angle ✗
- paralleling technique ✓

Types of Detector



Film

Phosphor Plate

CCD with wires

CCD (wireless)

Phosphor Plate Readers

Durr VistaScan

Gendex DenOptics

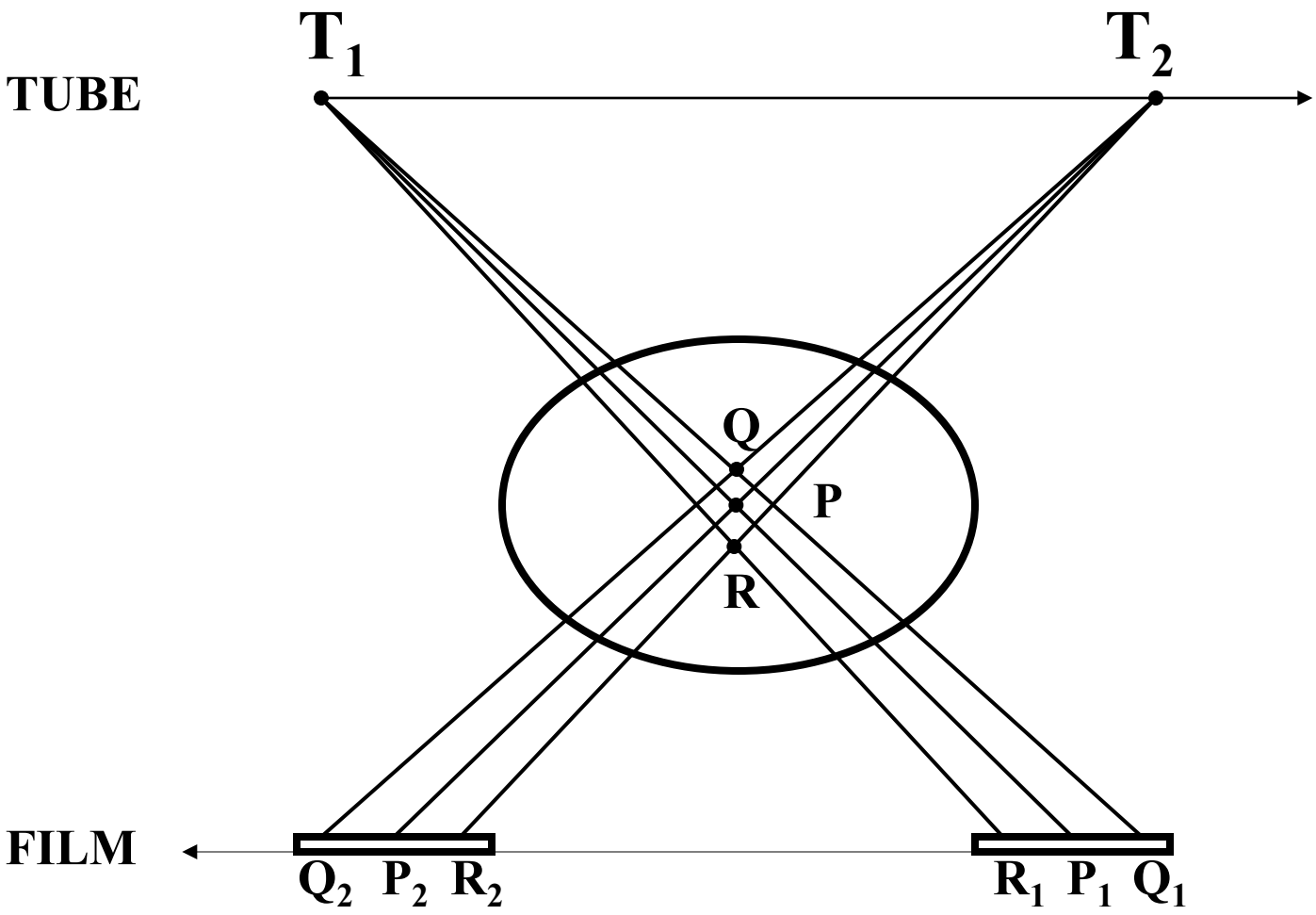
Soredex Diagora

Extra-oral: Lateral Cephs

+ Good overview
+ Useful for orthodontics
– Magnification / Distortion
– Distance measurements not reliable

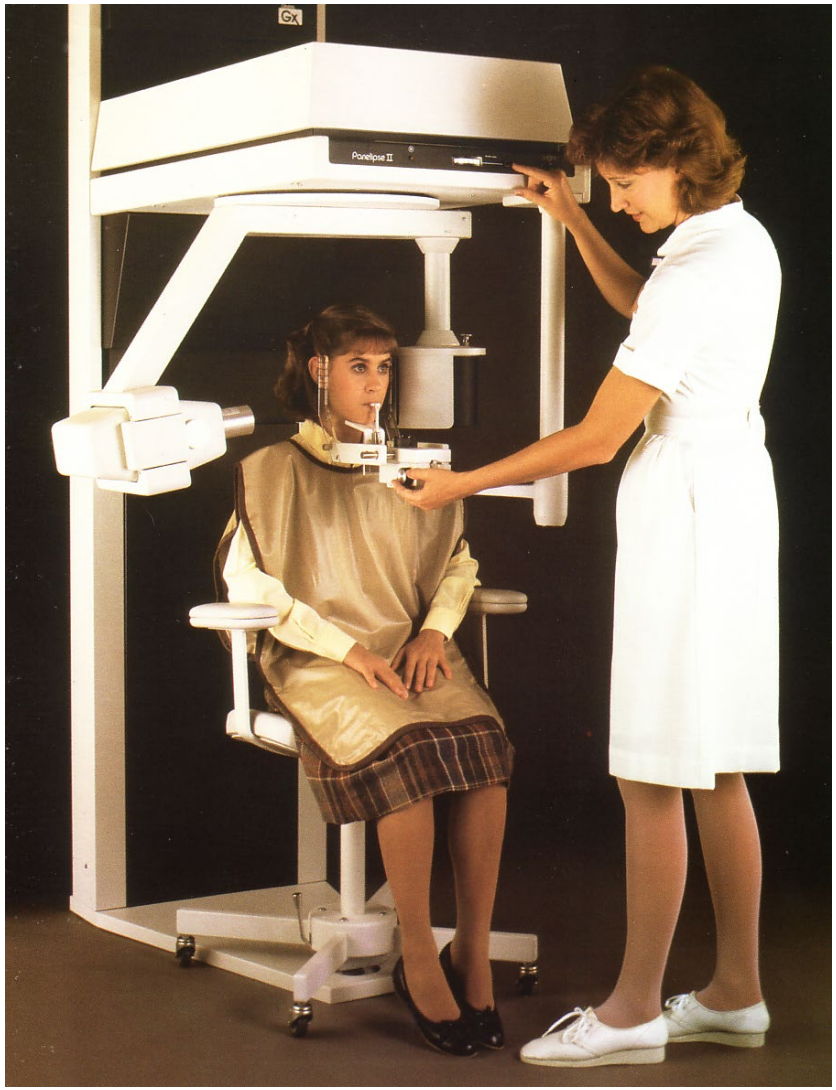
Conventional Tomography

(tomography by blurring)

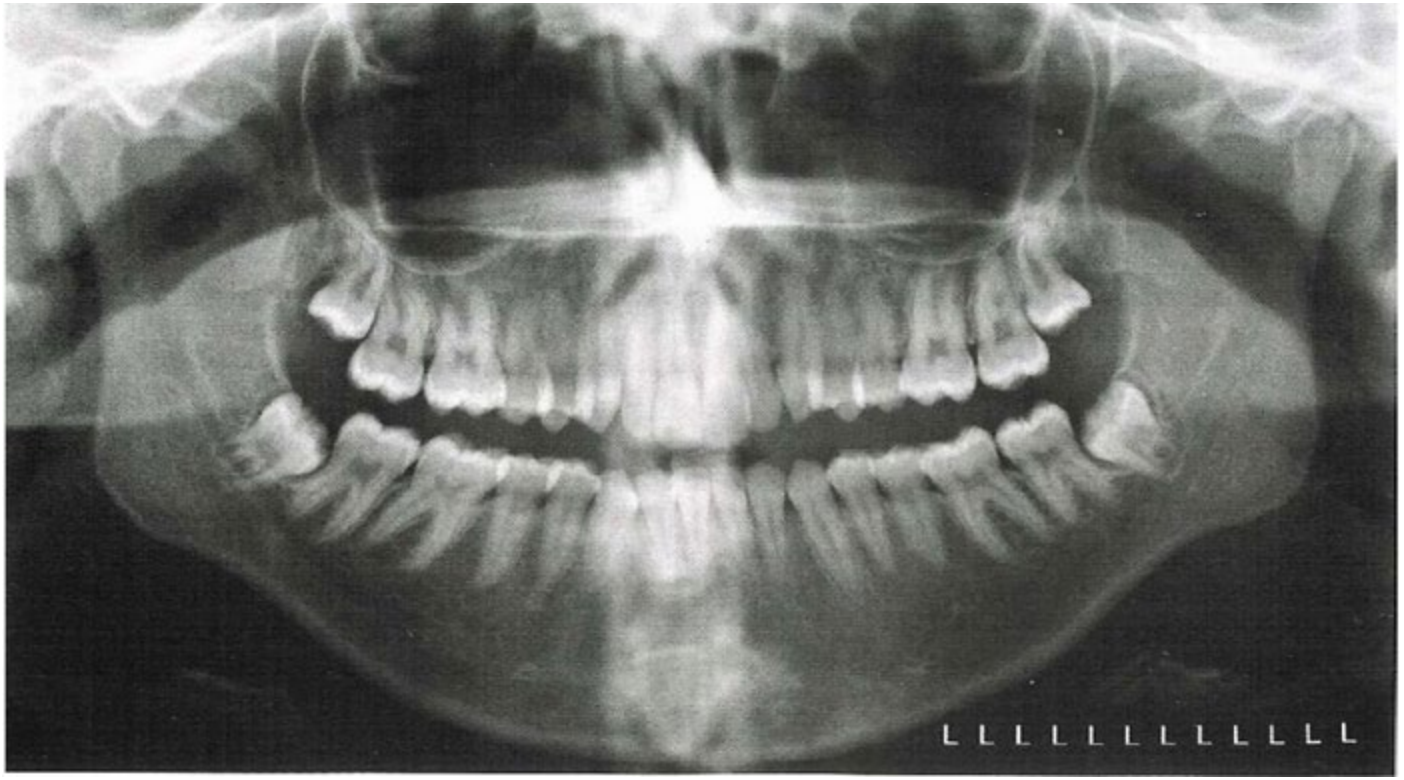


Dental Panoramic Tomography (DPT)

(tomography by blurring)



Dental Panoramic Tomography (DPT, OPG, OPT)



- \+ **Very good overview**
  - \+ **Mandibular fractures, unerupted teeth**
- \+ **Sufficient detail for caries diagnosis**
- – **Variable Magnification / Distortion**
- – **Patient positioning is crucial**

DPTs are useful for:

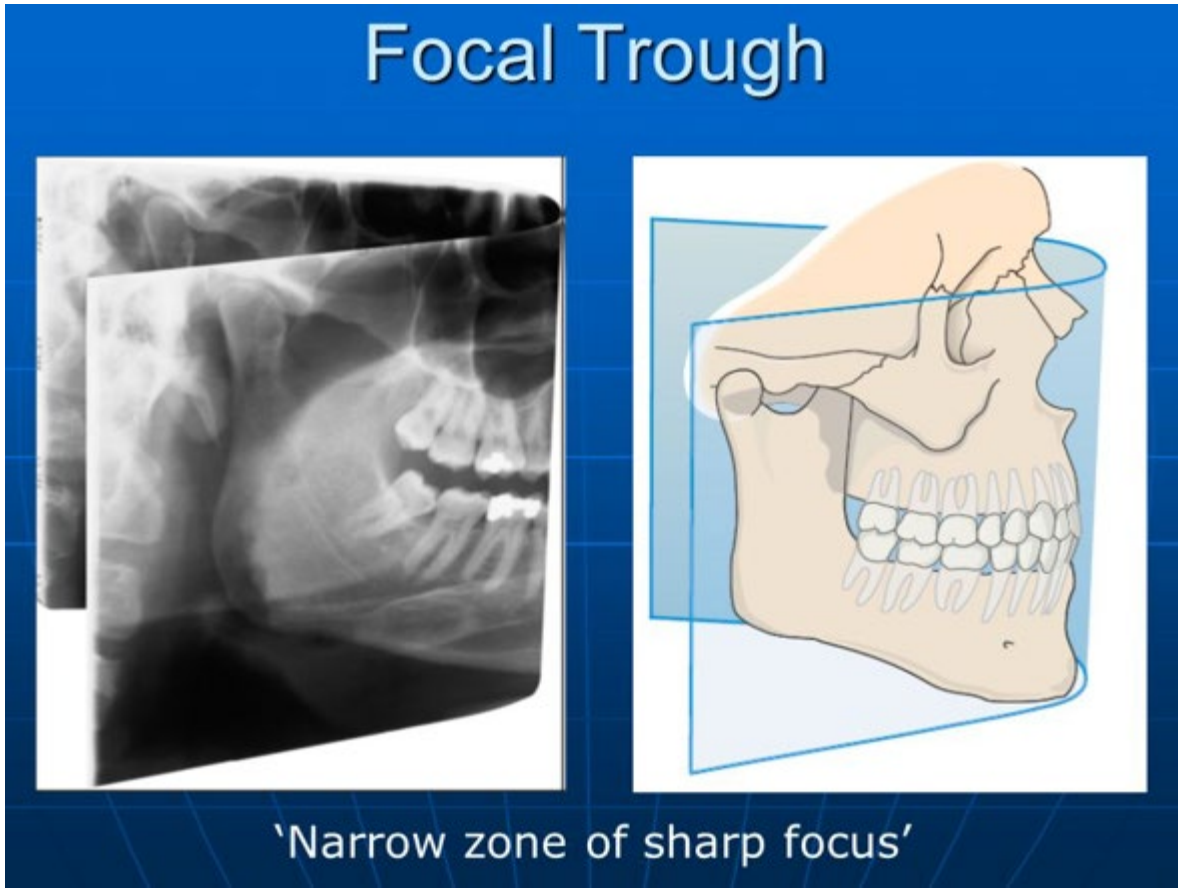
- Overall status of teeth and supporting bone
- Anatomical anomalies and pathological conditions
- Triage between:
  - Sites where placing implants will be straight-forward
  - Sites where grafting or distraction will be needed
  - Sites where implants are not advisable

Measurements from DPTs are not accurate:

Reddy et al. Clin Oral Implants Res. 1994 Dec; 5(4):229-238

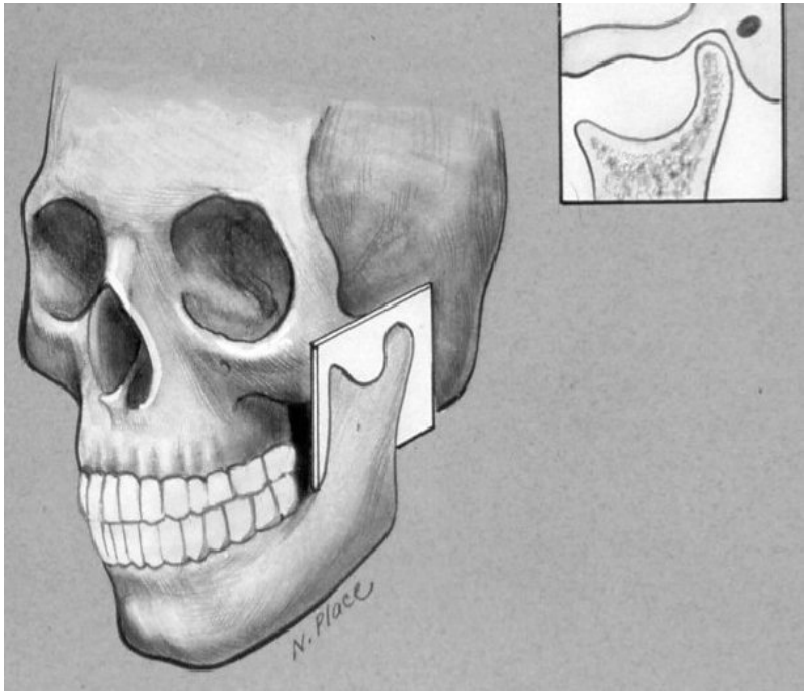
- Errors as large as 30% in estimating bone height from DPTs
- Bone width cannot be estimated at all.

Positioning is crucial



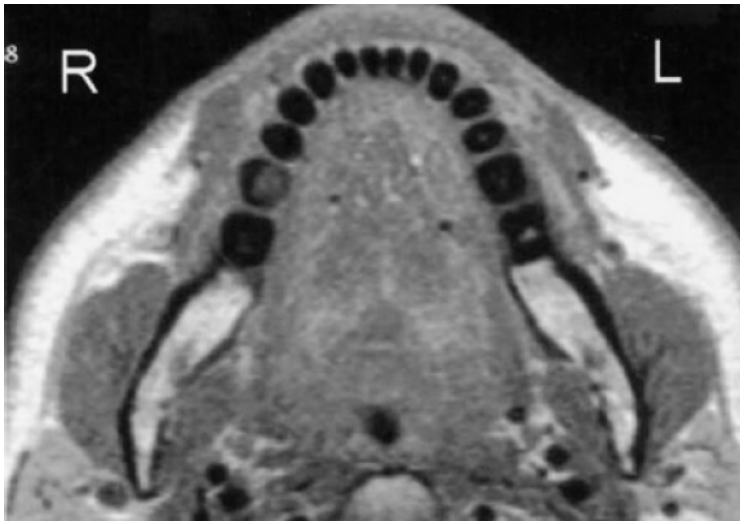
The focal trough is fixed to the machine (not the patient)

Cross-Sectional Imaging



- ~~Linear Tomography~~
- ~~Complex Motion Tomography (CMT)~~
- ~~Ultrasound~~
- ~~Magnetic Resonance Imaging (MRI)~~
- Computed Tomography ~~(CT~~ or CBCT)

Magnetic Resonance Imaging



+ no radiation dose
+ no metallic artefact
- large, expensive machine
- teeth generate no signal

Advanced imaging: Magnetic resonance imaging in implant dentistry

A review

Crawford F. Gray, Thomas W. Redpath, Francis W. Smith, Roger T. Staff

Article first published online: 31 JAN 2003

DOI: 10.1034/j.1600-0501.2003.140103.x

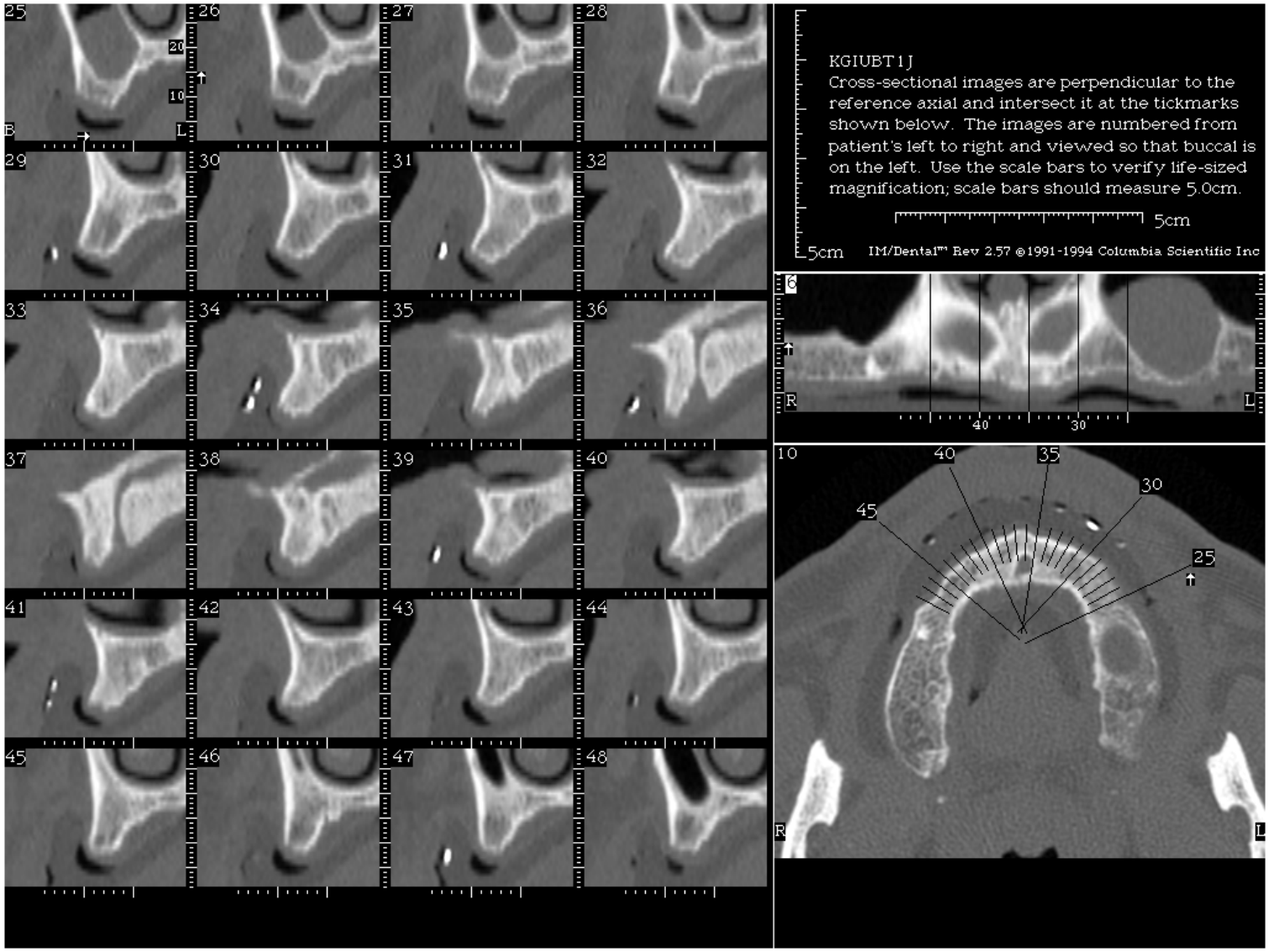
Issue

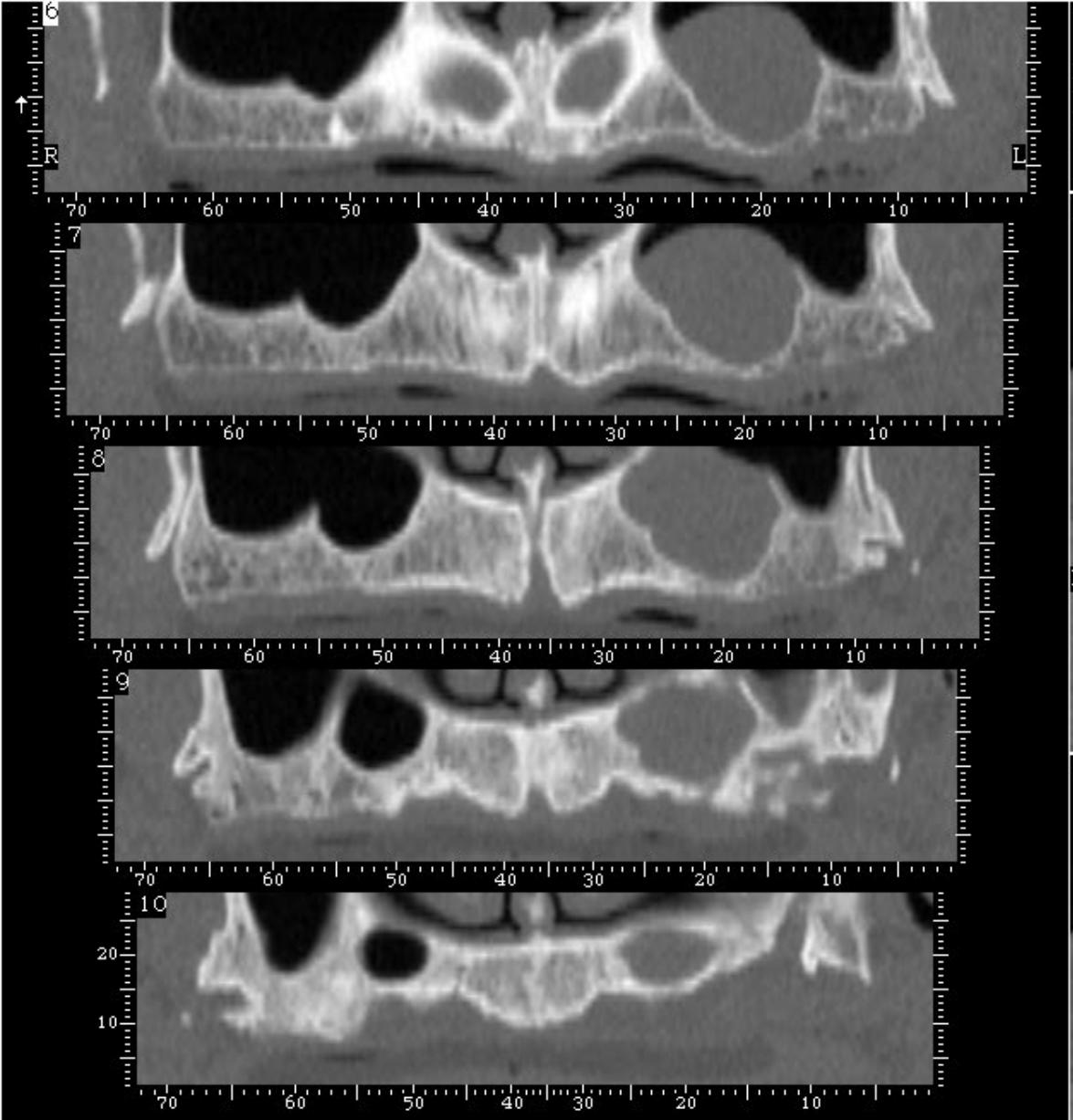
Clinical Oral Implants Research

Volume 14, Issue 1, pages 18–27, February 2003

Computed Tomography (CT)

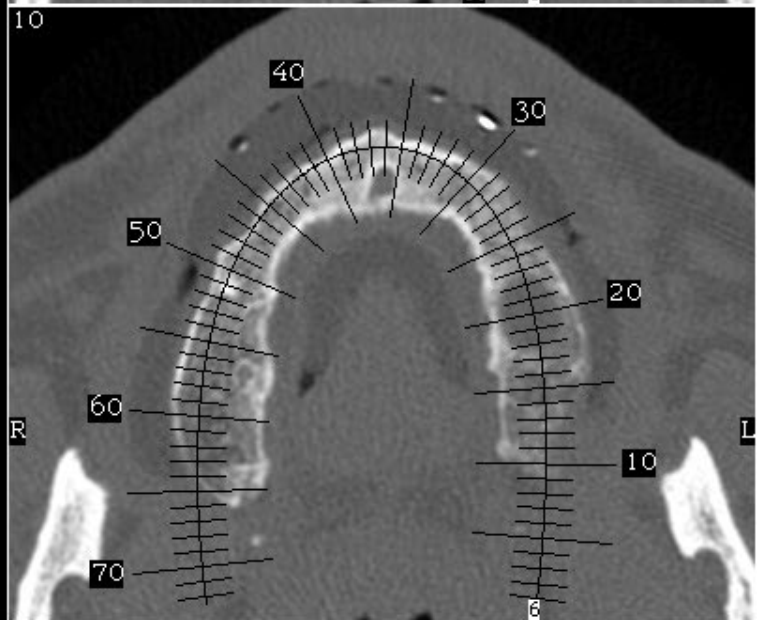
(tomography by computation)



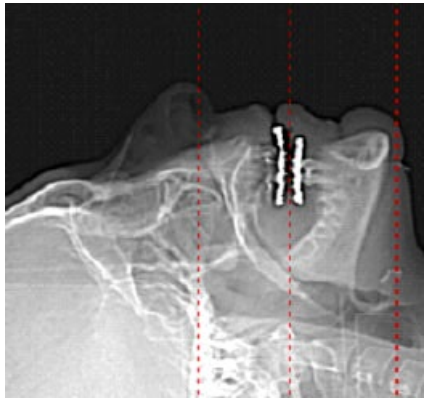


KGIUBT1J Panoramic images are perpendicular to the reference axial and intersect it at the curves shown below. Images are numbered from buccal to lingual and are viewed from buccal.

IM/Dental™ Rev 2.57 ©1991-1994 Columbia Scientific Inc



Dental (CB)CT Scans



The dentoalveolar region has high natural contrast

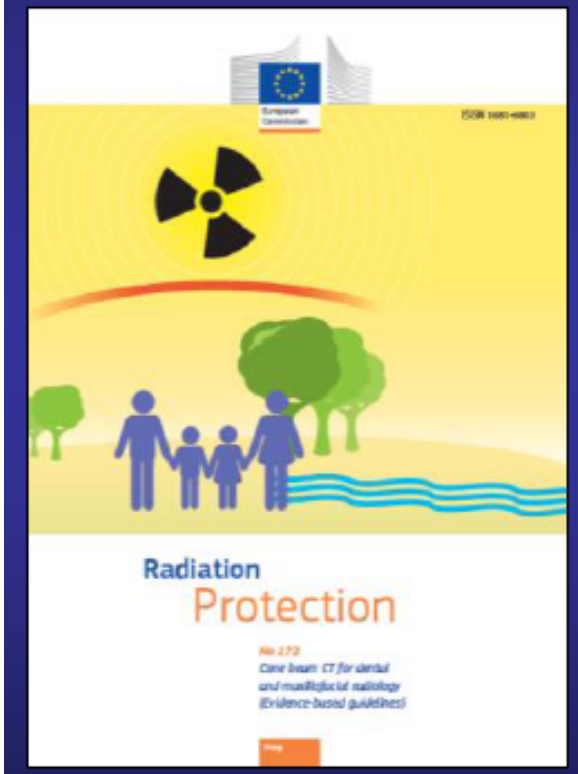
So we can get away with
- high resolution images
- low radiation dose

We can reduce the dose and get away with images that would not be acceptable for a diagnostic medical CT scan.

- **CBCT is useful for:**
  - **planning dental implants**
  - **periapical disease**
  - **root canals, root fractures etc**
  - **impacted, supernumerary and abnormal teeth**
  - **maxillofacial surgery**
  - **cleft palate assessment**
  - **TMJ and airway analysis**

- **CBCT is not good for:**
  - **dental caries**
  - **soft tissue tumours**

Systematic Review of Indications for CBCT



The SEDENTEXCT project (2008-2011)

4.18: Where CBCT images include the teeth, care should be taken to check for periapical disease when performing a clinical evaluation (report).

GP

4.19: CBCT is not indicated as a standard method for demonstration of root canal anatomy.

GP

4.20: Limited volume, high resolution CBCT may be indicated, for selected cases where conventional intraoral radiographs provide information on root canal anatomy which is equivocal or inadequate for planning treatment, most probably in multi-rooted teeth.

GP

4.21: Limited volume, high resolution CBCT may be indicated for selected cases when planning surgical endodontic procedures. The decision should be based upon potential complicating factors, such as the proximity of important anatomical structures.

GP

4.22: Limited volume, high resolution CBCT may be indicated in selected cases of suspected, or established, inflammatory root resorption or internal resorption, where three-dimensional information is likely to alter the management or prognosis of the tooth.

D

4.33: Limited volume, high resolution CBCT may be justifiable for selected cases, where endodontic treatment is complicated by concurrent factors, such as resorption lesions, combined periodontal/endodontic lesions, perforations and atypical pulp anatomy.

C

4.34: Limited volume, high resolution CBCT is indicated in the assessment of dental trauma (suspected root fracture) in selected cases, where conventional intraoral radiographs provide inadequate information for treatment planning.

B

Prof Keith Horner

Grading systems used for levels of evidence [adapted from Scottish Intercollegiate Guidelines Network (SIGN), 2008].

Grade	
A	At least one meta-analysis, systematic review, or RCT rated as 1++, and directly applicable to the target population; or a systematic review of RCTs or a body of evidence consisting principally of studies rated as 1+, directly applicable to the target population, and demonstrating overall consistency of results
B	A body of evidence including studies rated as 2++, directly applicable to the target population, and demonstrating overall consistency of results; or extrapolated evidence from studies rated as 1++ or 1+
C	A body of evidence including studies rated as 2+, directly applicable to the target population and demonstrating overall consistency of results; or extrapolated evidence from studies rated as 2++
D	Evidence level 3 or 4; or extrapolated evidence from studies rated as 2+
GP	Good Practice (based on clinical expertise of the guideline group and Consensus of stakeholders)

ELSEVIER
SAUNDERS

(Review Paper)

THE DENTAL
CLINICS
OF NORTH AMERICA

Dent Clin N Am 52 (2008) 707–730

What is Cone-Beam CT and How Does it Work?

William C. Scarfe, BDS, FRACDS, MS[a,*],
Allan G. Farman, BDS, PhD, DSc, MBA[b]

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[b]*Department of Surgical/Hospital Dentistry, University of Louisville School of Dentistry, Room 222C, 501 South Preston Street, Louisville, KY 40292, USA*

Int. J. Oral Maxillofac. Surg. 2009; 38: 609–625
doi:10.1016/j.ijom.2009.02.028, available online at http://www.sciencedirect.com

International Journal of
Oral & Maxillofacial Surgery

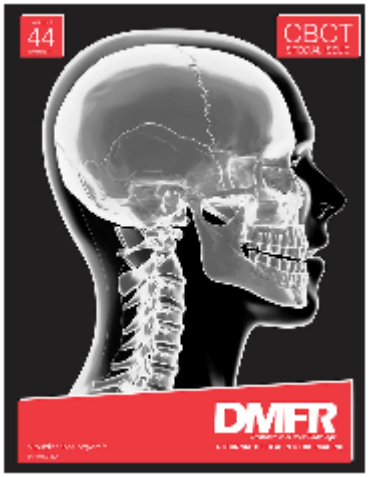
Invited Review Paper

Imaging

Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: A systematic review of the literature

W. De Vos[1], J. Casselman[2,3], G. R. J. Swennen[1,3]

[1]Division of Maxillo-Facial Surgery, Department of Surgery, General Hospital St-Jan Bruges, Ruddershove 10, 8000 Bruges, Belgium; [2]Department of Radiology and Medical Imaging, General Hospital St-Jan Bruges, Ruddershove 10, 8000 Bruges, Belgium; [3]3-D Facial Imaging Research Group, (3-D FIRG), GH St-Jan, Bruges and Radboud University, Nijmegen, 3-D FIRG, Ruddershove 10, 8000 Bruges, Belgium

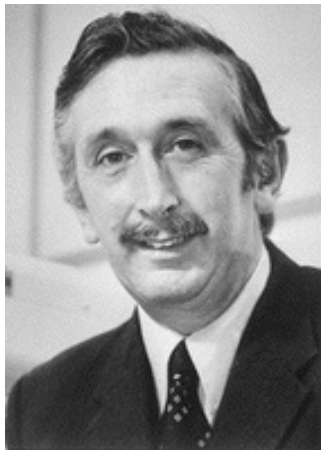


DentoMaxilloFacial Radiology

VOLUME 44, ISSUE 1, 2015

CBCT Special Issue

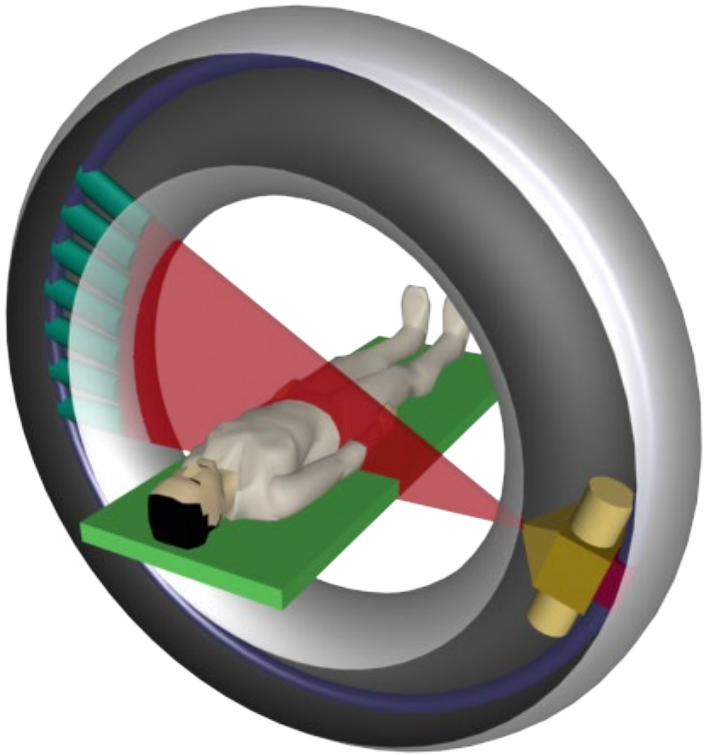
how CT works…



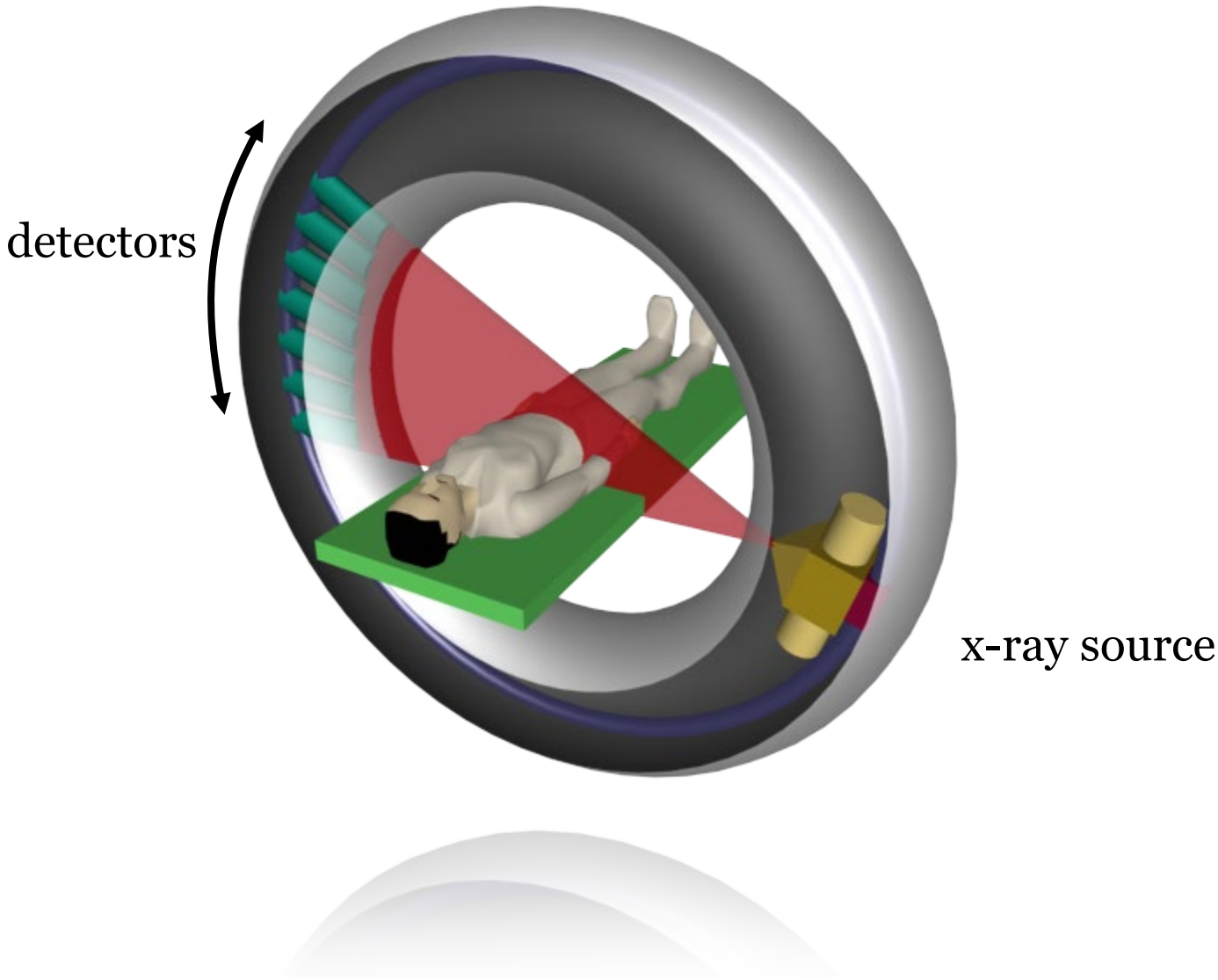
Godfrey Hounsfield

Allan Cormack

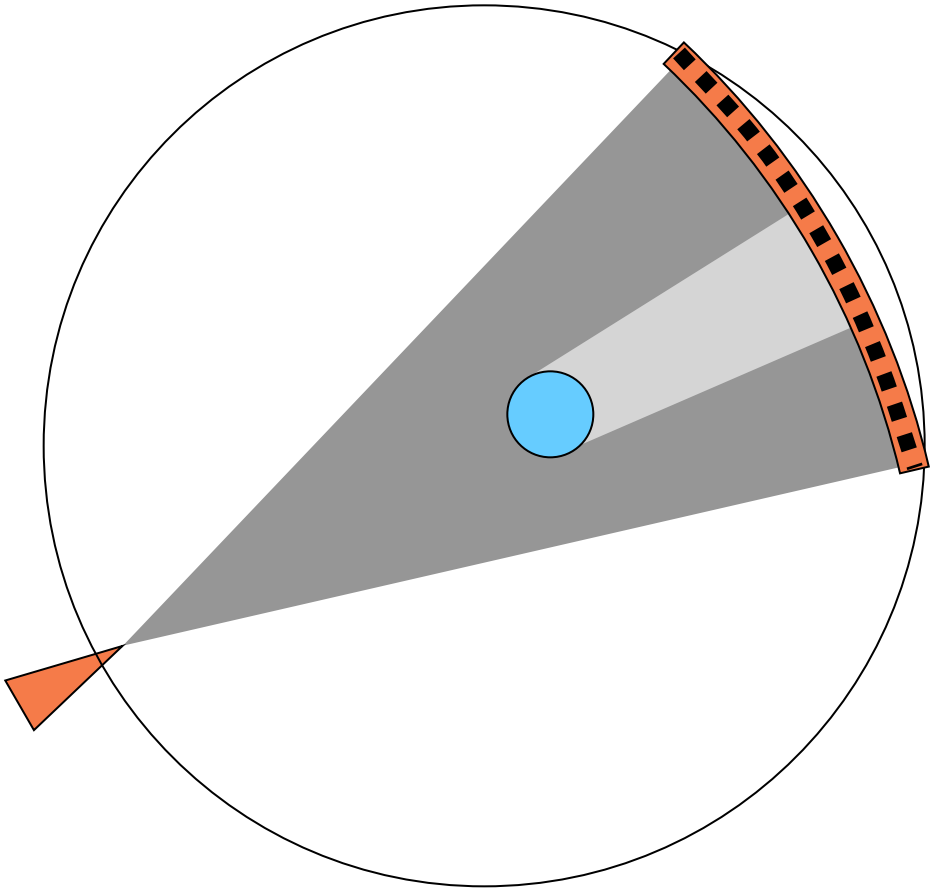
Nobel prize in Medicine, 1979



Animation courtesy of Demetrios J. Halazonetis
www.dhal.com

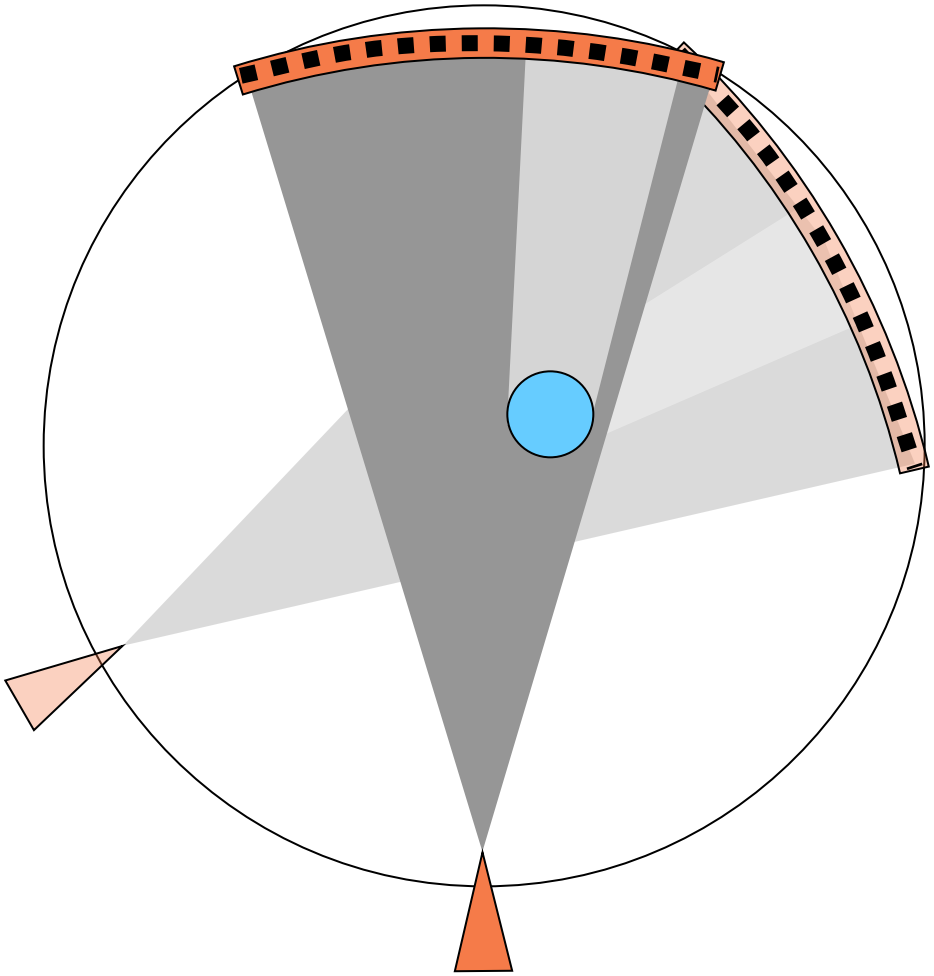

detectors
x-ray source

acquisition



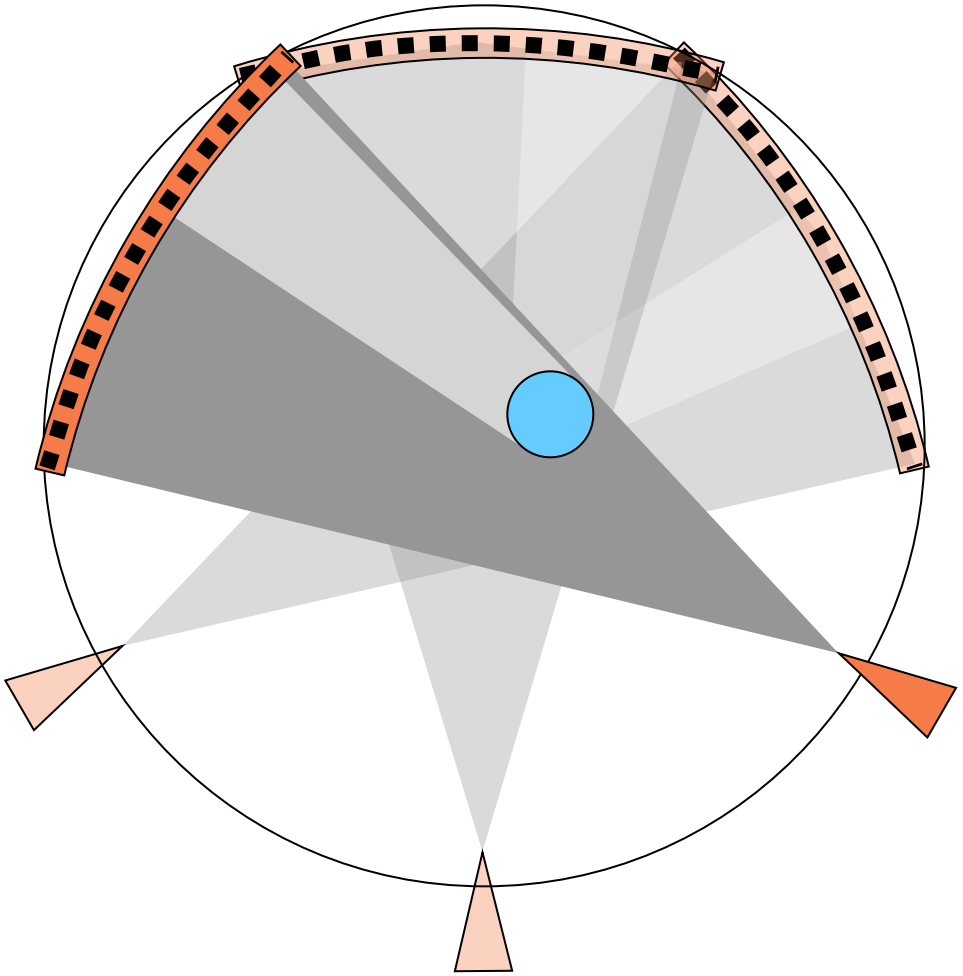
Animation courtesy of Demetrios J. Halazonetis

acquisition



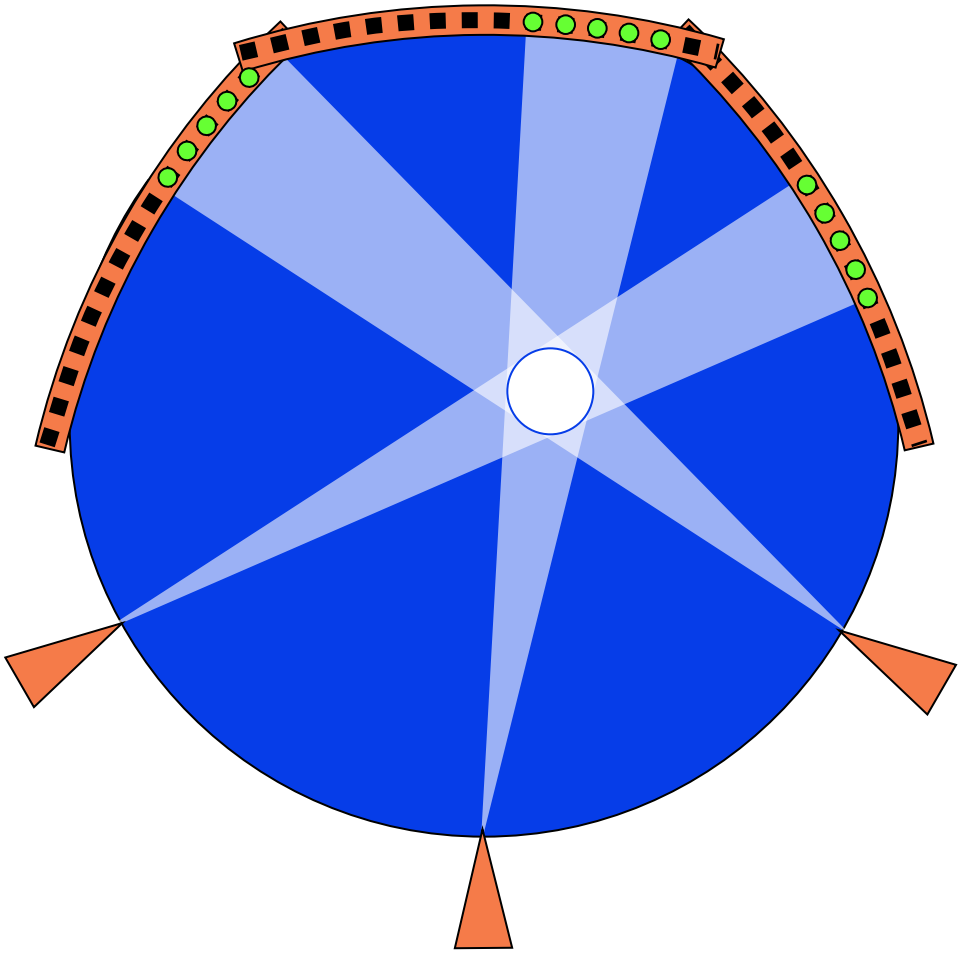
Animation courtesy of Demetrios J. Halazonetis

acquisition



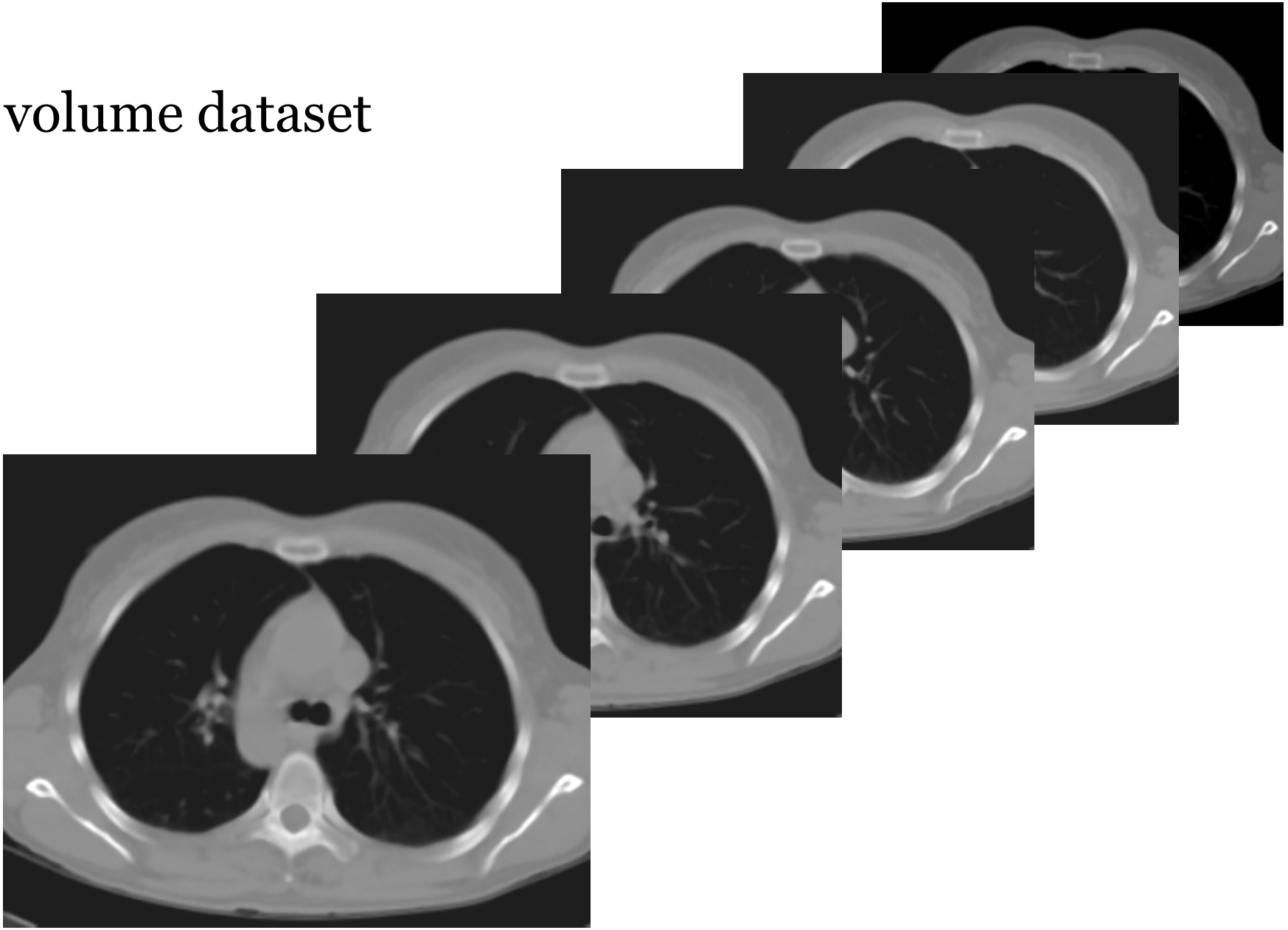
Animation courtesy of Demetrios J. Halazonetis

reconstruction

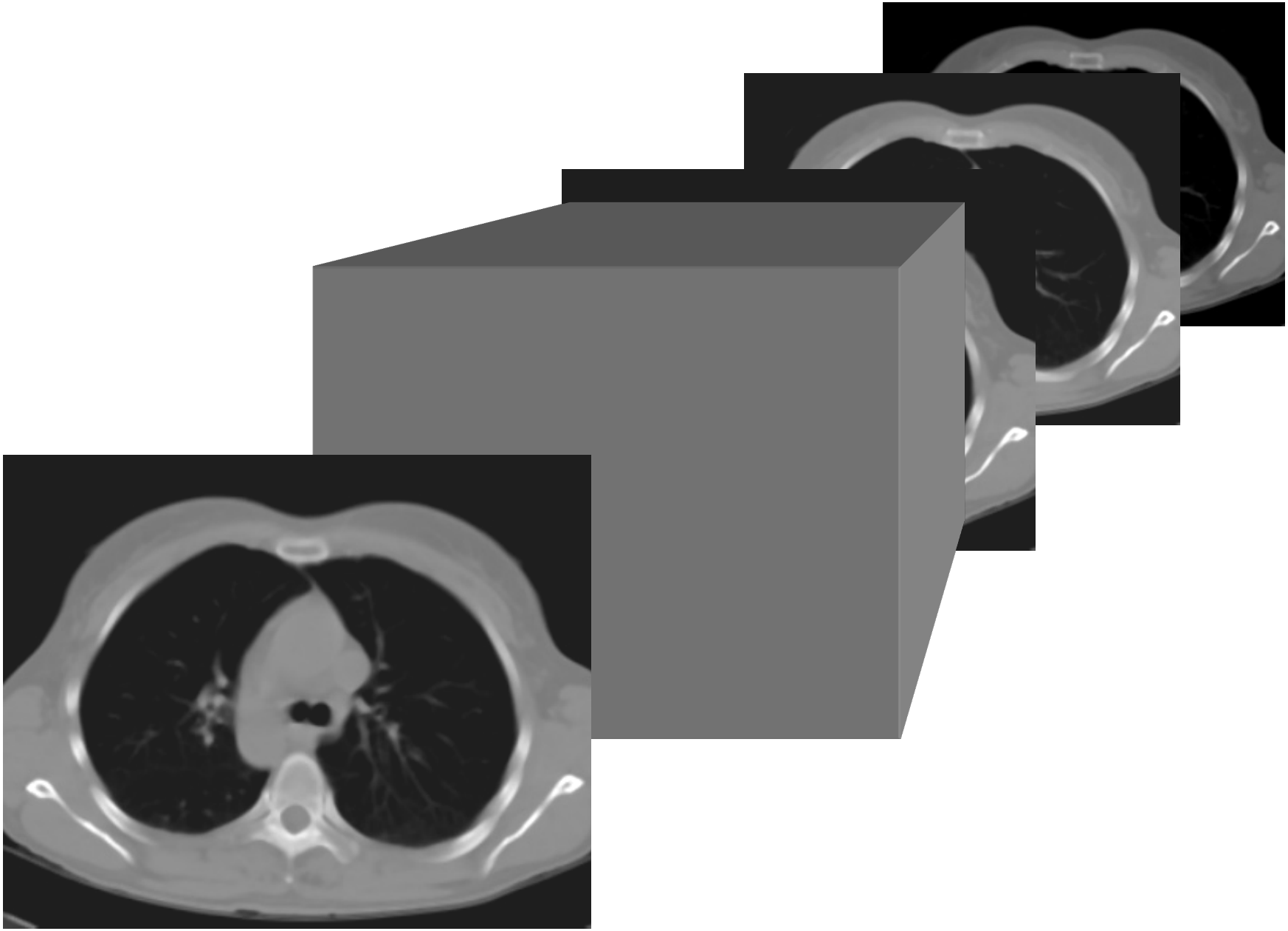


Animation courtesy of
Demetrios J. Halazonetis

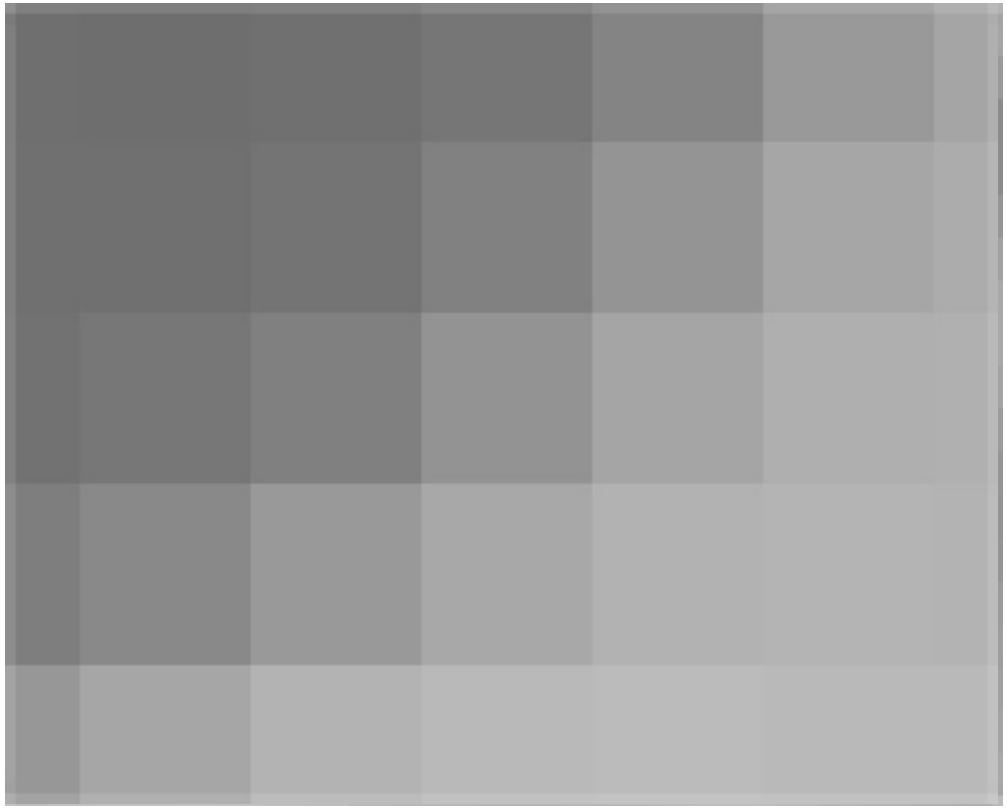
volume dataset



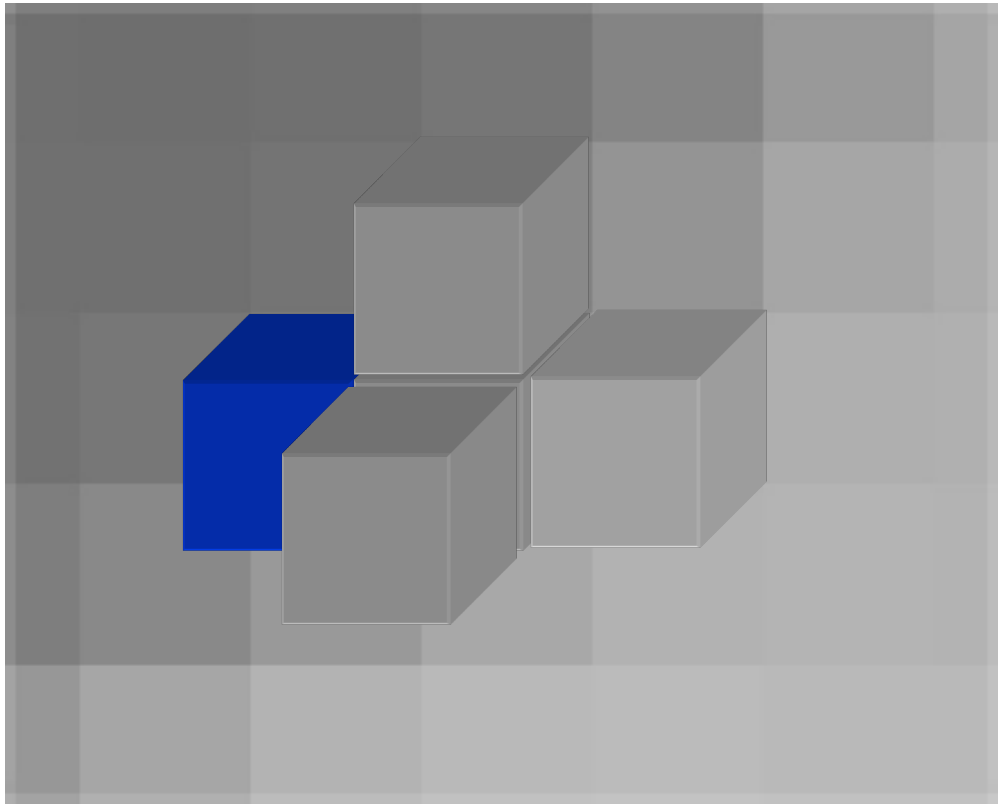
Animation courtesy of
Demetrios J. Halazonetis



Animation courtesy of
Demetrios J. Halazonetis

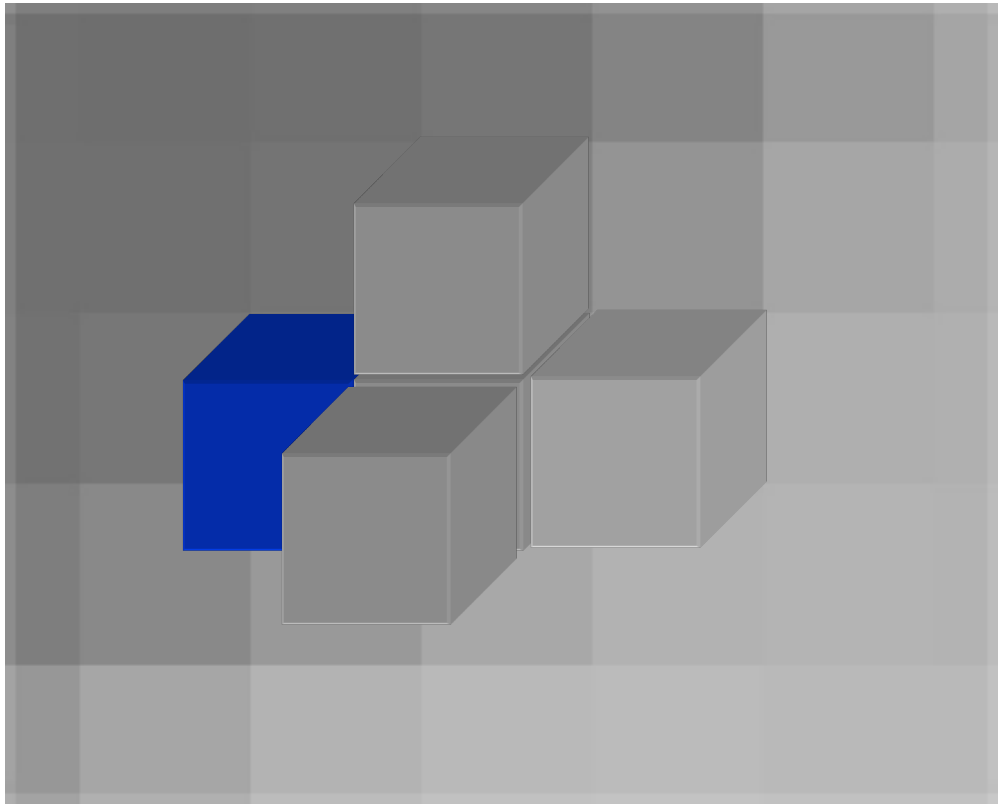


Animation courtesy of Demetrios J. Halazonetis



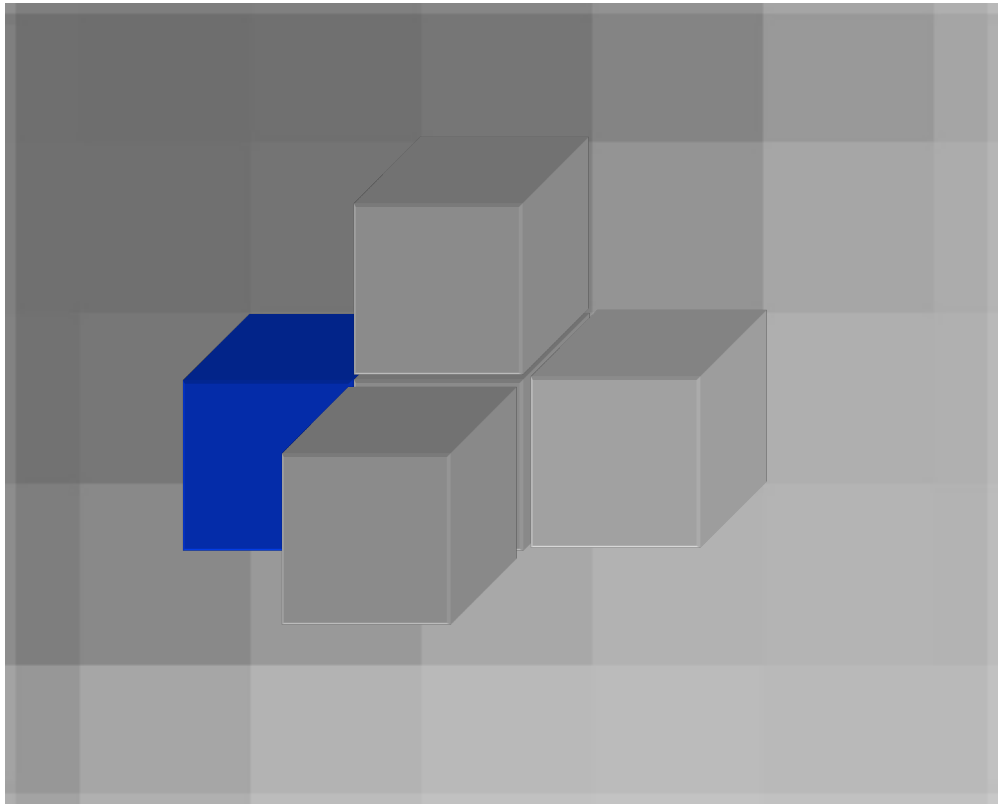
Animation courtesy of
Demetrios J. Halazonetis

Voxels (**Vo**lume **el**ements)



Animation courtesy of Demetrios J. Halazonetis

Voxels (**Vo**lume **el**ements)

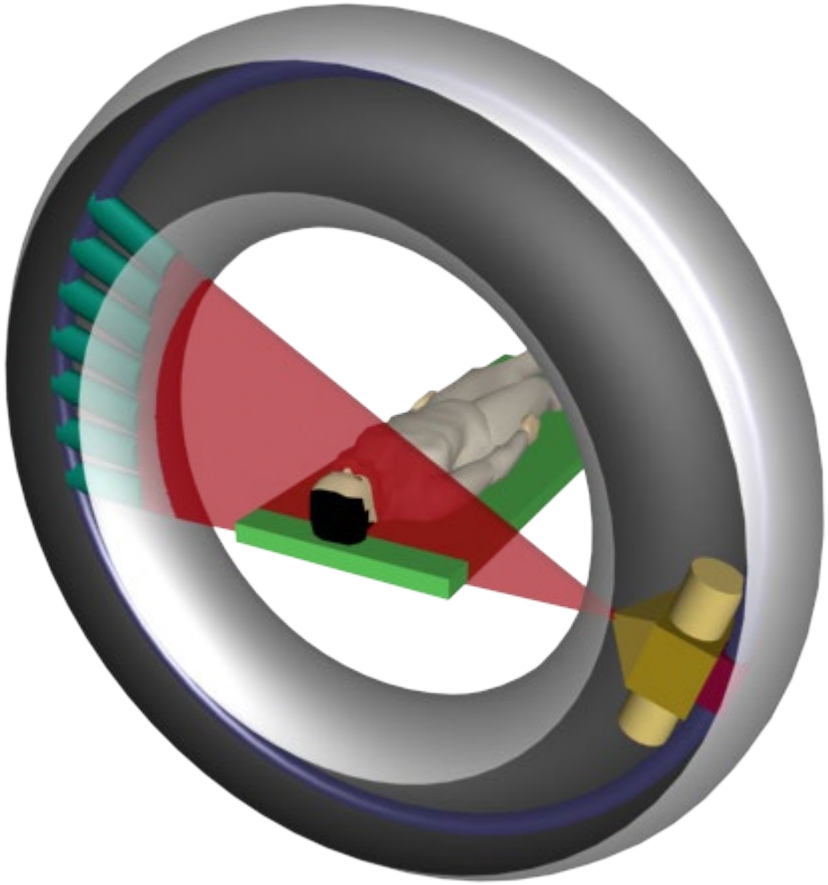


density:
0 - 4095

512 x 512 x $\frac{400}{\text{slices}}$ ≈ 100 million voxels (200 Mb)

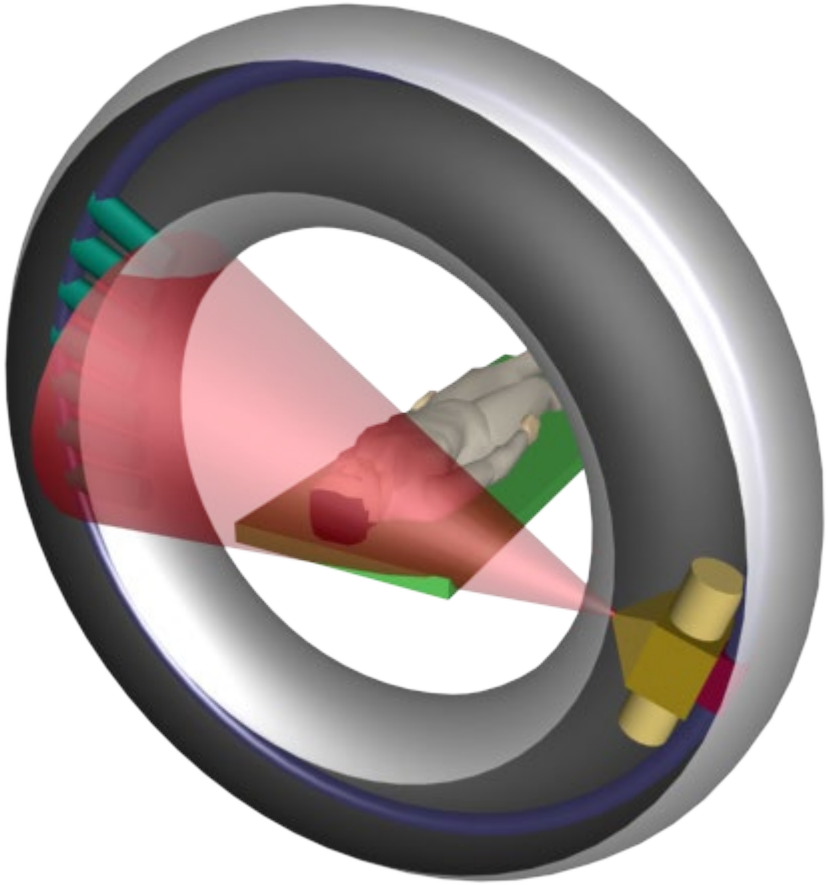
Animation courtesy of Demetrios J. Halazonetis

cone-beam CT (CBCT)



Animation courtesy of
Demetrios J. Halazonetis

cone-beam CT (CBCT)



Animation courtesy of
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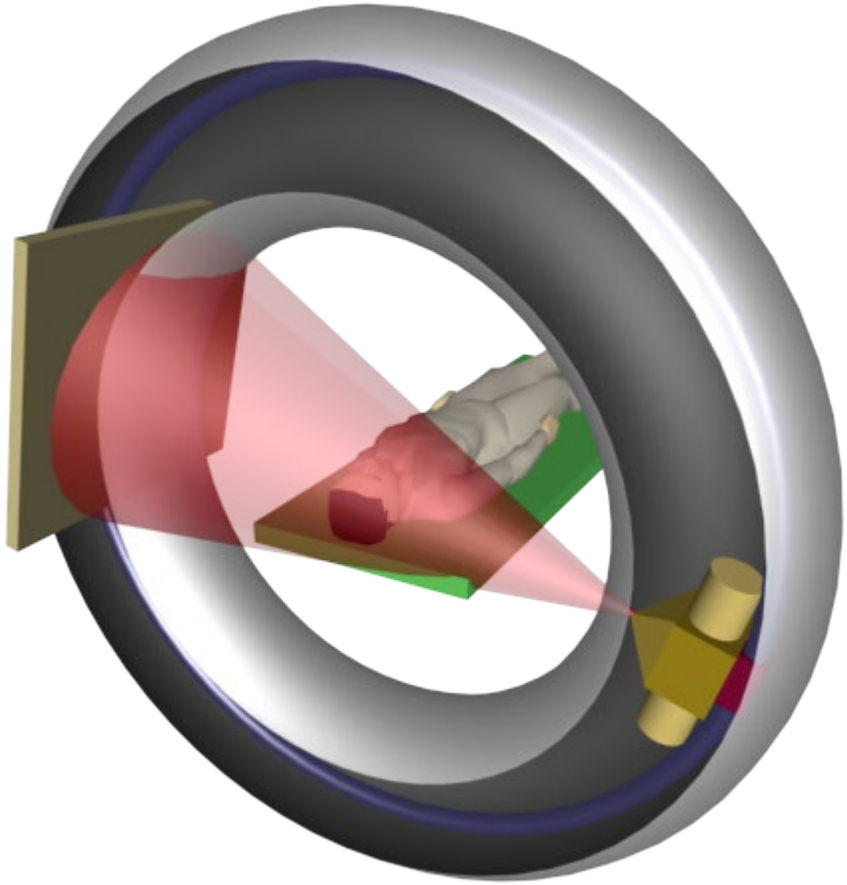
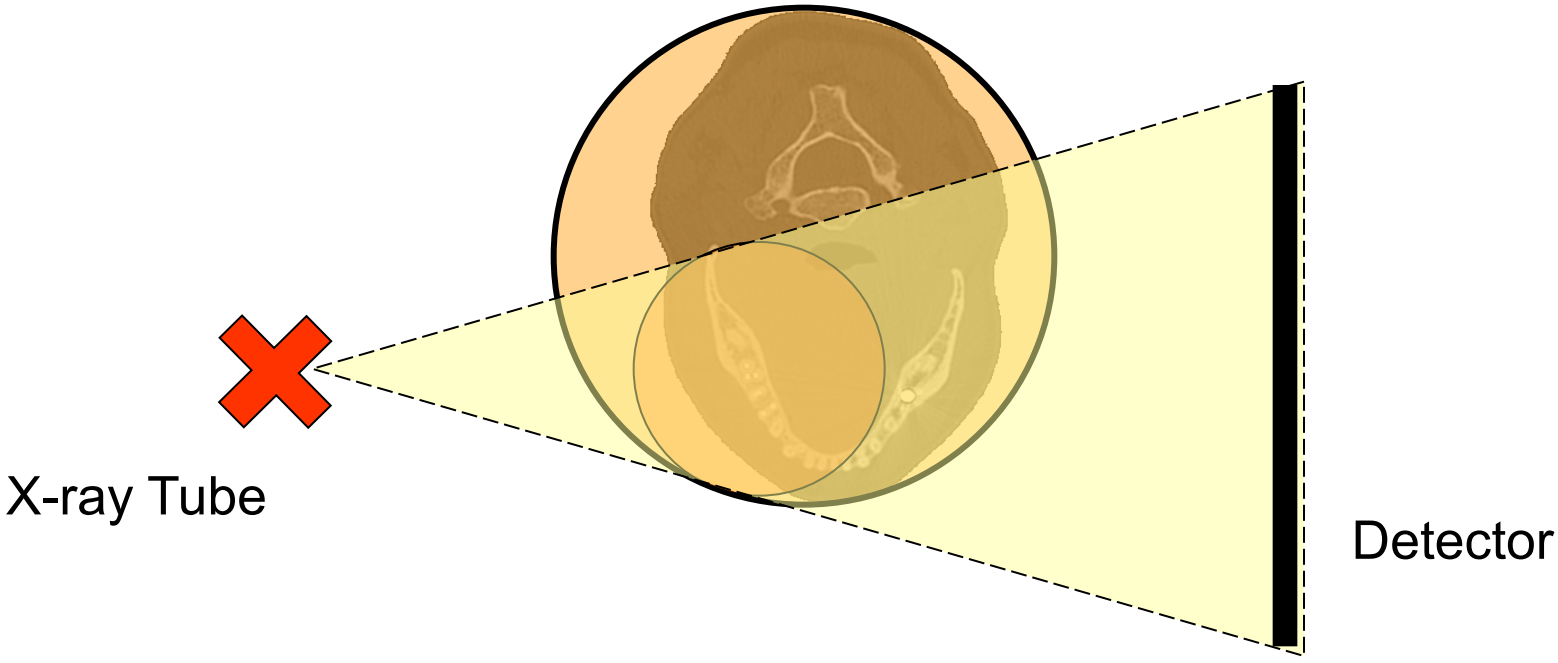
cone-beam CT (CBCT)



Animation courtesy of
Demetrios J. Halazonetis

cone-beam CT (CBCT)



Notes e.g. specific imaging parameters / protocols / concerns

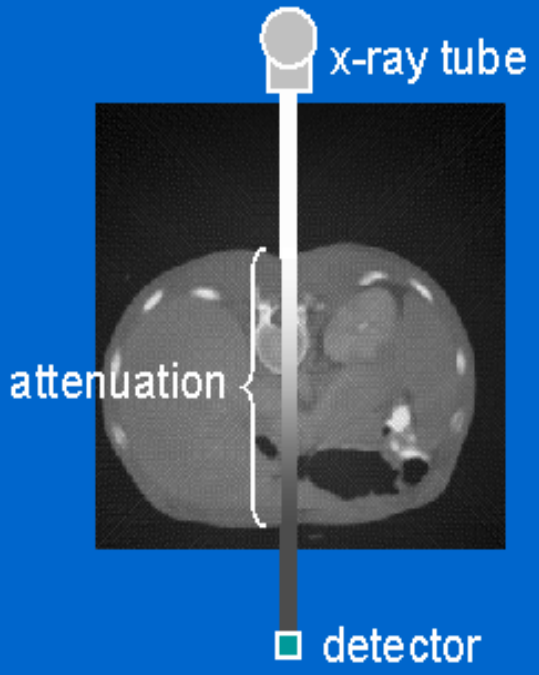
PLEASE AVOID SCANNING THE SPINE

"Sorry mate – no can do!"

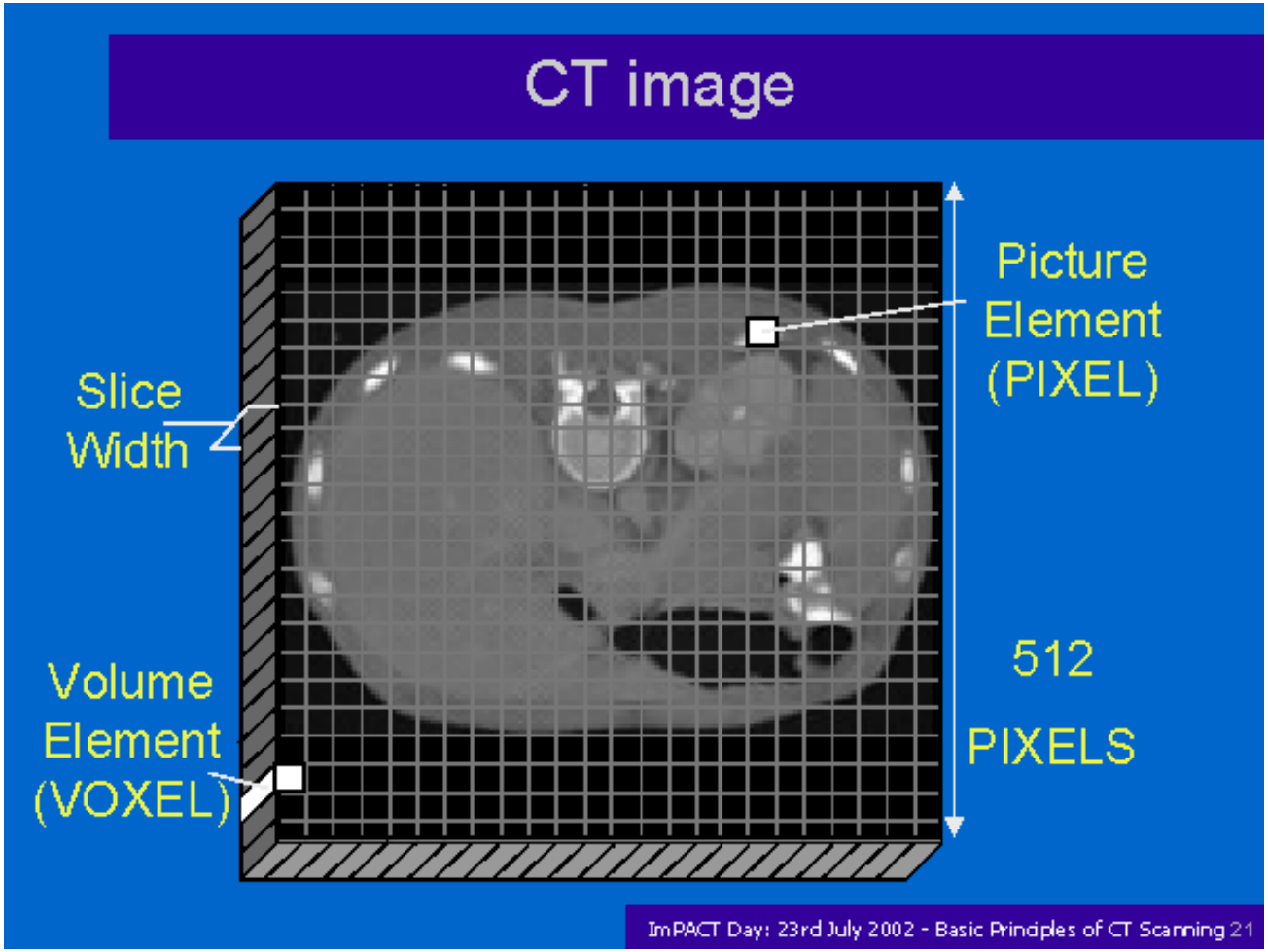
Medical CT Scanner

What are we measuring?

- The average linear attenuation coefficient, μ, between tube and detectors
- Attenuation coefficient reflects the degree to which the x-ray intensity is reduced by a material
- Expressed as "Hounsfield Units"

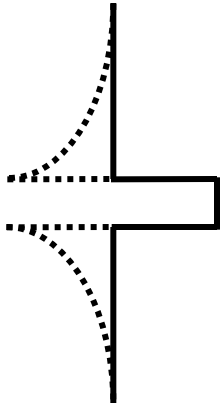


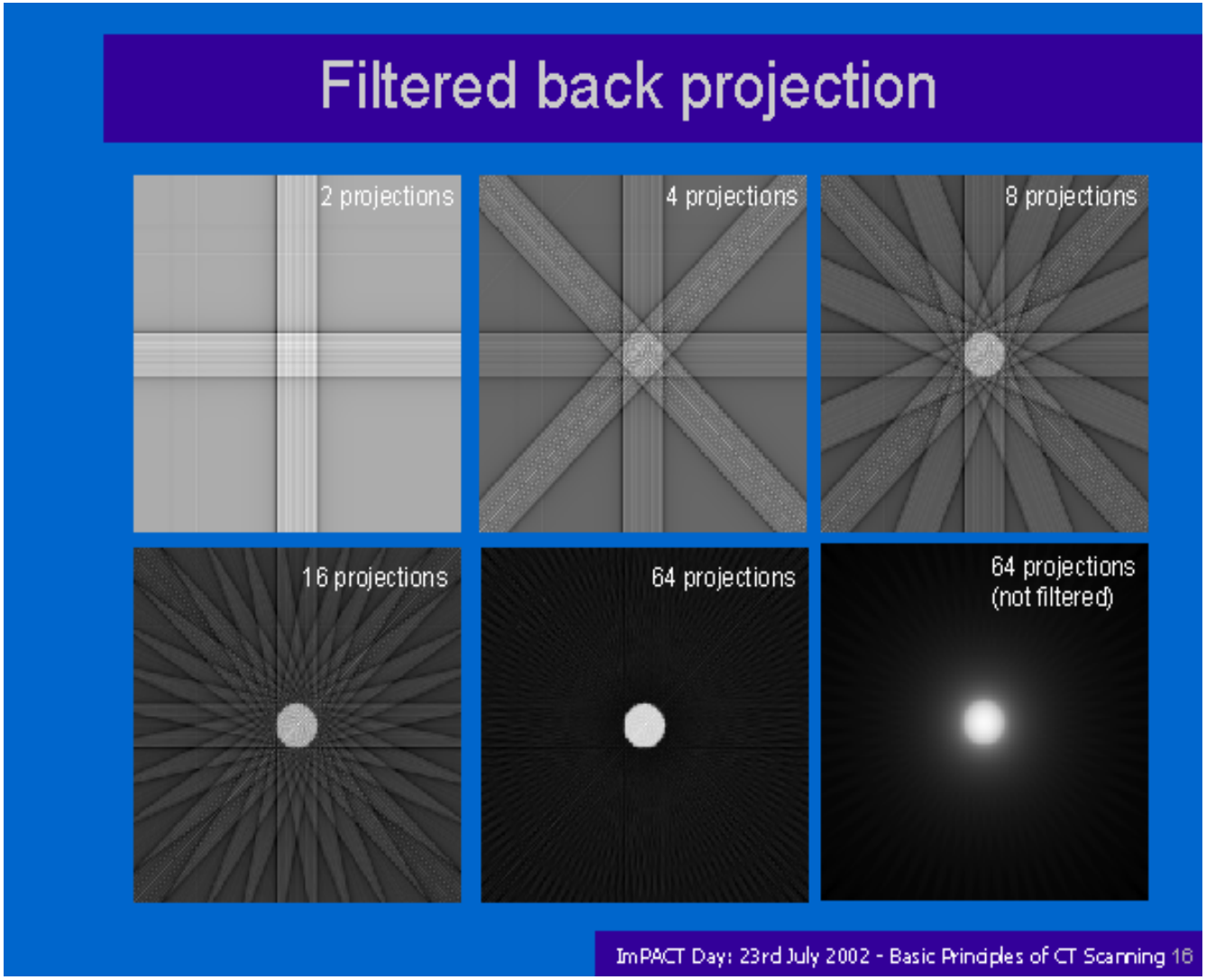
Slide from: http://www.impactscan.org



"(Trans)Axial Slice"

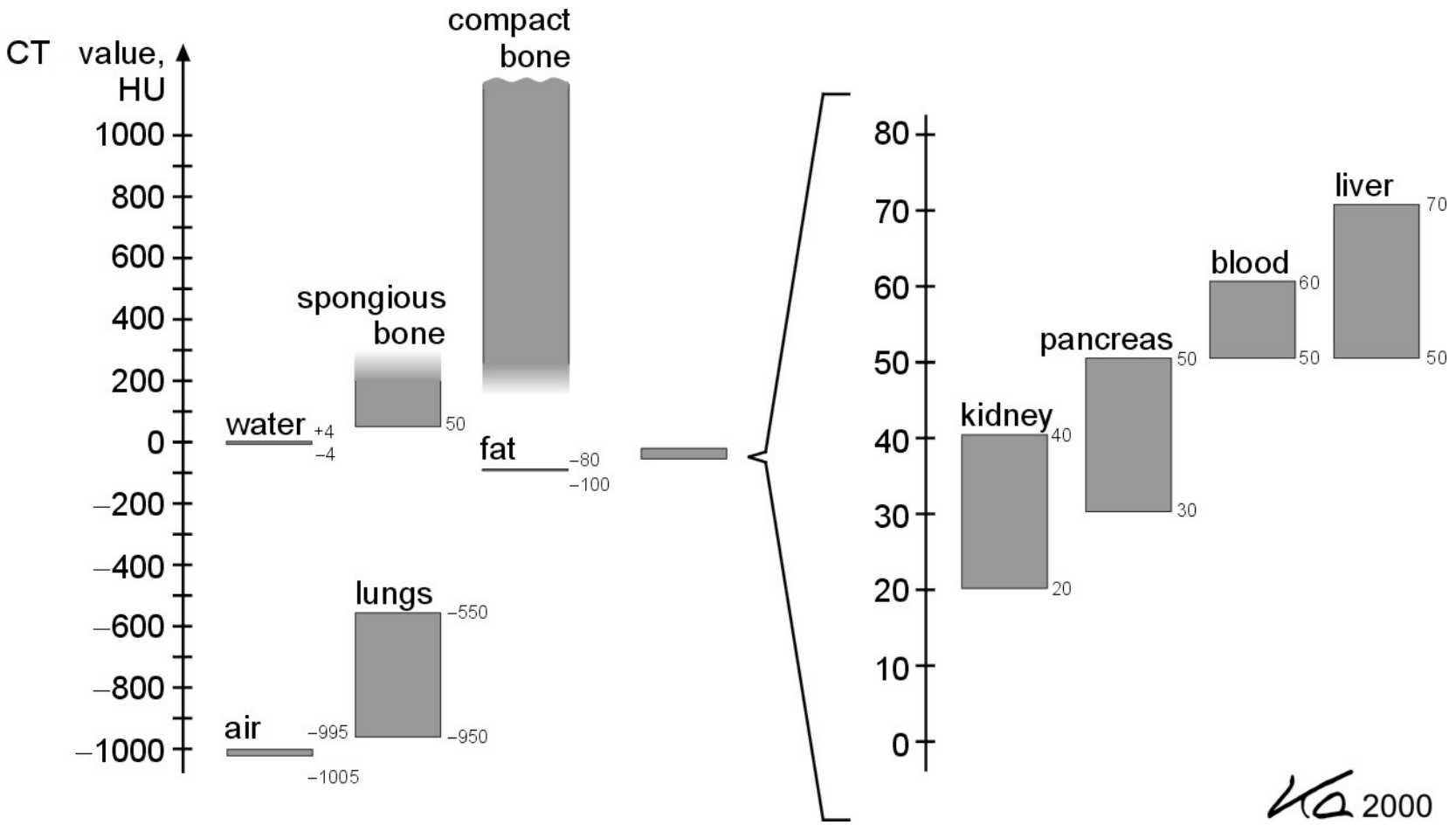
Slide from: http://www.impactscan.org





Also known as: "Convolution & Back Projection"

Slide from: http://www.impactscan.org



The Hounsfield Scale was devised for medical CT scanners - 120kVp and Large Field Of View

From: Kalender WA. *Computed Tomography.* Munich: Publicis MCD Verlag, ISBN 3-89578-081-2, 2000.

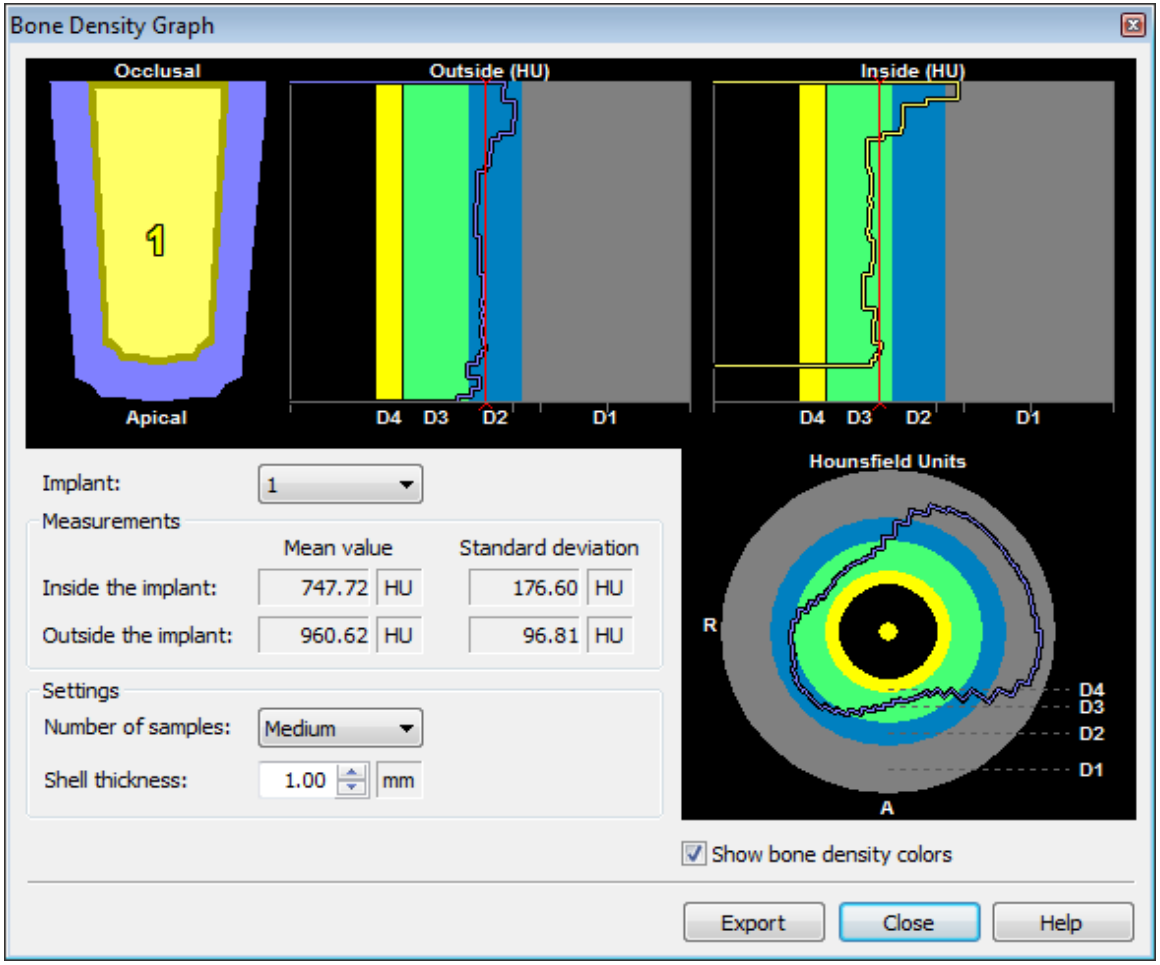
Why is Density Important?

- **Segmentation – making physical models or drill guides**
- **Virtual 3D models e.g. in SimPlant**
- **Clinical application of bone densities e.g. Carl Misch scale**

Table 1. Misch classification of bone density

Density	Hounsfield range	Type of bone
D1	> 1250	Dense cortical bone
D2	851–1250	Thick dense to porous cortical bone on crest and coarse trabecular bone within
D3	351–850	Thin porous cortical bone on crest and fine trabecular bone within
D4	150–350	Fine trabecular bone

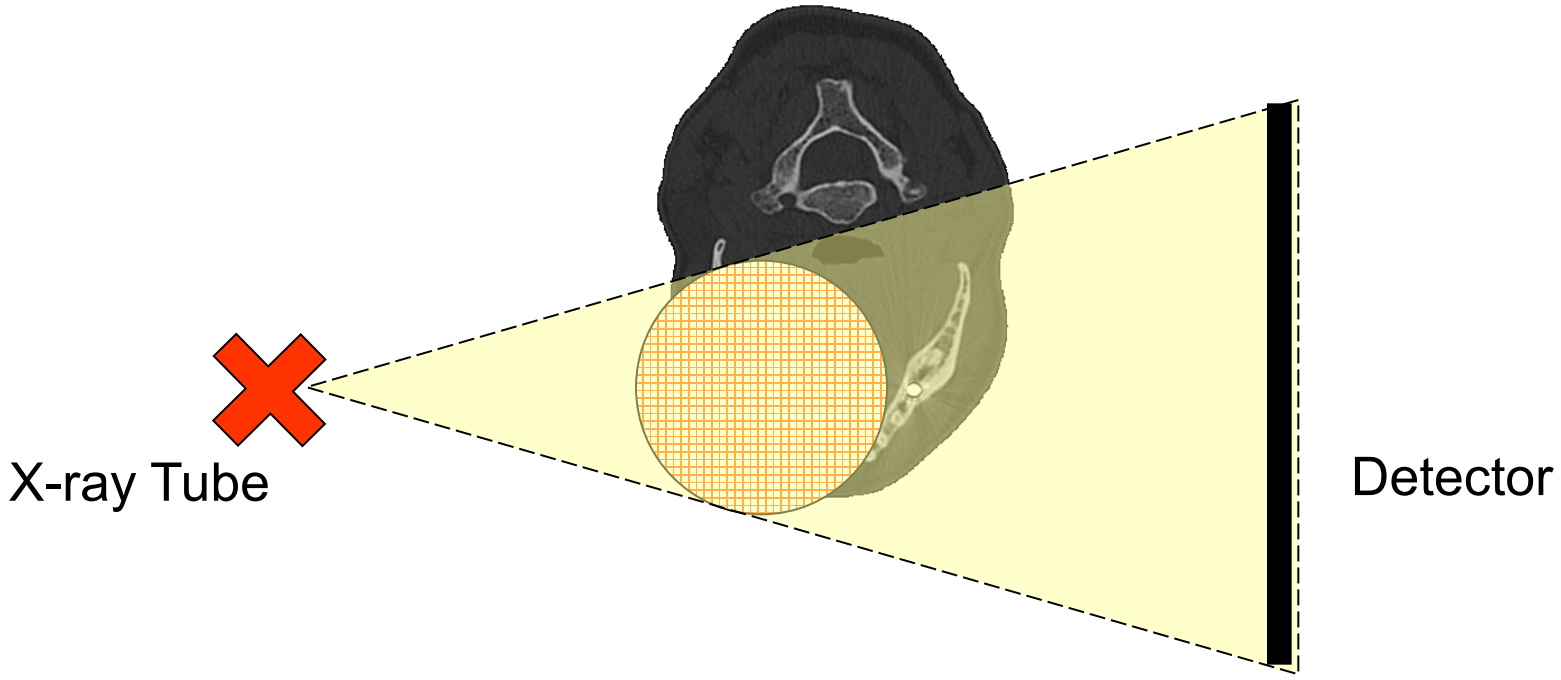
Adapted from: Misch C. *Contemporary Implant Dentistry.* 2rd edn. Mosby, St Louis, 1999


Bone Density Graph
Occlusal
Outside (HU)
Inside (HU)
1
Apical
D4 D3 D2 D1
D4 D3 D2 D1
Implant:
1
Measurements
Mean value
Standard deviation
Inside the implant:
747.72 HU
176.60 HU
Outside the implant:
960.62 HU
96.81 HU
Settings
Number of samples:
Medium
Shell thickness:
1.00 mm
Hounsfield Units
R
D4
D3
D2
D1
A
Show bone density colors
Export
Close
Help

Three reasons why CBCT pixel values don't lie on the Hounsfield scale:

- **The Hounsfield Scale is defined at 120kVp, but most CBCT scanners run at 80-90kVp**
- **The x-ray spectrum contains more low energy photons because of scattered radiation**
- **The voxel densities cannot be calculated accurately!**

Limitation of Small Field Of View CBCT



- **CBCT measures the density within the Field Of View only**
- **Material outside the Field Of View has an unpredictable effect**
- **Software corrections means pixels may change with updates**

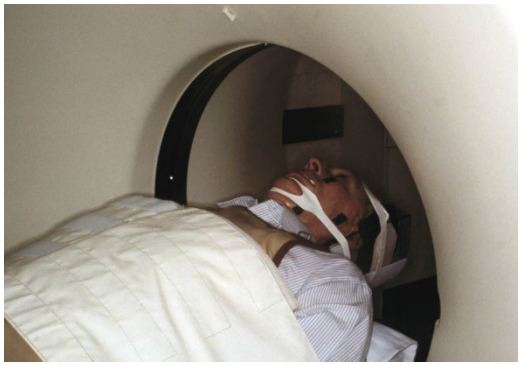
4cm x 4cm

6cm x 4cm

8cm x 5cm

10cm x 6cm

Medical CT Scanners:



- Lie down geometry
- Claustrophobic for patients
- Soft tissues collapse
  + good for studying sleep apnoea?
- TMJ not in natural position
- Higher radiation dose in most cases
+ Accurate density measurements

Cone Beam CT Scanners:

+ Sitting up geometry

+ More comfortable for patient

+ Ability to also produce 2D DPT and Ceph

+ Lower radiation dose (up to 10x)

- Density measurements are not reliable

The Best CBCT Scanner on the Market?

Toshiba Aquilion ONE medical CT Scanner

320 detector rows

operates in cone beam mode

0.5s scan time

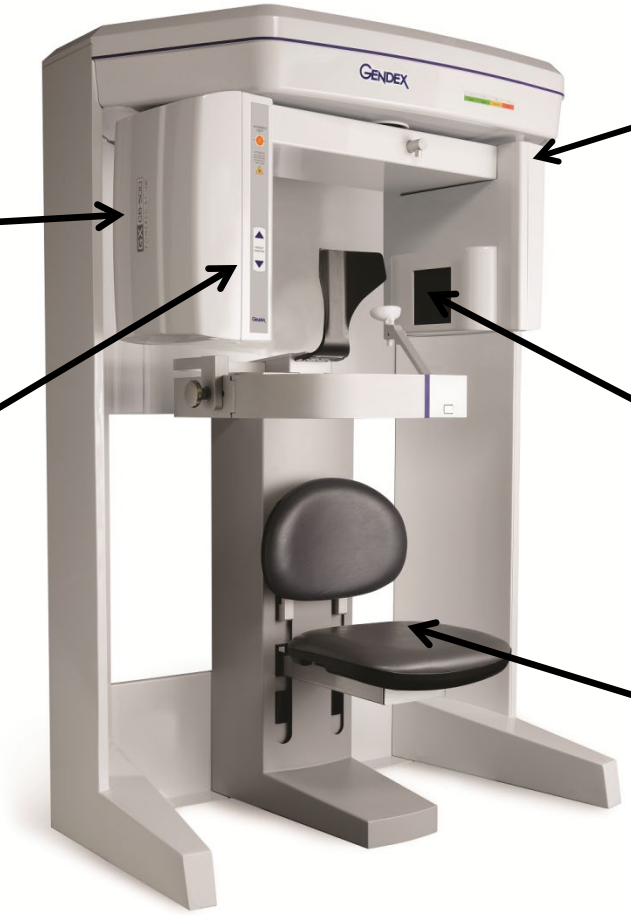
volume capture
24cm x 16cm max

Effective Doses
typical Mx 100μSv
typical Mn 150μSv

Around £1M

Aquilion™ is a trademark of Toshiba Medical Systems Corporation

CB-500 CBCT Scanner



fast scan times
4.8s to 23s

low dose
typical Mx 35µSv
typical Mn 60µSv

pulsed x-ray tube

adjustable collimator
4 to 8.6 cm height
8.6 or 15.6 cm width

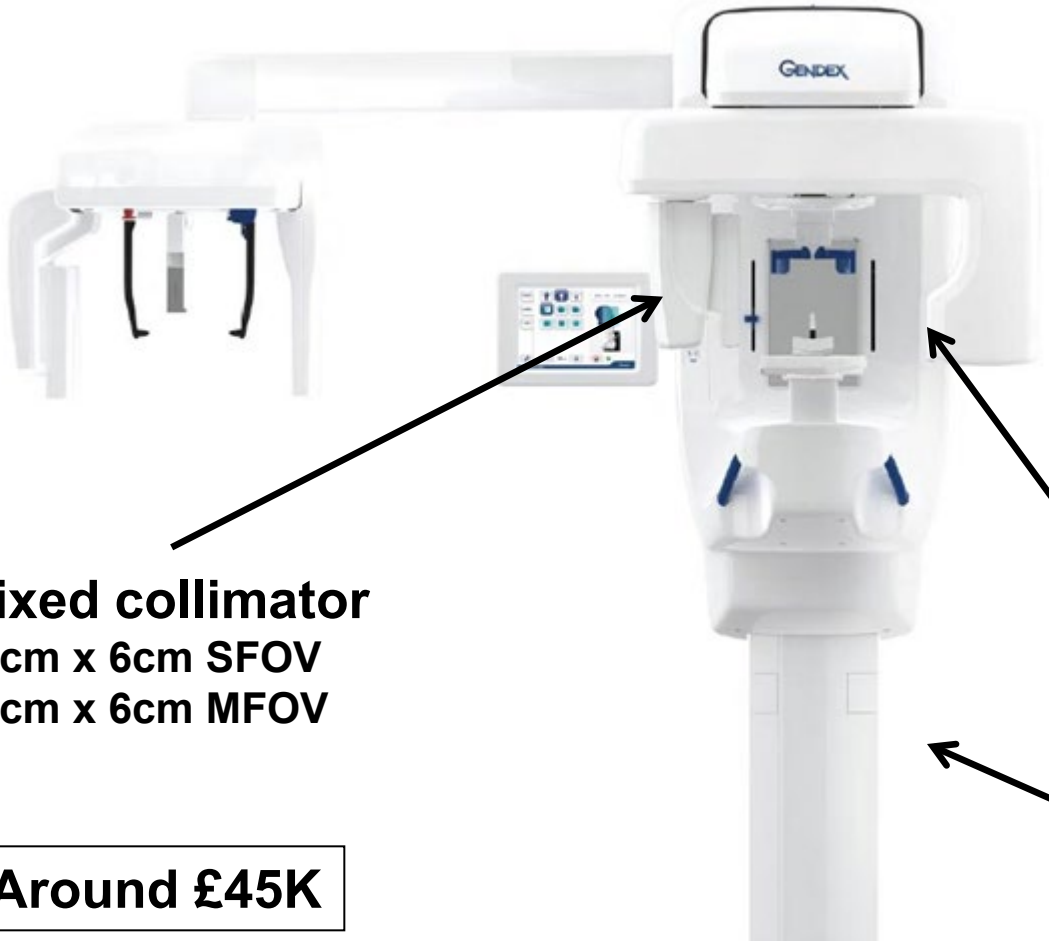
large detector
8cm x 8cm

adjustable chair

Around £90K

Gendex™ is a trademark of Gendex Dental Systems of Lake Zurich, USA

DP-700 CBCT Scanner



variable mA
fixed scan times
11s for SFOV
45s for MFOV

medium dose
typical Mx 60µSv
typical Mn 100µSv

fixed collimator
4cm x 6cm SFOV
8cm x 6cm MFOV

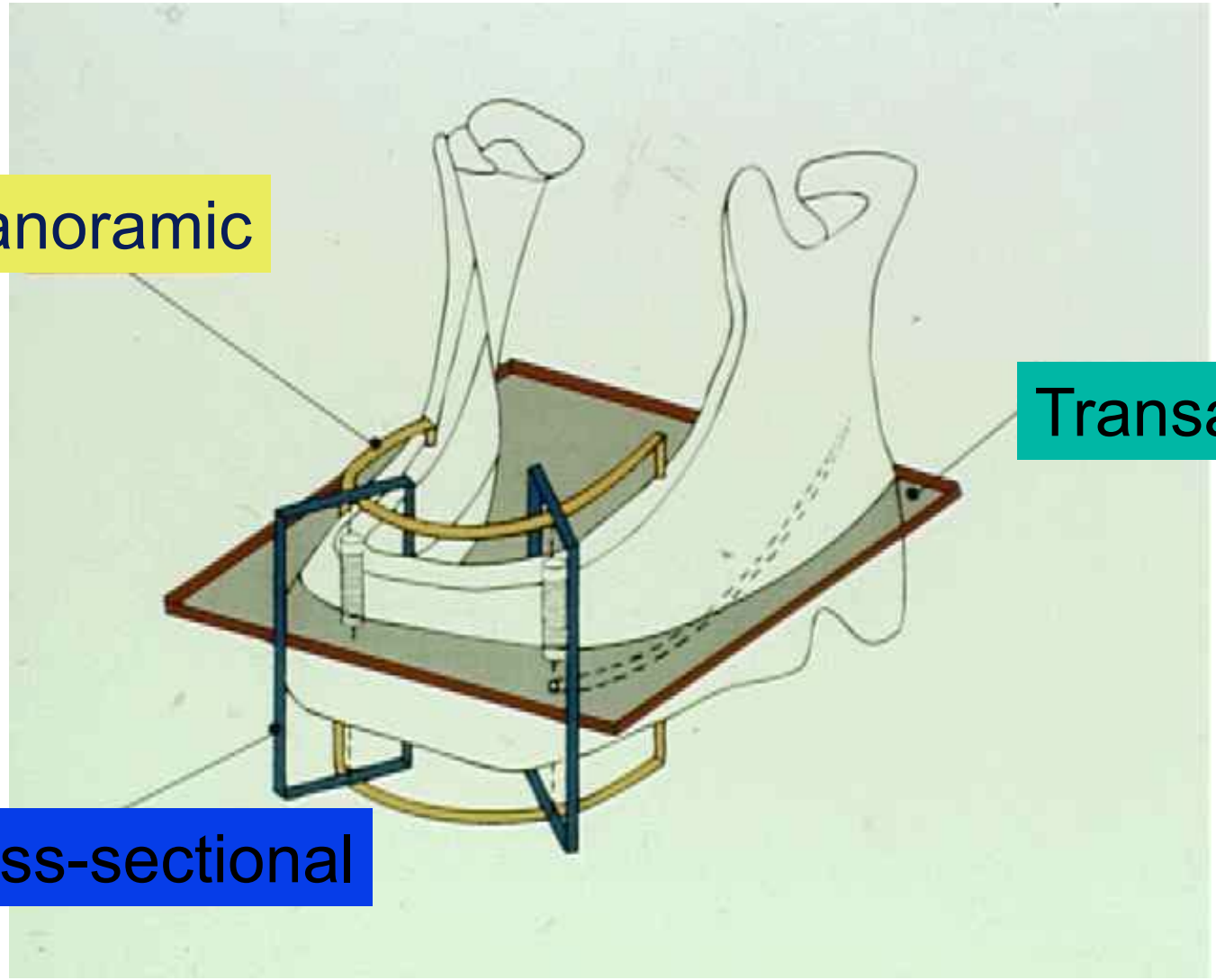
small detector

no chair

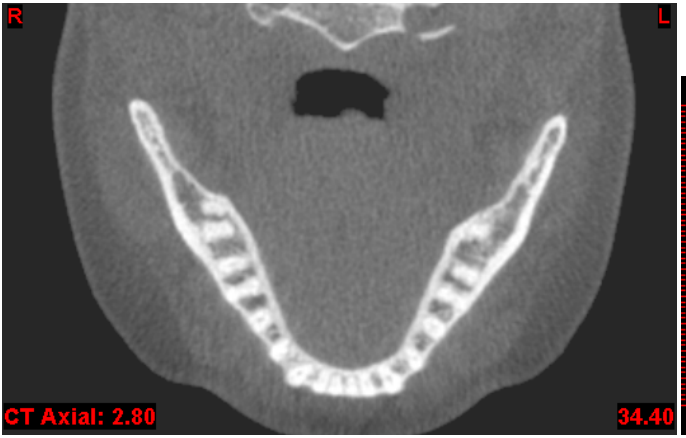
Around £45K

Gendex™ is a trademark of Gendex Dental Systems of Lake Zurich, USA

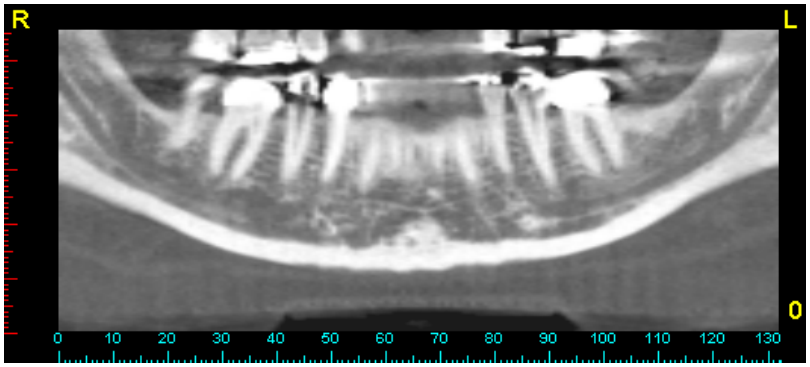
Basic CBCT images



Basic CBCT images



Axials



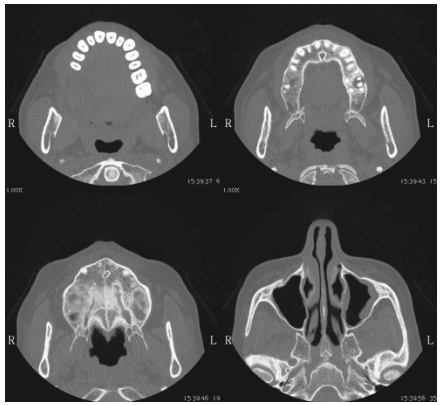
Panoramics

Cross Sections

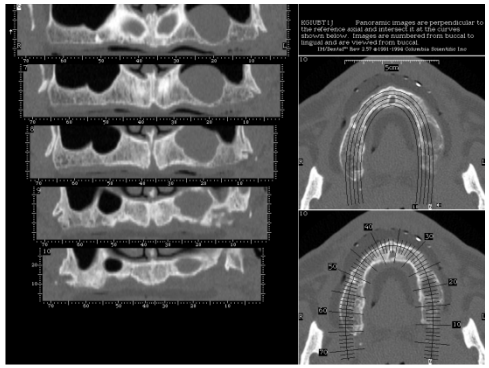
Sagittal

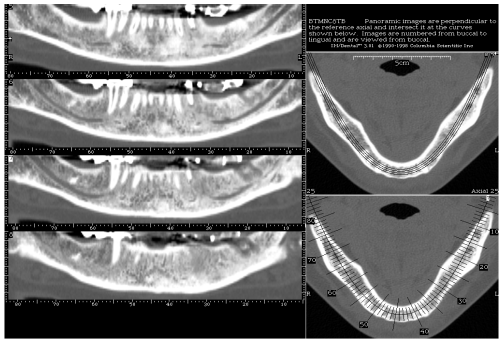
Coronal

(Trans)axial slices from CBCT Scanner

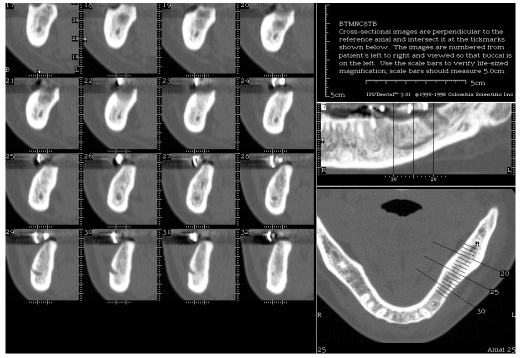


Reformatted Panoramics

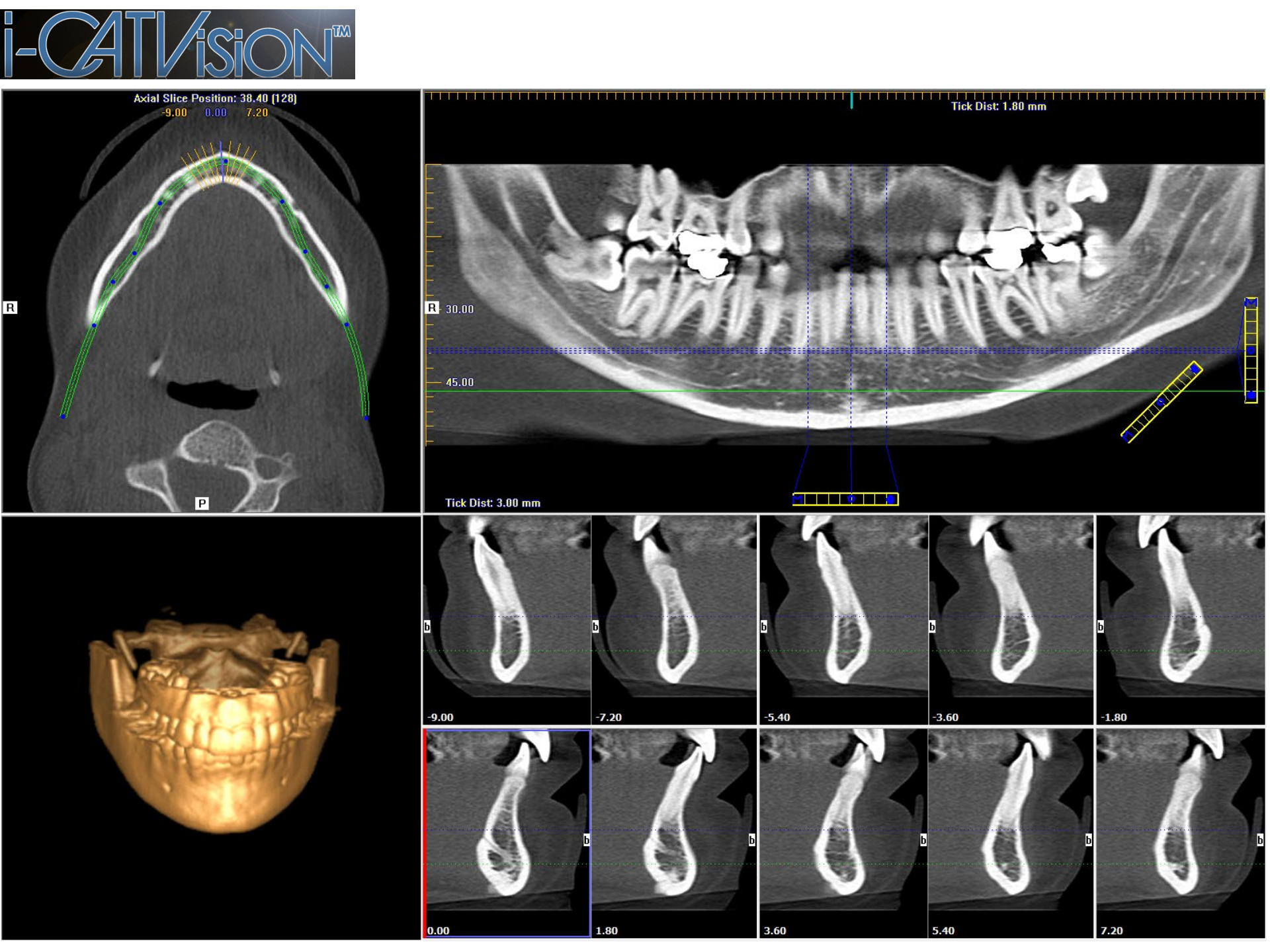




Reformatted Panoramics



Reformatted Cross-Sections


i-CATVision™
Axial Slice Position: 38.40 (128)
-9.00 0.00 7.20
R
P
Tick Dist: 1.80 mm
R 30.00
45.00
Tick Dist: 3.00 mm
b
-9.00
-7.20
-5.40
-3.60
-1.80
0.00
1.80
3.60
5.40
7.20

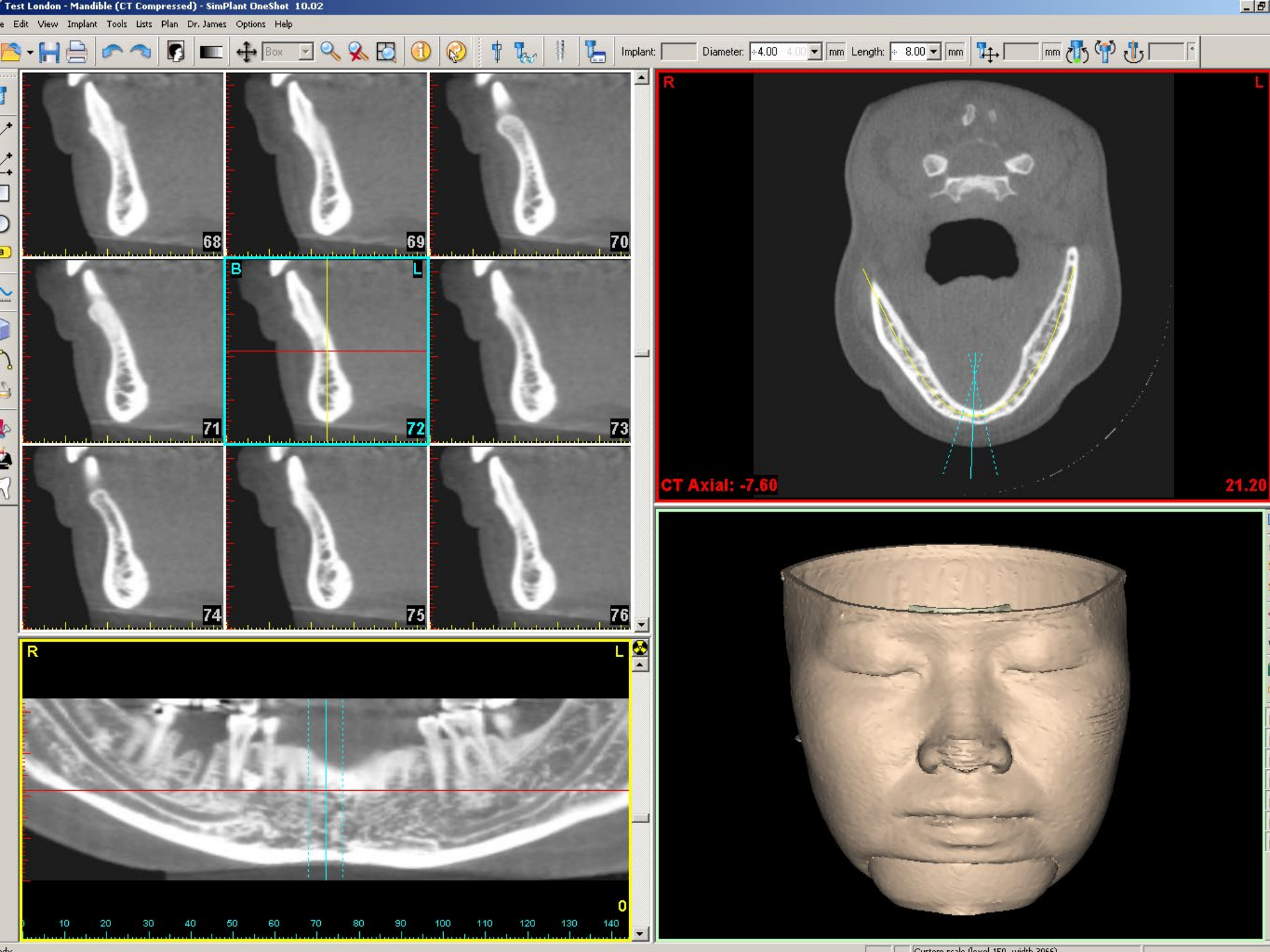

Test London - Mandible (CT Compressed) - SimPlant OneShot 10.02
Edit View Implant Tools Lists Plan Dr. James Options Help
Implant: Diameter: 4.00 mm Length: 8.00 mm
68
69
70
B
L
71
72
73
74
75
76
R
L
CT Axial: -7.60
21.20
R
L
0
10 20 30 40 50 60 70 80 90 100 110 120 130 140

Image Quality in CBCT scans

- Noise

- *electronic noise (dark current)*
- *photon noise (not enough x-rays)*

- Artefact

- *patient movement*
- *metal objects within the patient*
- *rings (machine calibration, poor operator technique)*

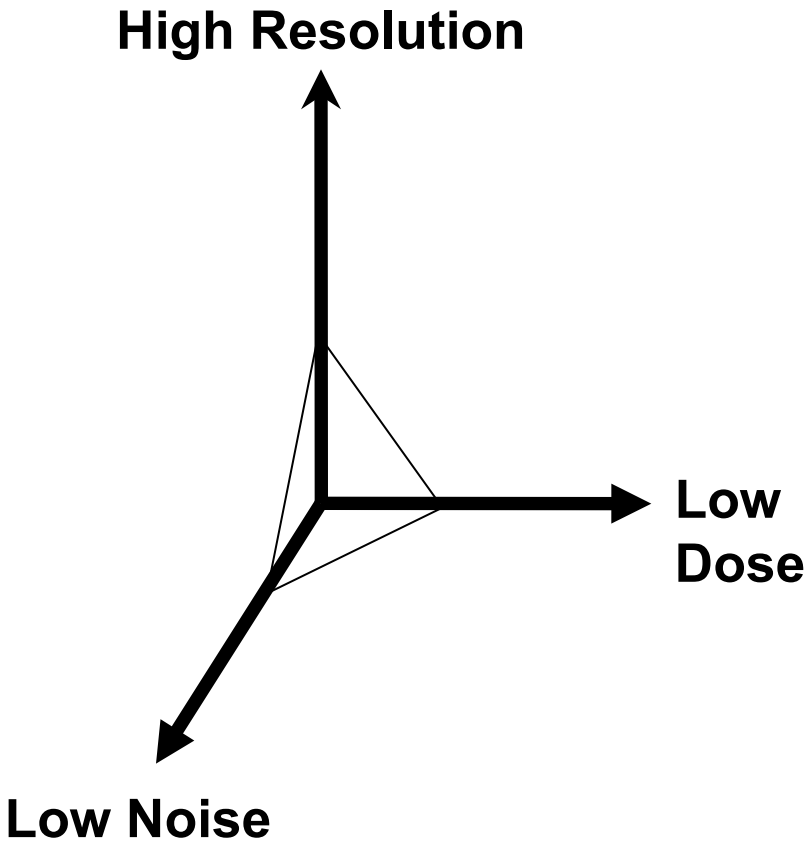
- Spatial Resolution (resolution at high contrast)

- *depends on machine design*
  (focal spot size, detector elements, sampling, mechanical stability)
- *voxel size can only limit the resolution – cannot increase it!*

- Contrast Resolution (resolution at low contrast)

- *depends on machine design (kVp, filtration, reconstruction algorithms)*

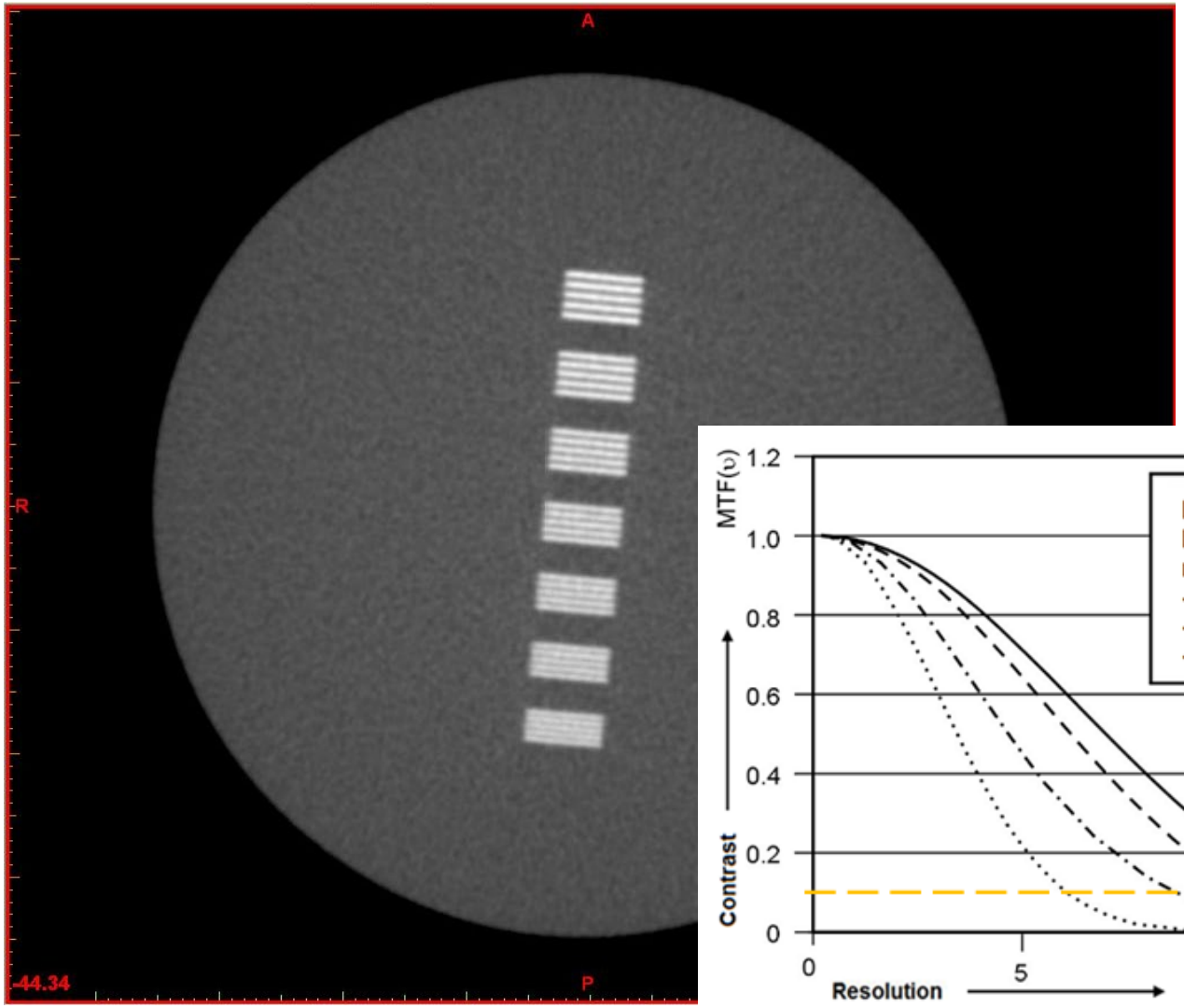
The impossible dream

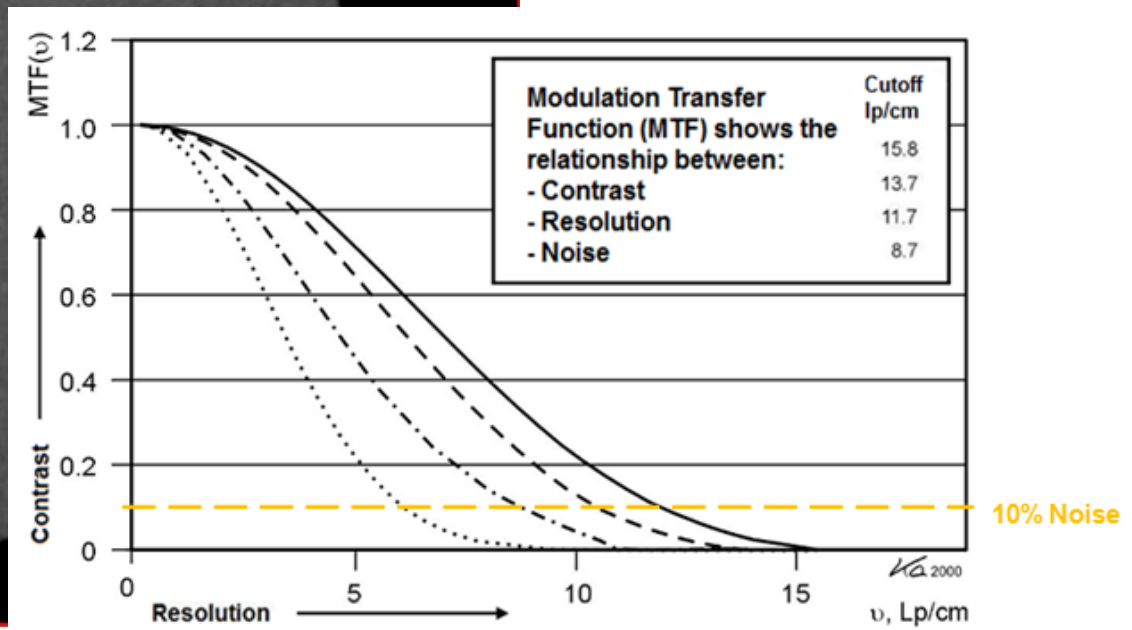


A good scanner will offer a range of voxel sizes, mAs and field sizes to suit the imaging task at hand.

Spatial Resolution

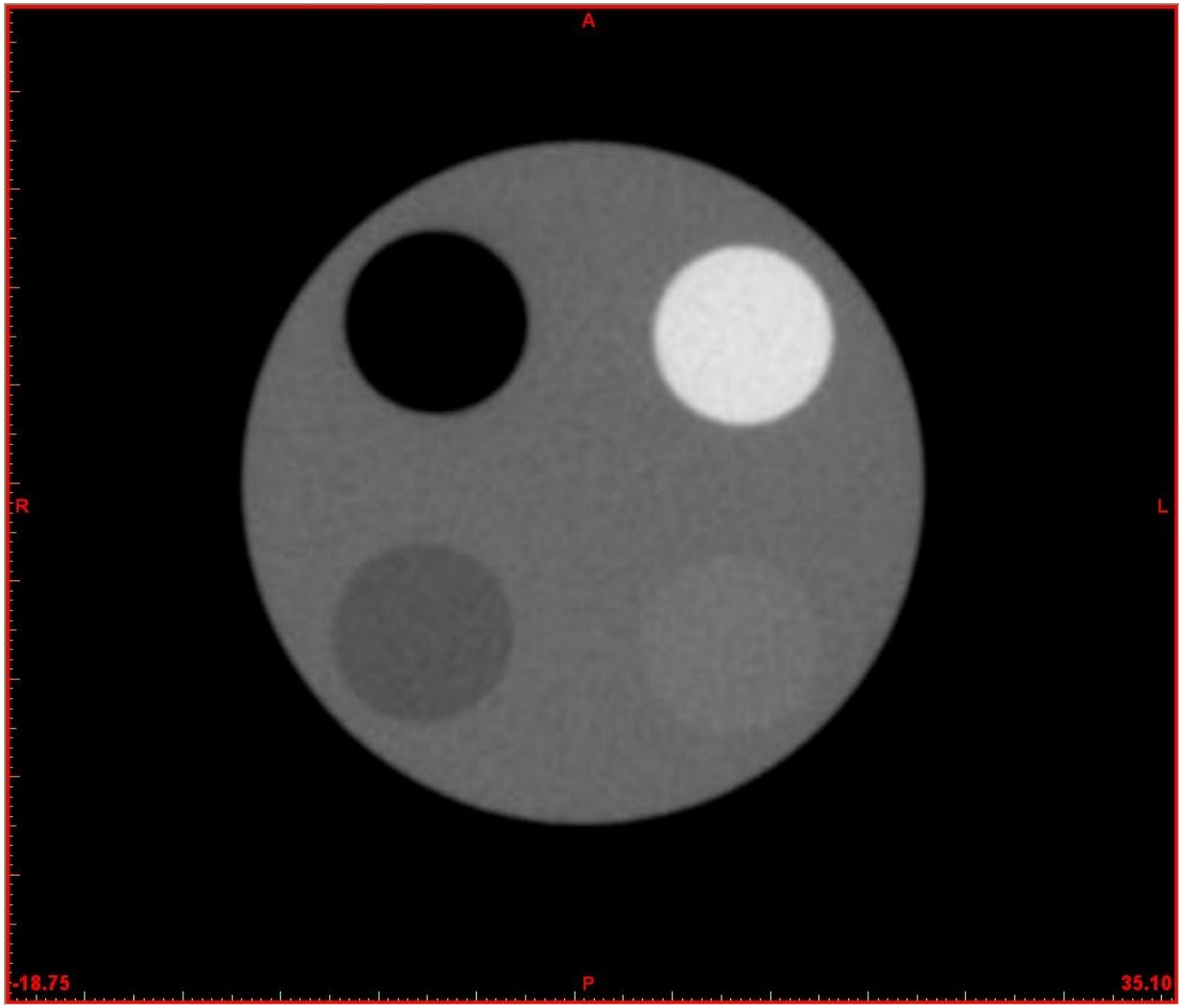
Detail at high contrast





Contrast Resolution

Detail at low contrast



Spatial and Contrast Resolution

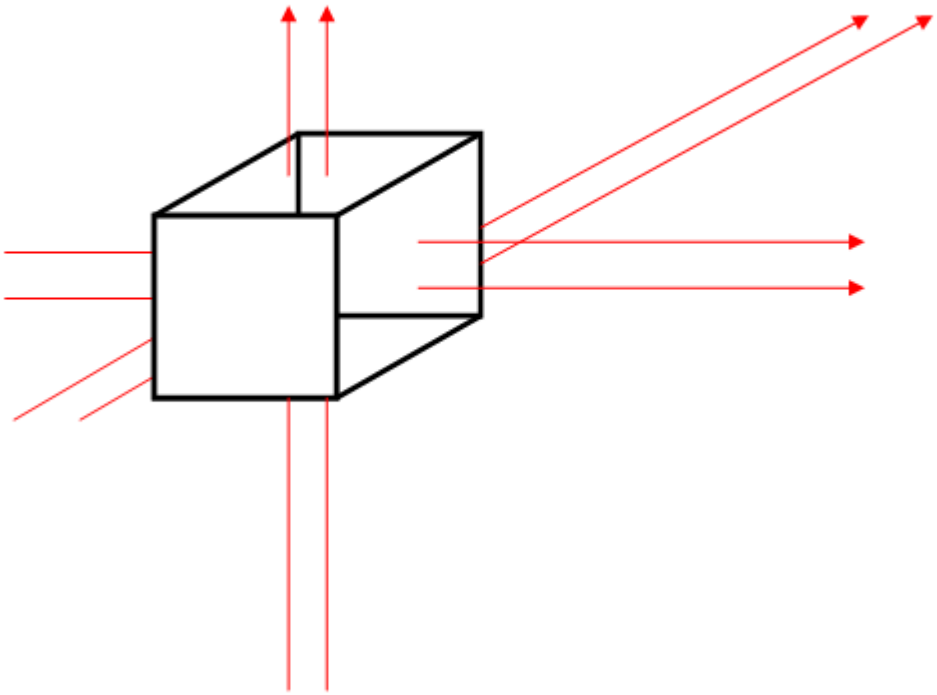
Noise in CT / CBCT images

Noise = unstructured contribution to the image which has no counterpart in the object.

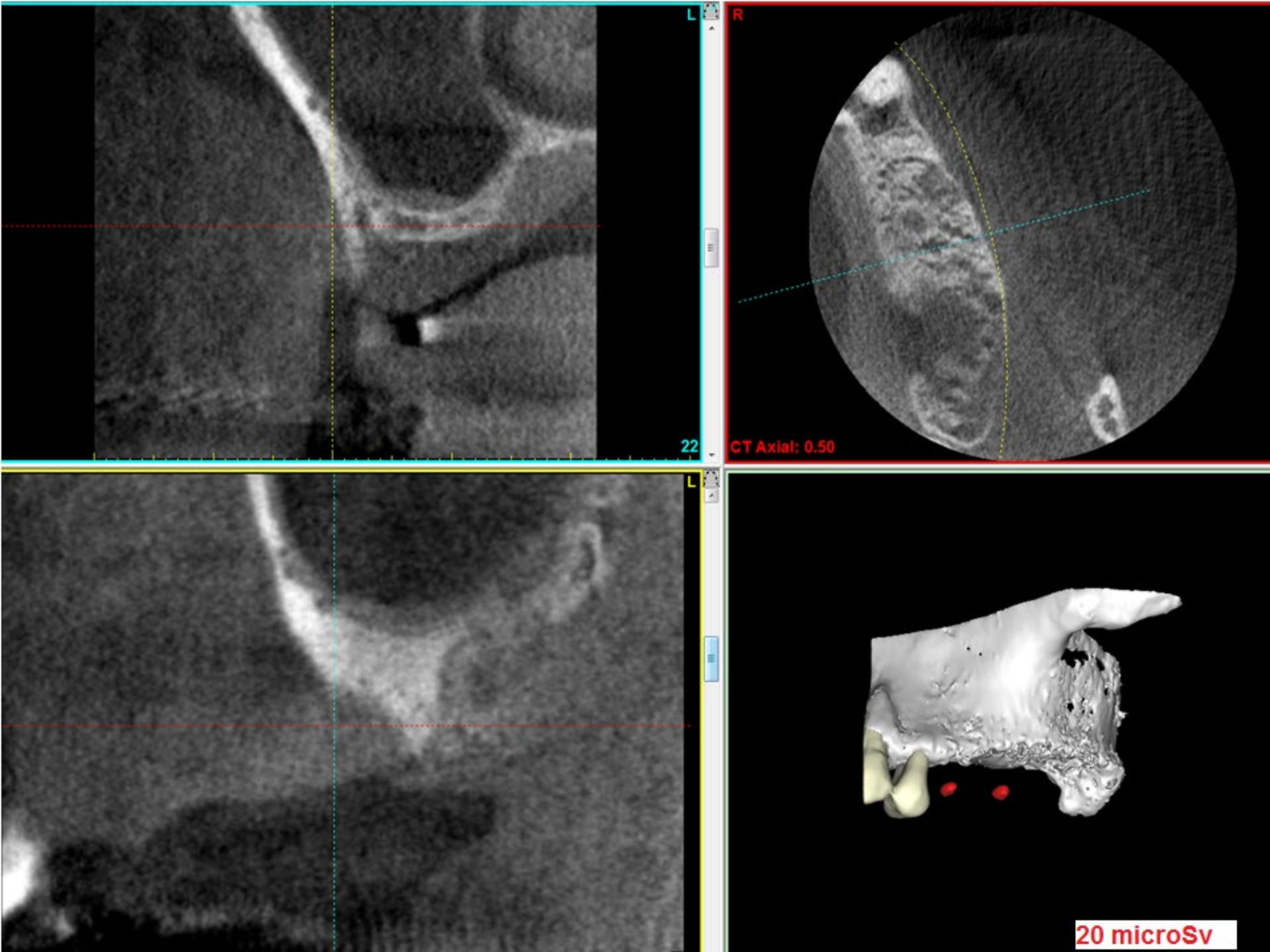
- **Electronic noise (dark current)**
- **Photon noise (not enough x-rays)**
  - **Signal-to-Noise Ratio is proportional to $\sqrt{n}$**
  - **Where n is the number of x-ray photons**

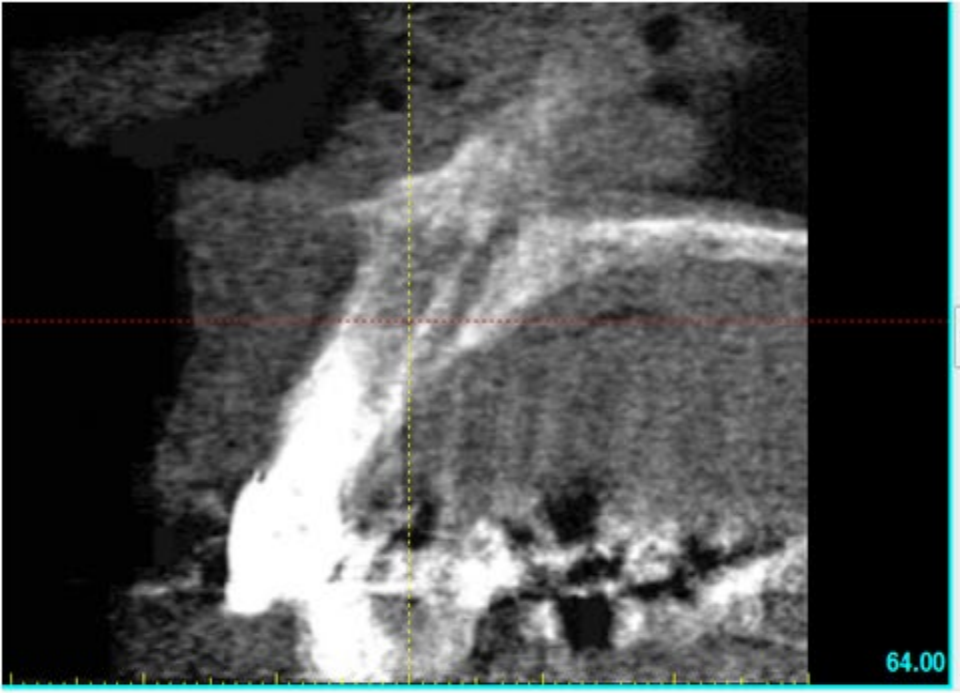
Noise depends on voxel size

x-rays
(from all
directions)

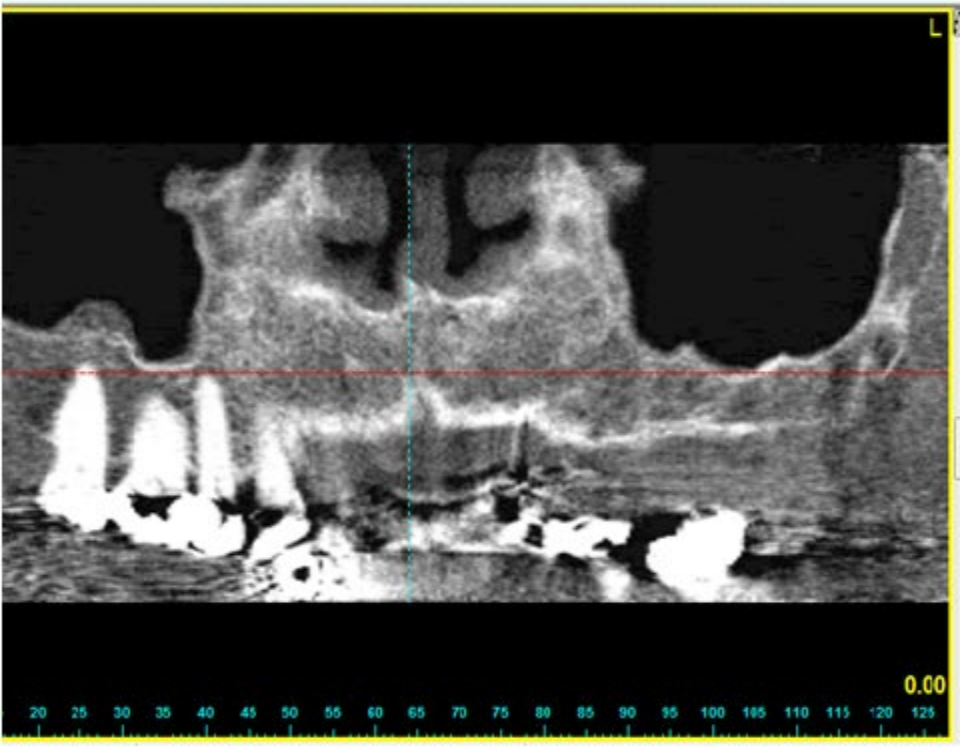


If you halve (1/2) each side of a cube e.g. from 0.4mm to 0.2mm
Number of x-ray photons passing through it goes down by 8 (i.e. 1/8)
Noise goes up by $\sqrt{8} = 2.83$
mAs (dose) may have to be increased to compensate

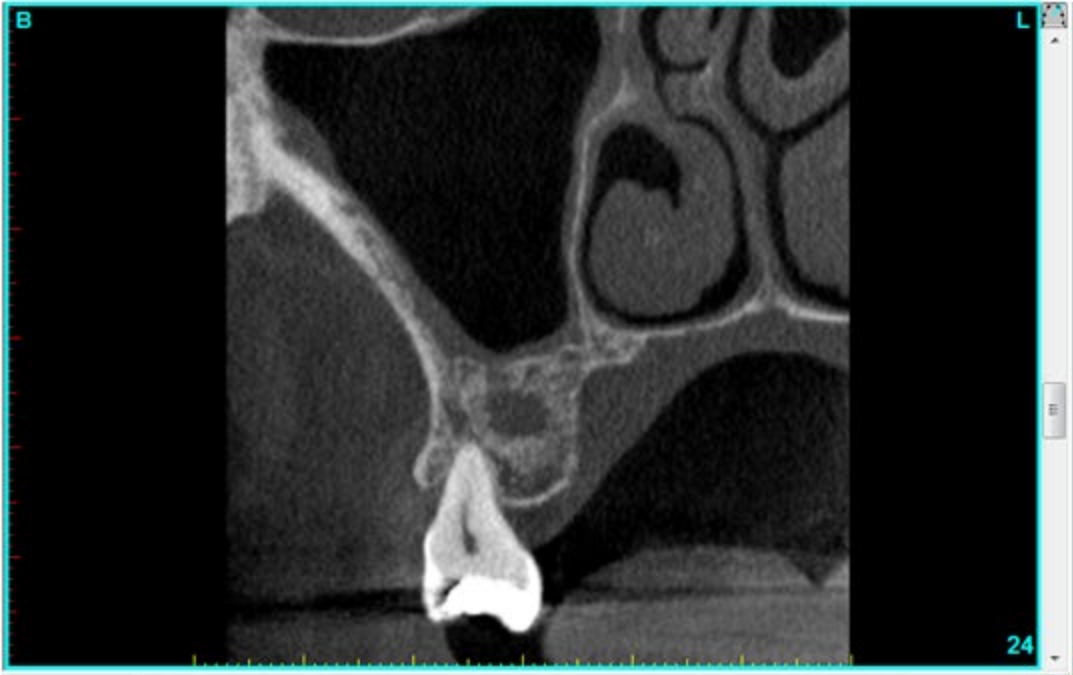

L
22
R
CT Axial: 0.50
L
20 microSv


64.00


CT Axial: -24.30
24.40

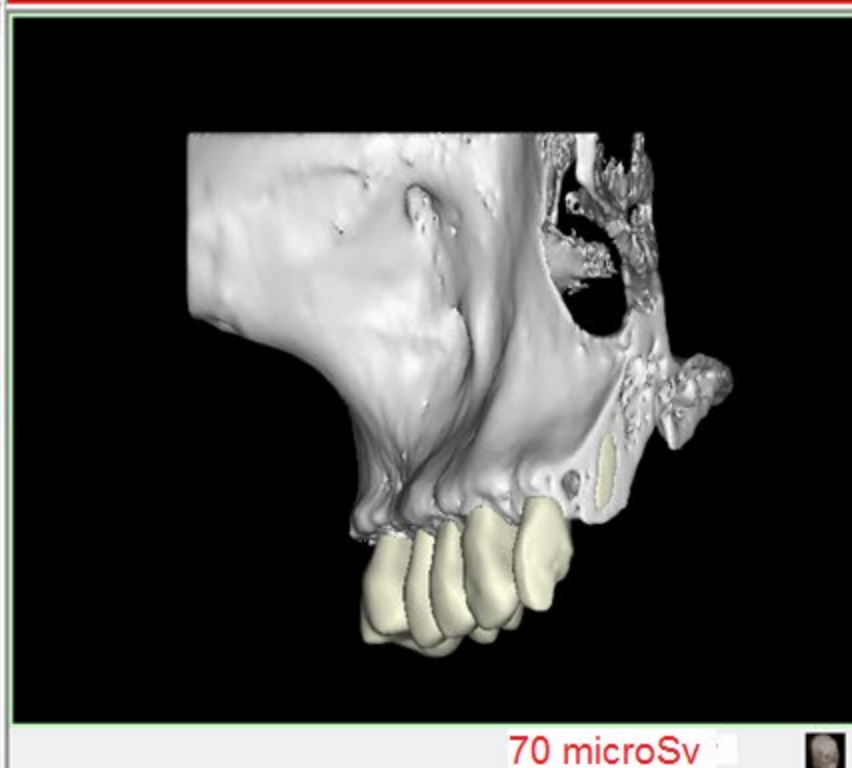

L
0.00
20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125

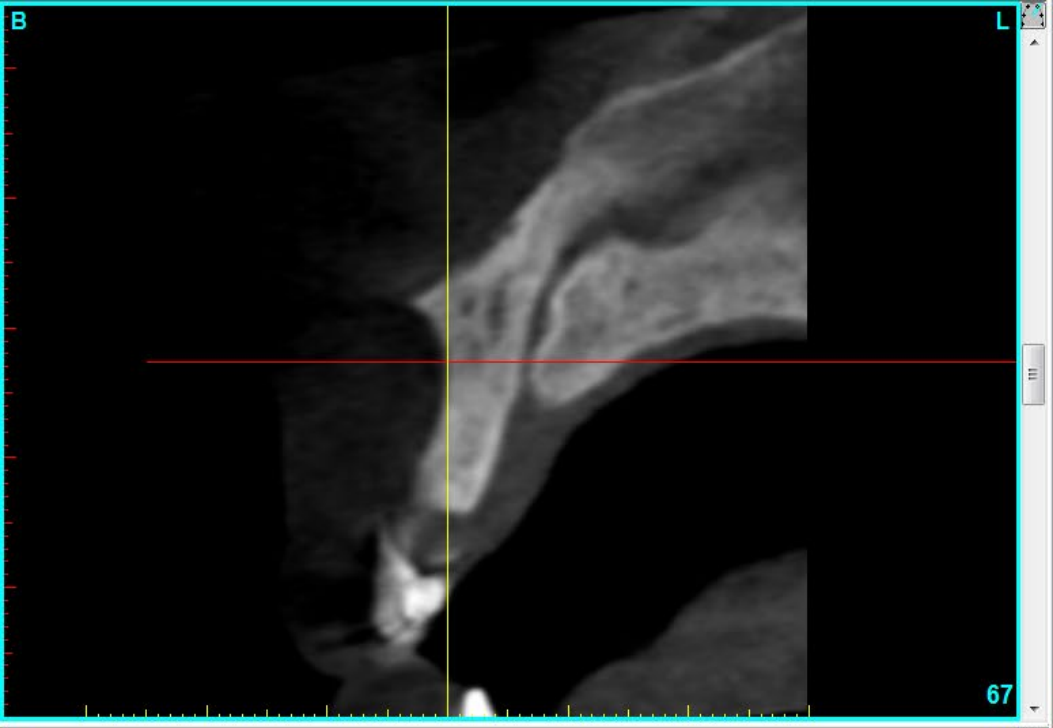

30 microSv

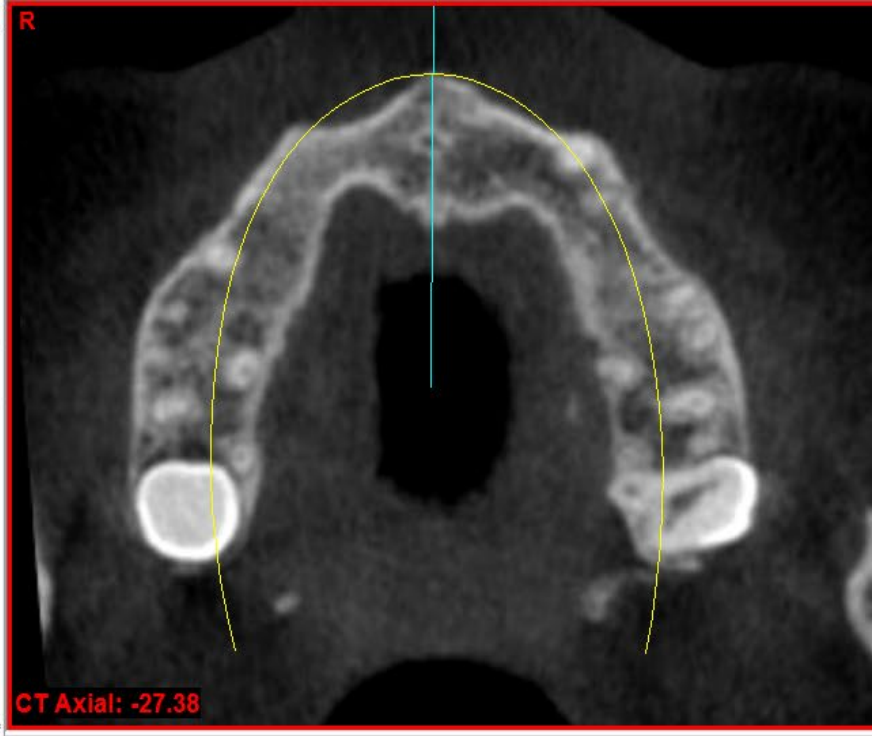

B
L
24

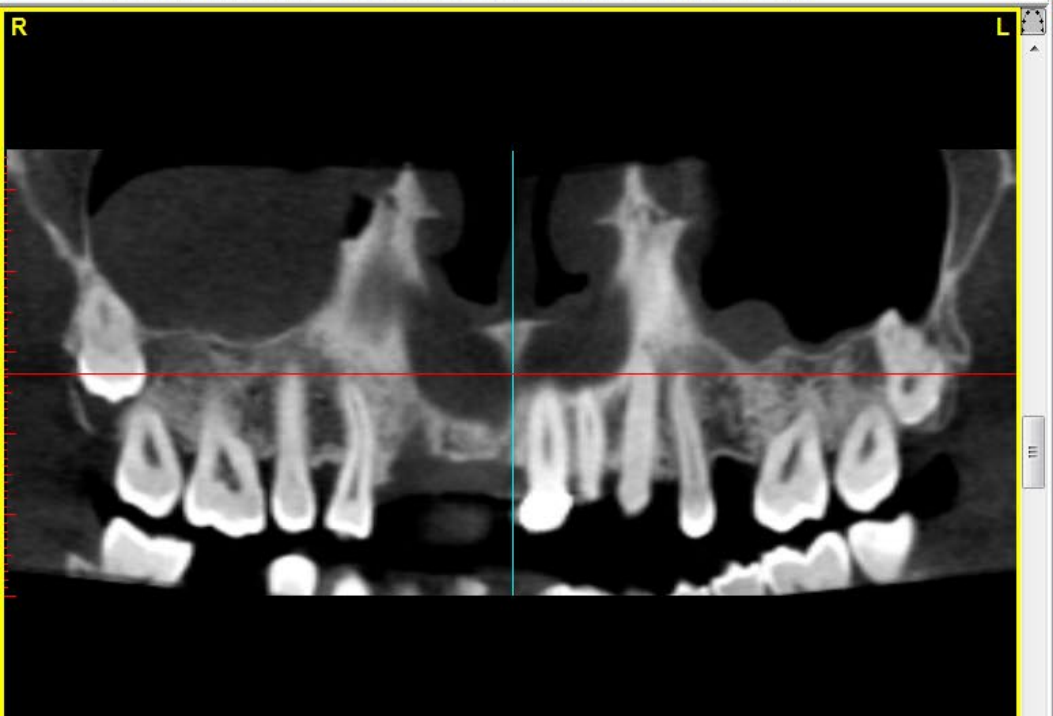

R
CT Axial: 0.00

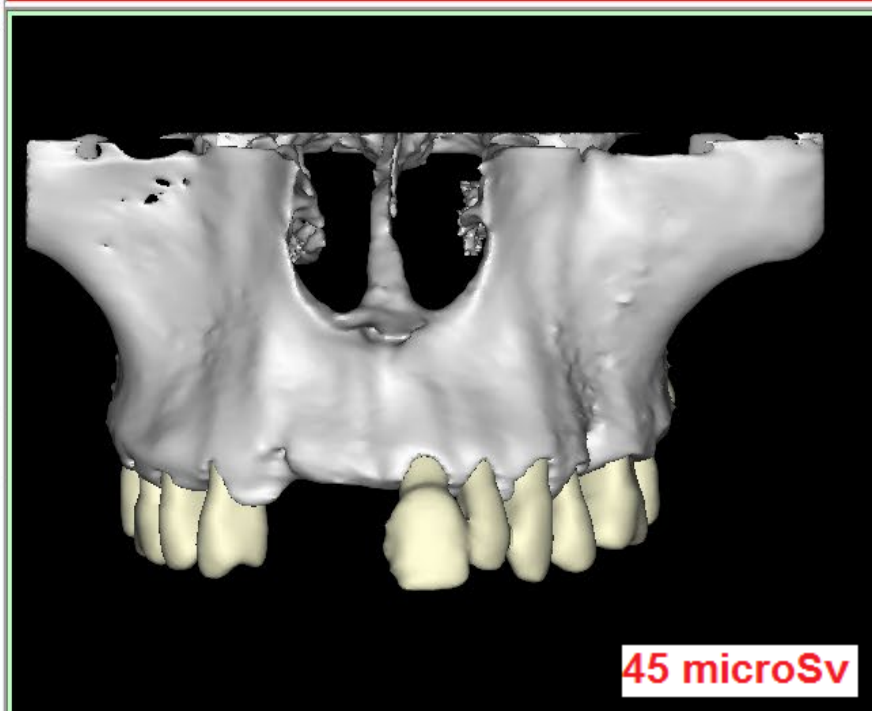

R
L
0.00
0
5
10
15
20
25
30
35
40
45
50
55
60


70 microSv


B
L
67


R
CT Axial: -27.38


R
L

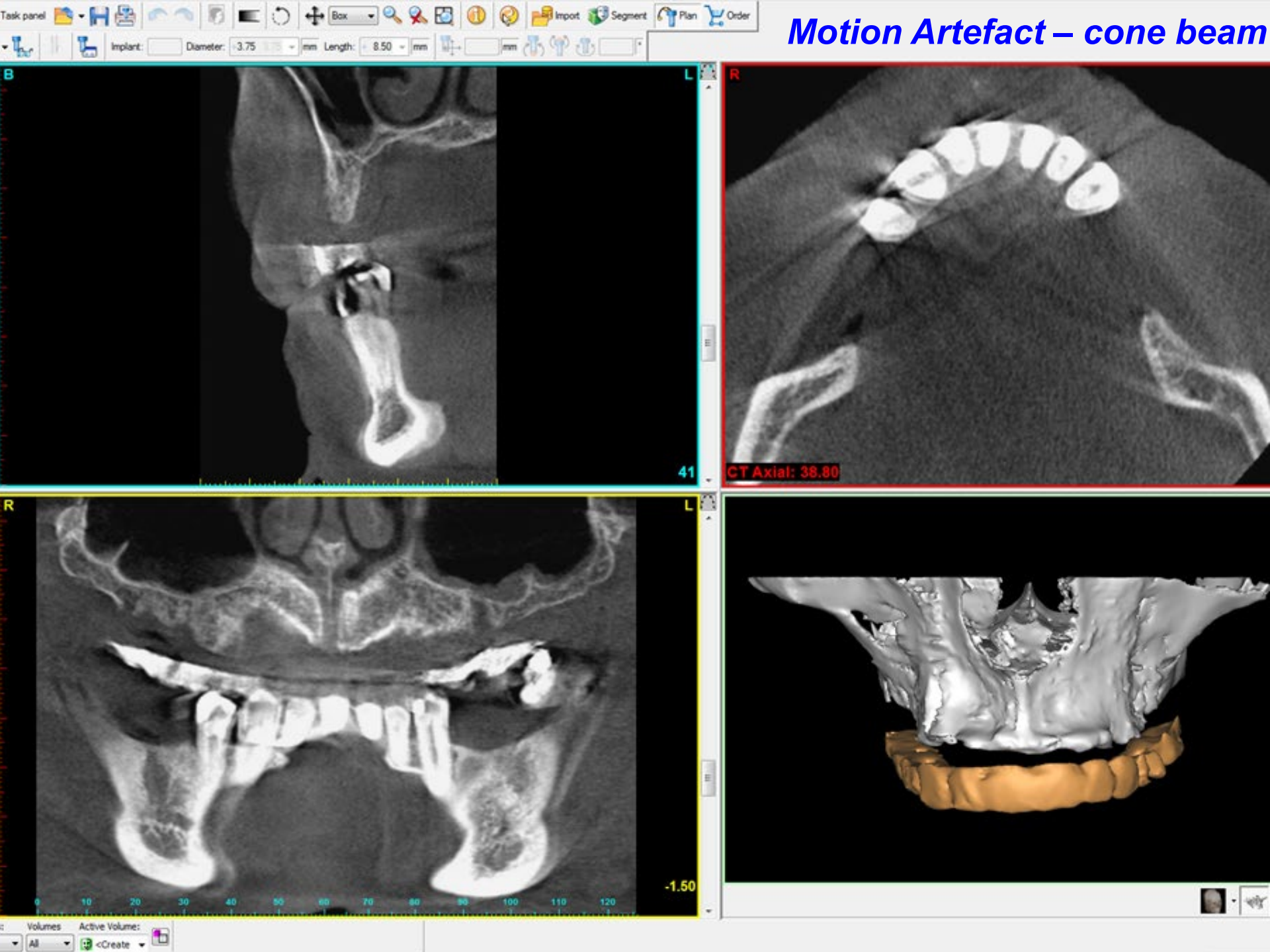

45 microSv

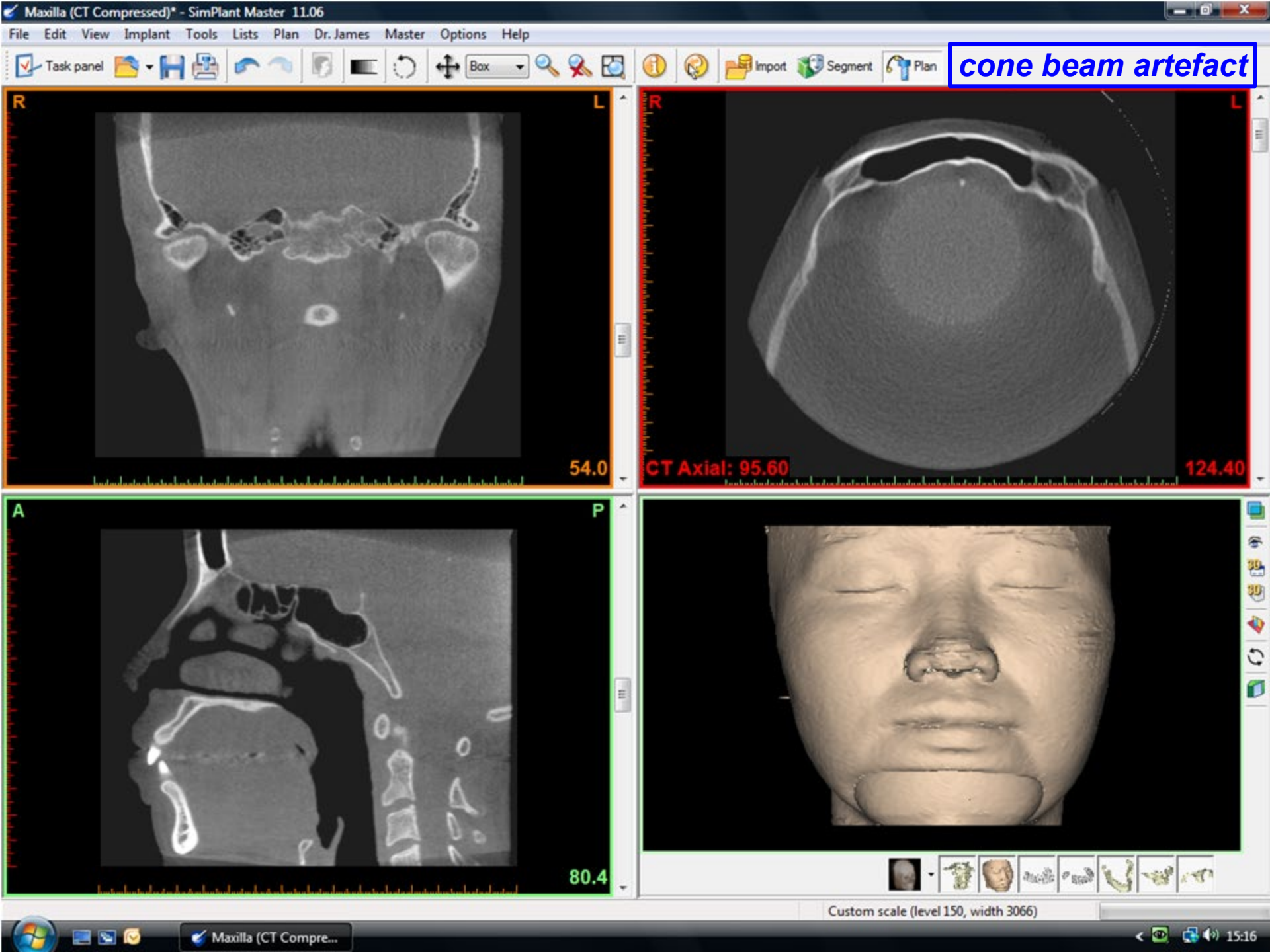
Artefacts in CT / CBCT images

Artefact = structured contribution to the image which has no counterpart in the object.

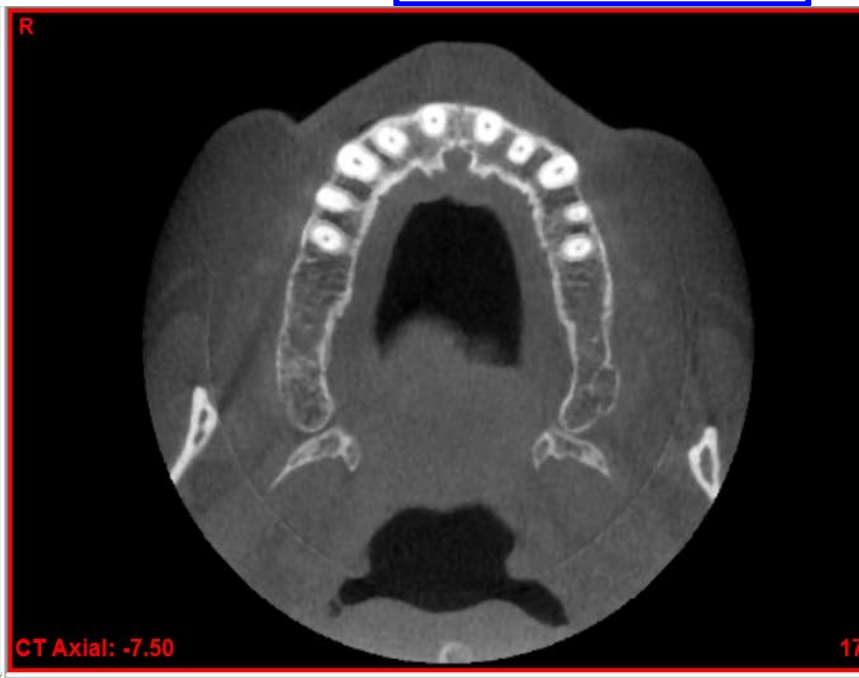
- **Motion artefact**
- **Cone beam artefacts**
- **Ring artefacts**
- **Starburst (streak) artefact**
- **Beam hardening**

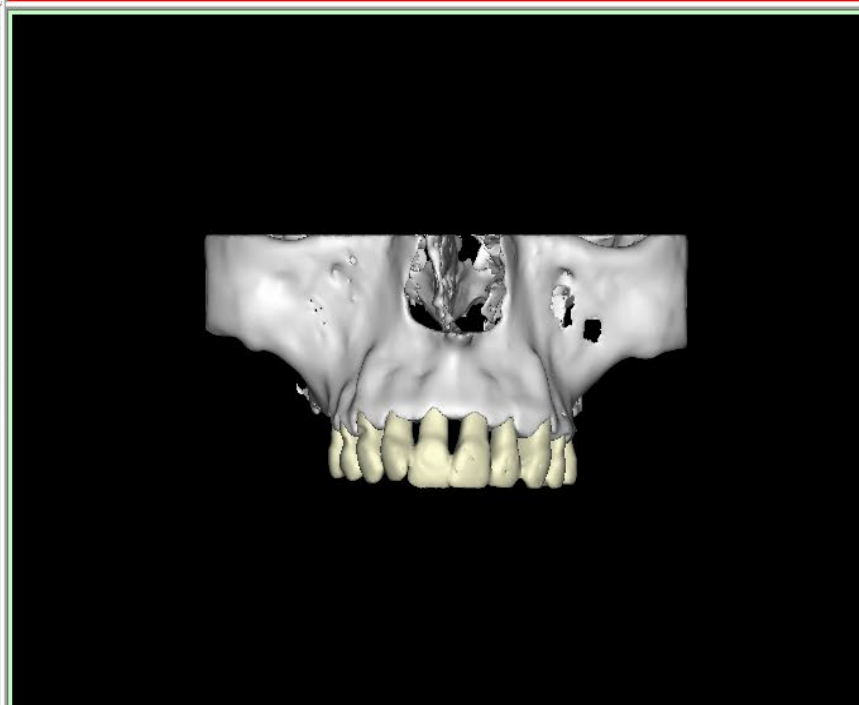
Motion Artefact – cone beam




Maxilla (CT Compressed)* - SimPlant Master 11.06
File Edit View Implant Tools Lists Plan Dr. James Master Options Help
Task panel
Box
Import
Segment
Plan
cone beam artefact
R
L
54.0
CT Axial: 95.60
124.40
A
P
80.4
Custom scale (level 150, width 3066)
Maxilla (CT Compre...
15:16

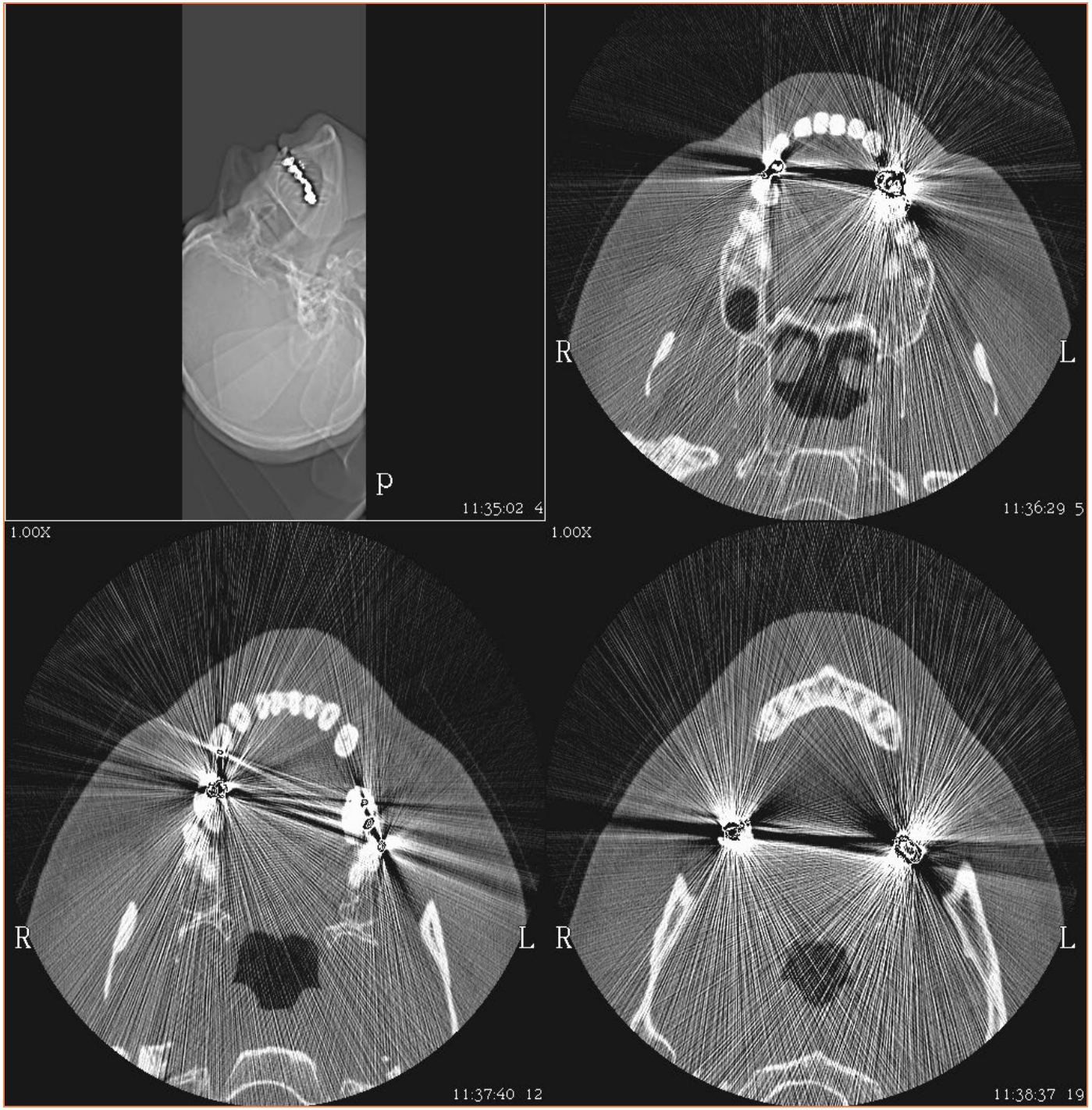
ring artefact





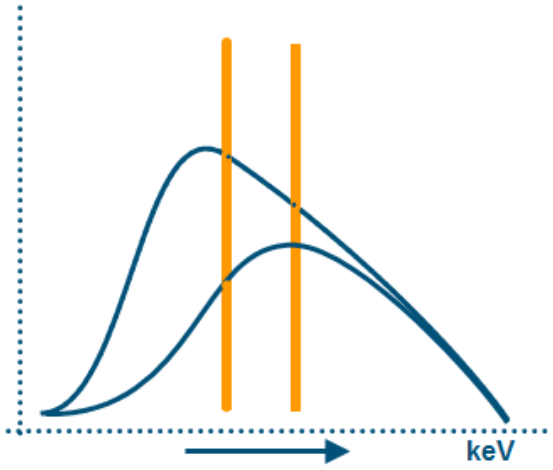
STARBURST ARTEFACT

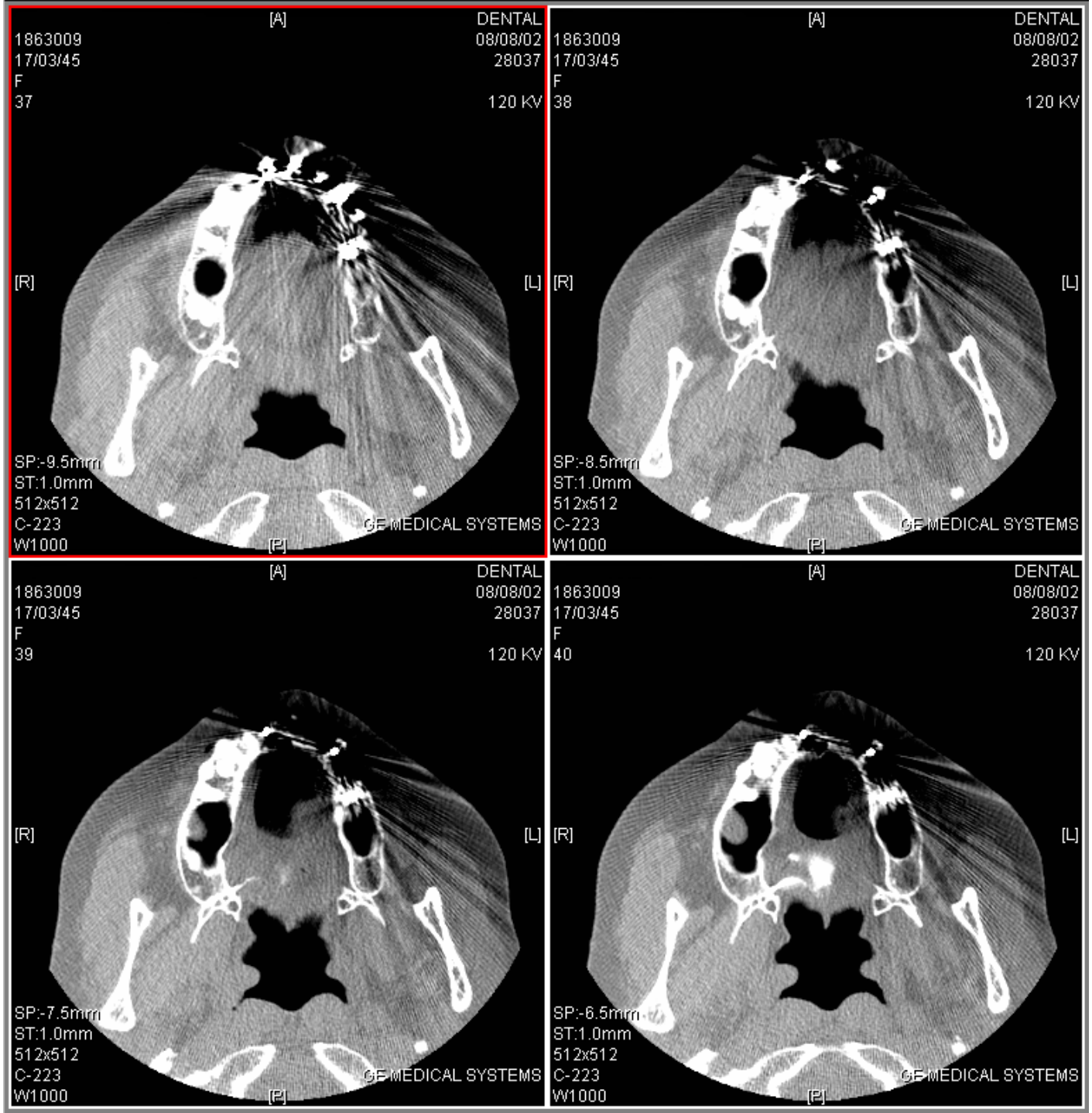
- **Starburst (streak) artefacts arise in CT scans when sharp changes in density are present, e.g. between air and bone or between bone and dense metals**
- **Starburst artefacts are caused by limitations in high frequency sampling**
- **Starburst artefacts are not caused by scattered radiation**

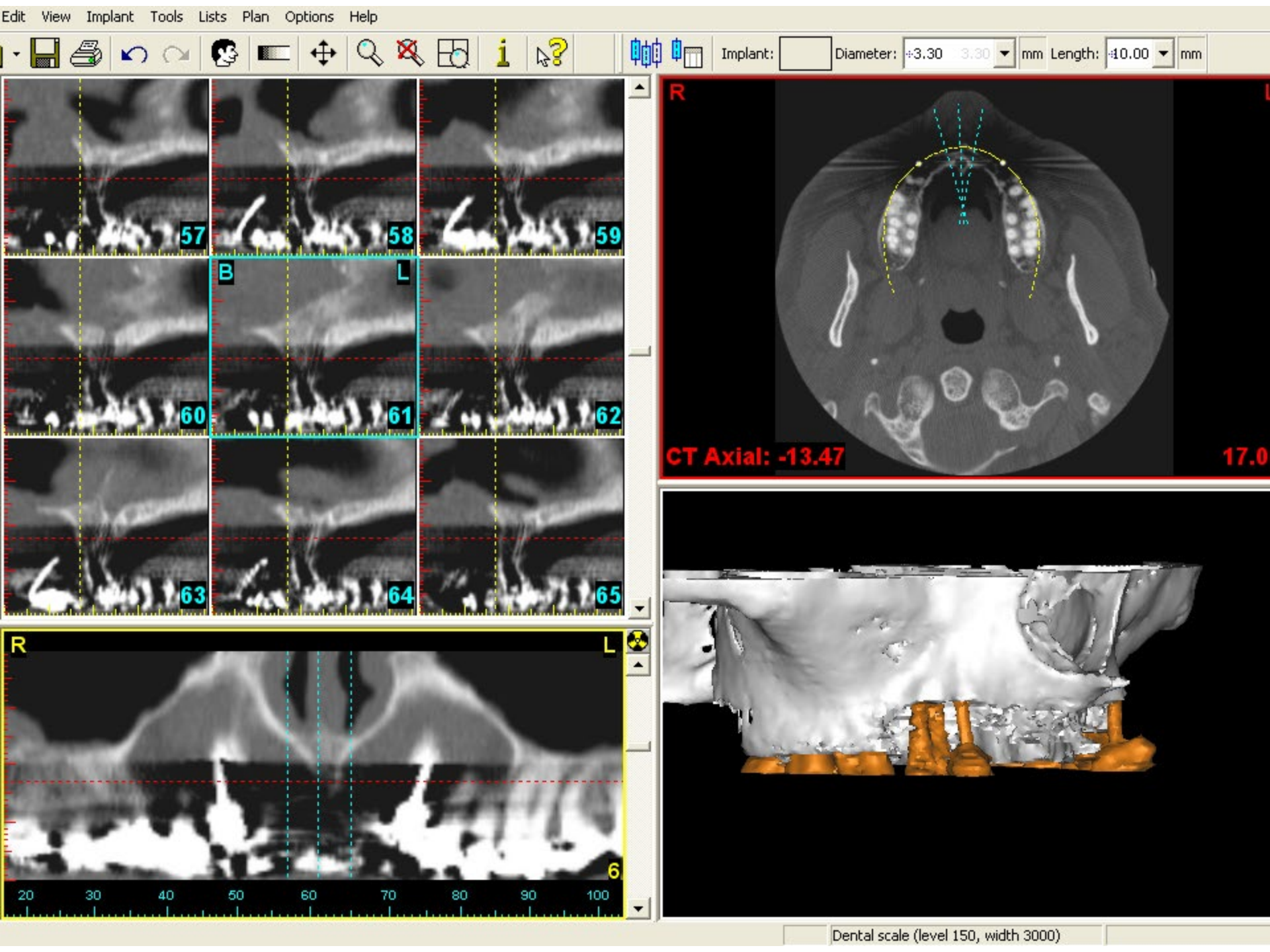

P
11:35:02 4
1.00X
R
L
11:36:29 5
1.00X
R
L
11:37:40 12
R
L
11:38:37 19

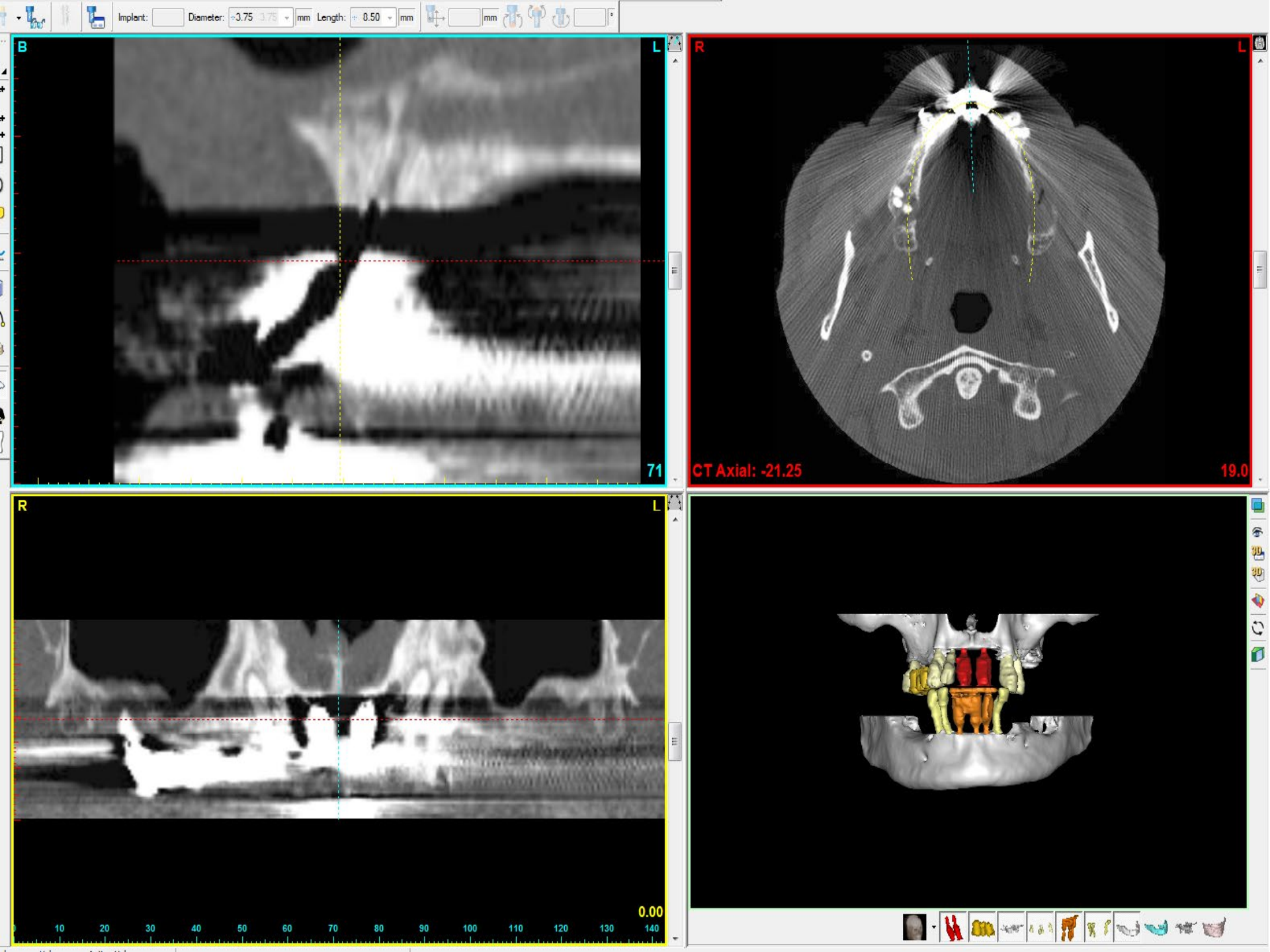
BEAM HARDENING ARTEFACT

- **Beam Hardening artefacts also occur in CT scans when metals are present**
- **Metals cause the low energy x-rays to be filtered out of the x-ray beam**
- **The average energy becomes higher**
- **The CT numbers become lower**
- **Parts of the image appear black**

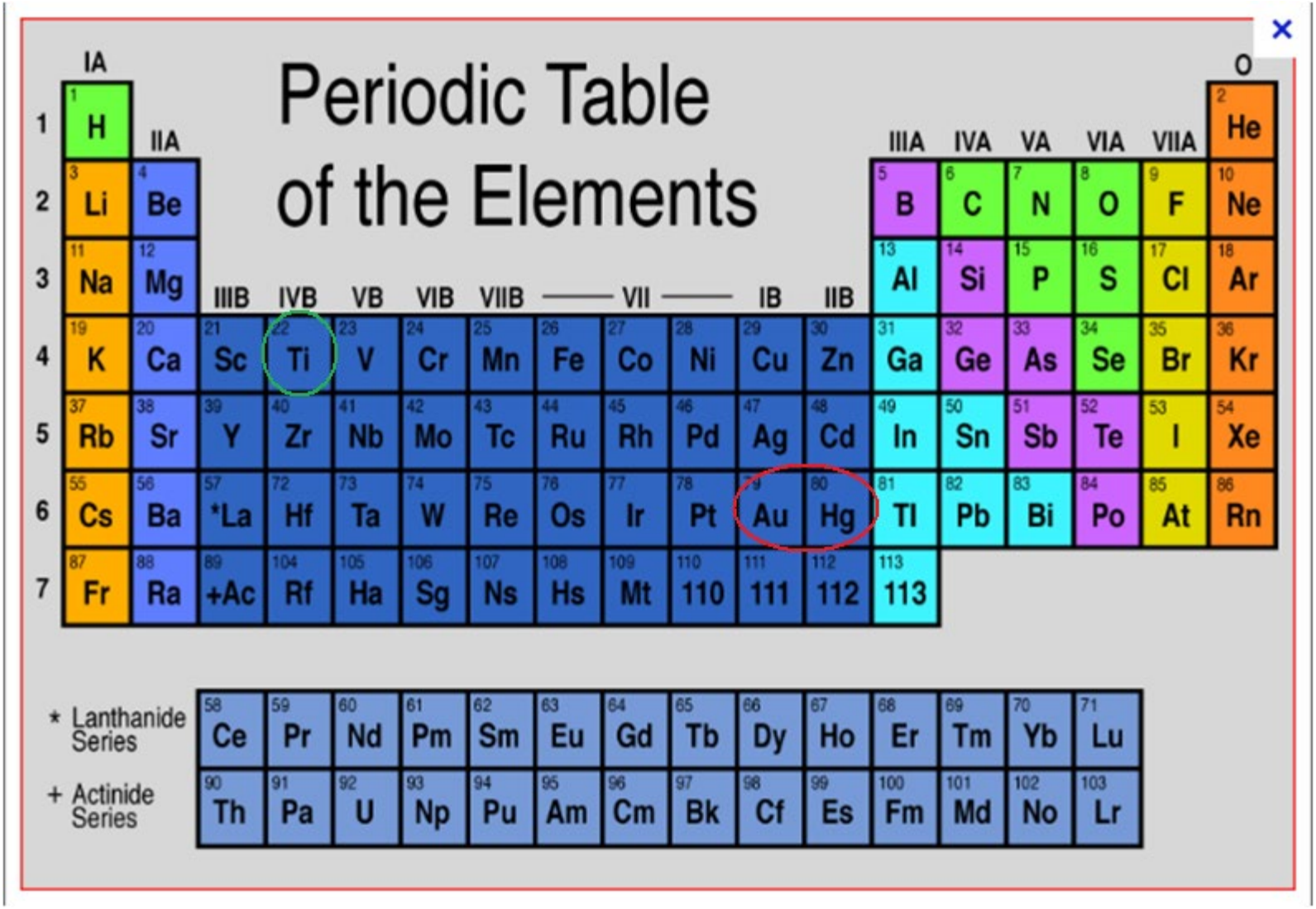



[A]
DENTAL
1863009
08/08/02
17/03/45
28037
F
37
120 KV
[R]
[L]
SP:-9.5mm
ST:1.0mm
512x512
C-223
W1000
GE MEDICAL SYSTEMS
[P]
[A]
DENTAL
1863009
08/08/02
17/03/45
28037
F
38
120 KV
[R]
[L]
SP:-8.5mm
ST:1.0mm
512x512
C-223
W1000
GE MEDICAL SYSTEMS
[P]
[A]
DENTAL
1863009
08/08/02
17/03/45
28037
F
39
120 KV
[R]
[L]
SP:-7.5mm
ST:1.0mm
512x512
C-223
W1000
GE MEDICAL SYSTEMS
[P]
[A]
DENTAL
1863009
08/08/02
17/03/45
28037
F
40
120 KV
[R]
[L]
SP:-6.5mm
ST:1.0mm
512x512
C-223
W1000
GE MEDICAL SYSTEMS
[P]


Edit View Implant Tools Lists Plan Options Help
Implant:
Diameter: 3.30
mm
Length: 10.00
mm
57
58
59
B
L
60
61
62
63
64
65
R
L
6
20 30 40 50 60 70 80 90 100
R
CT Axial: -13.47
17.0
Dental scale (level 150, width 3000)


Implant:
Diameter: 3.75 mm
Length: 0.50 mm
B
L
71
R
L
CT Axial: -21.25
19.0
R
L
0.00
10 20 30 40 50 60 70 80 90 100 110 120 130 140

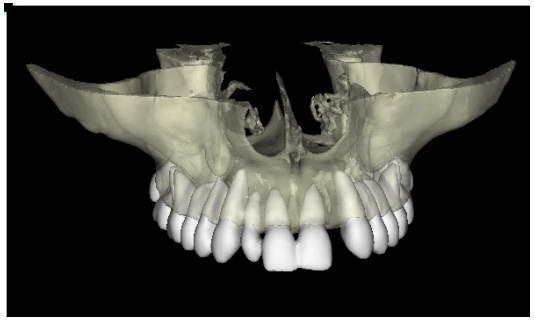
High-Z materials cause the worst artefacts

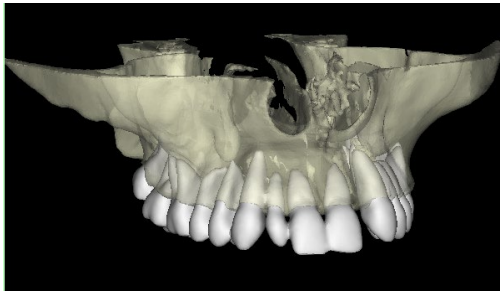


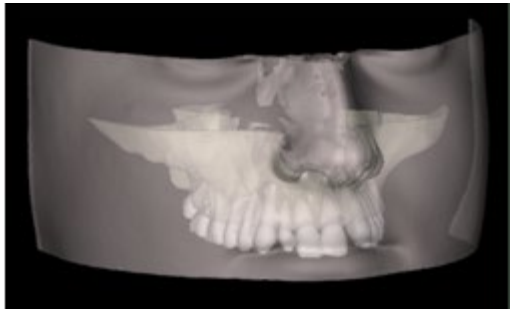
HOW TO AVOID ARTEFACTS

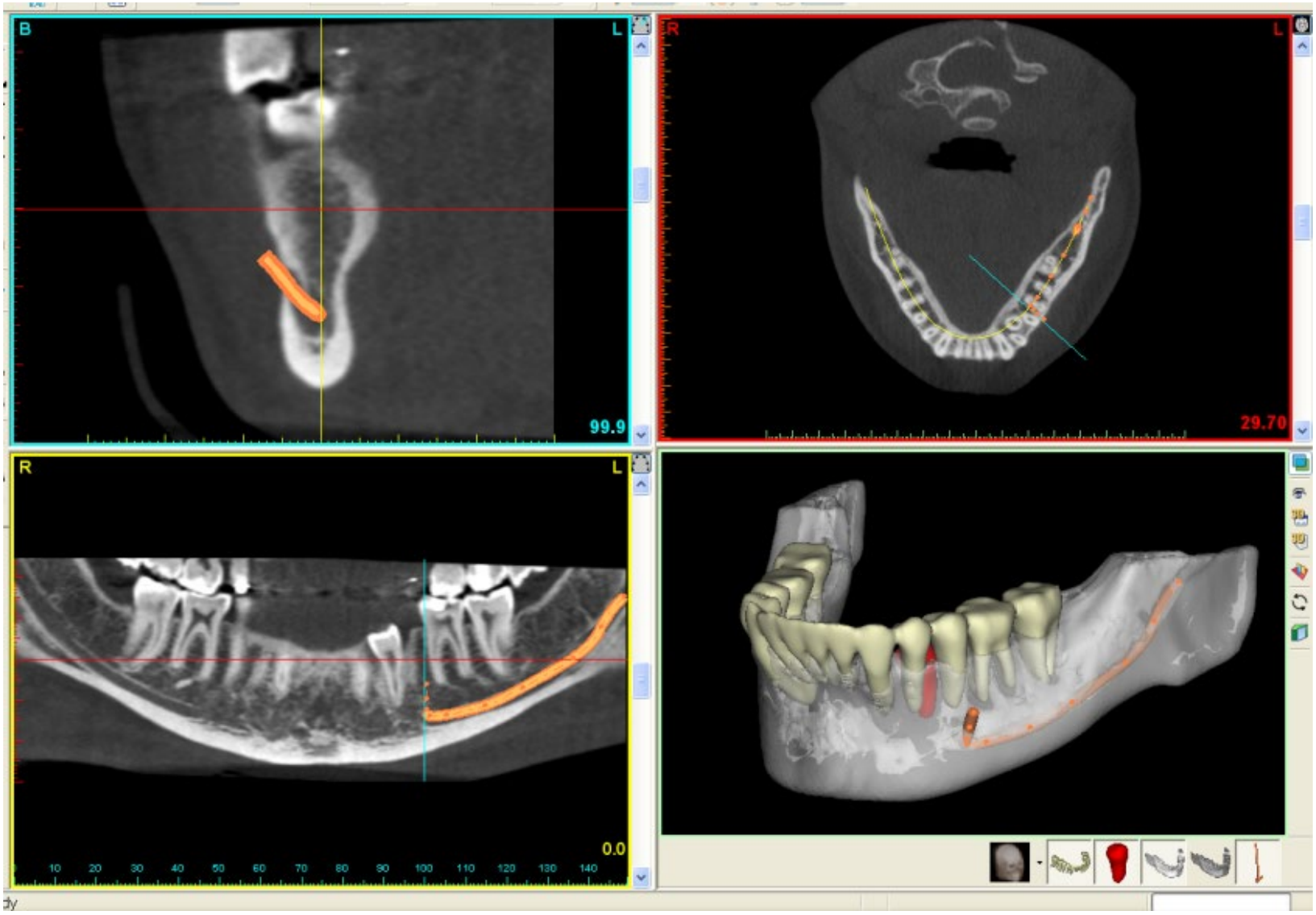
- **Titanium implants produce little artefact, gold produces a lot**
- **Remove dentures or other fixtures that include metal**
- **Consider replacing amalgam with composites**
- **Consider extracting teeth that will be sacrificed anyway.**

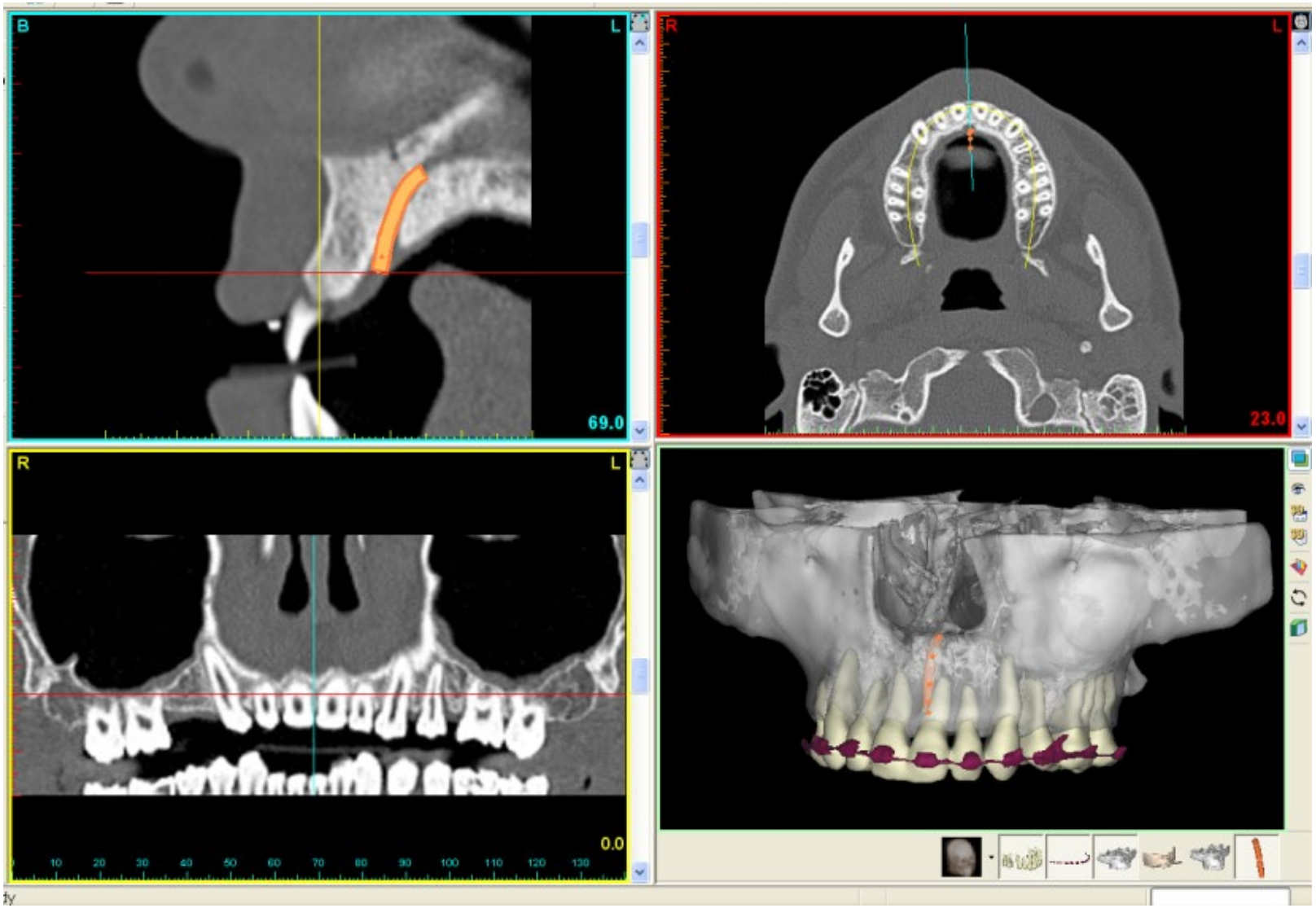
Segmentation



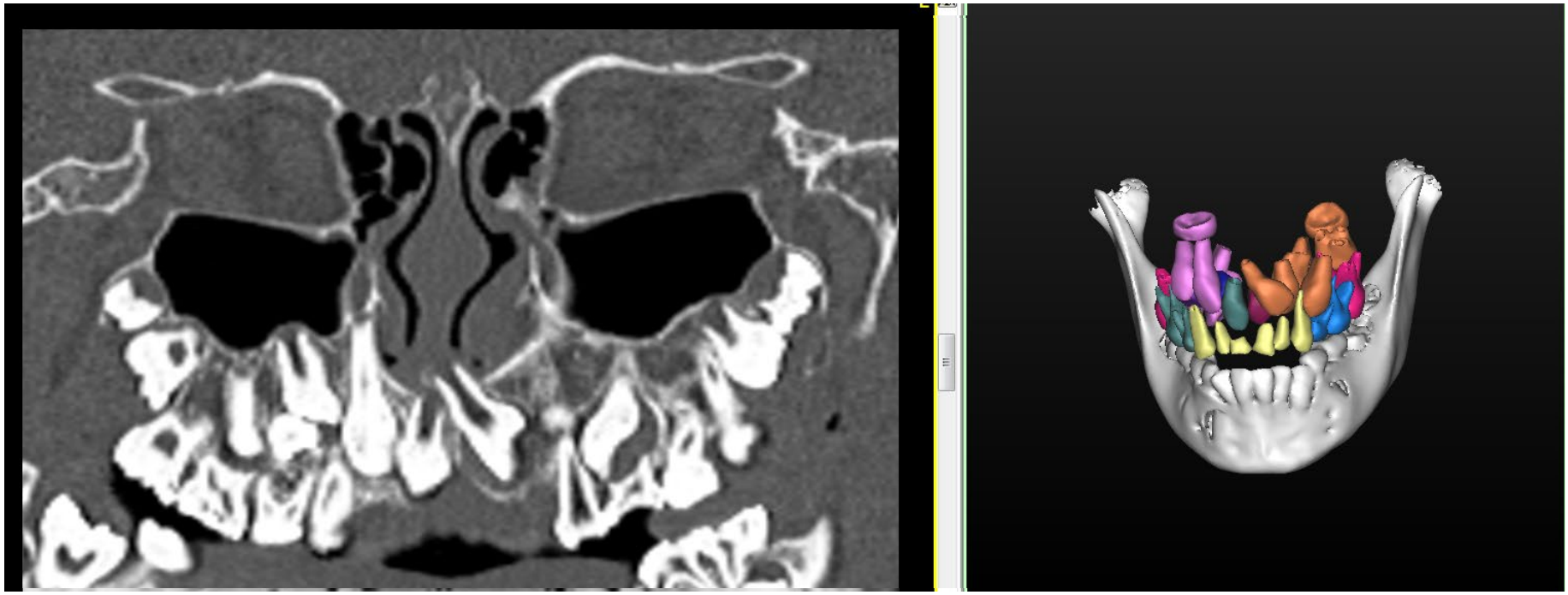




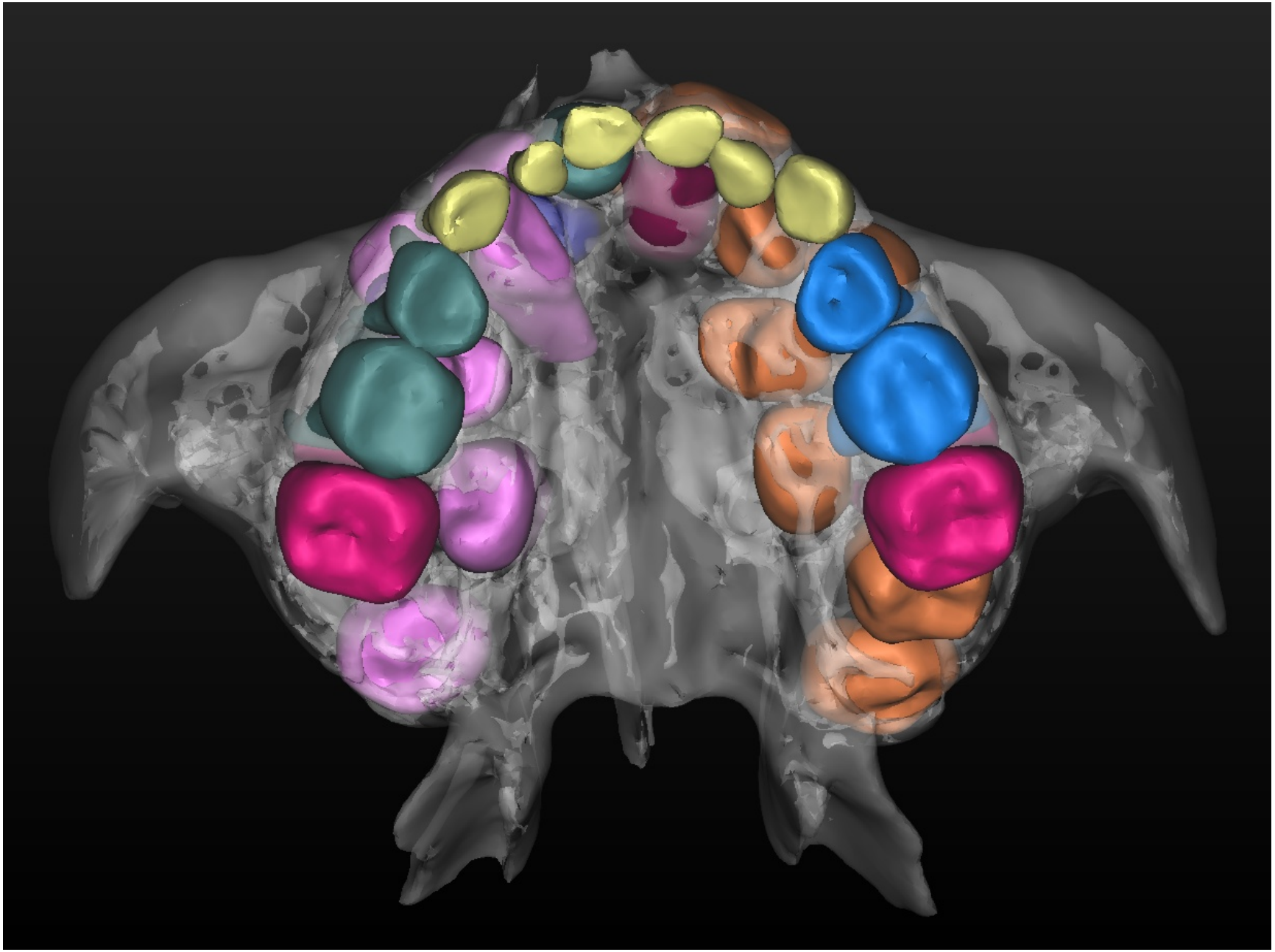

B
L
99.9
R
L
29.70
R
L
0.0
10 20 30 40 50 60 70 80 90 100 110 120 130 140


B
L
69.0
R
L
23.0
R
L
0.0
10 20 30 40 50 60 70 80 90 100 110 120 130

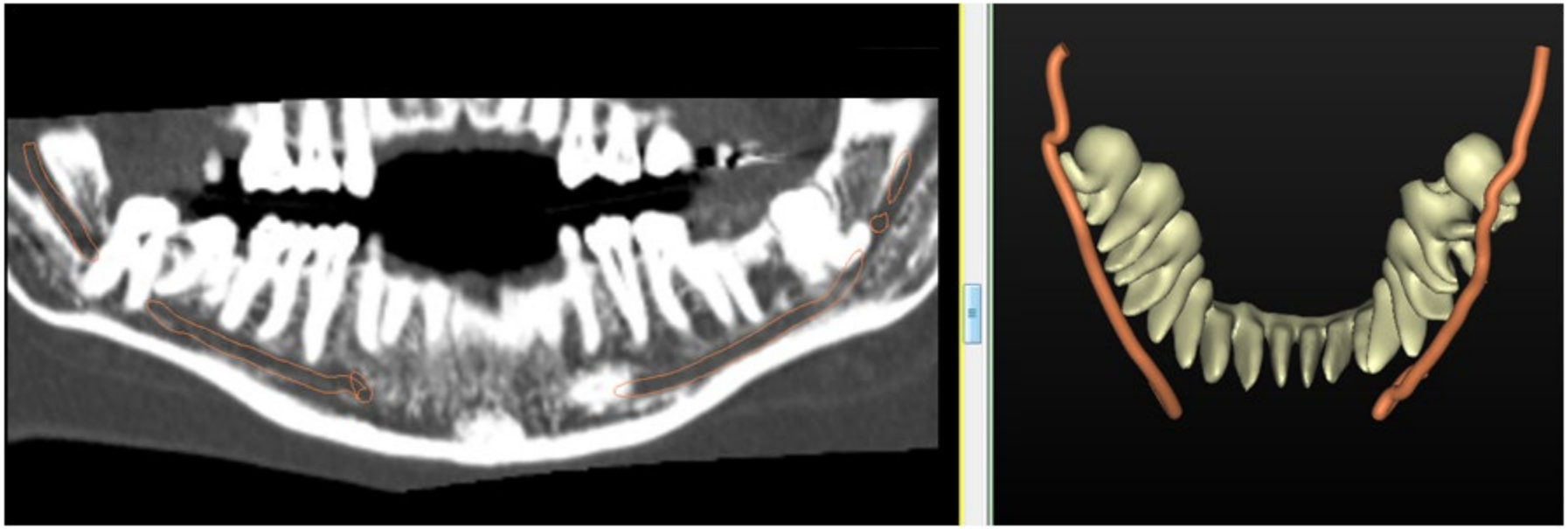
Hyperdontia



Courtesy of Nicolette Schroeder



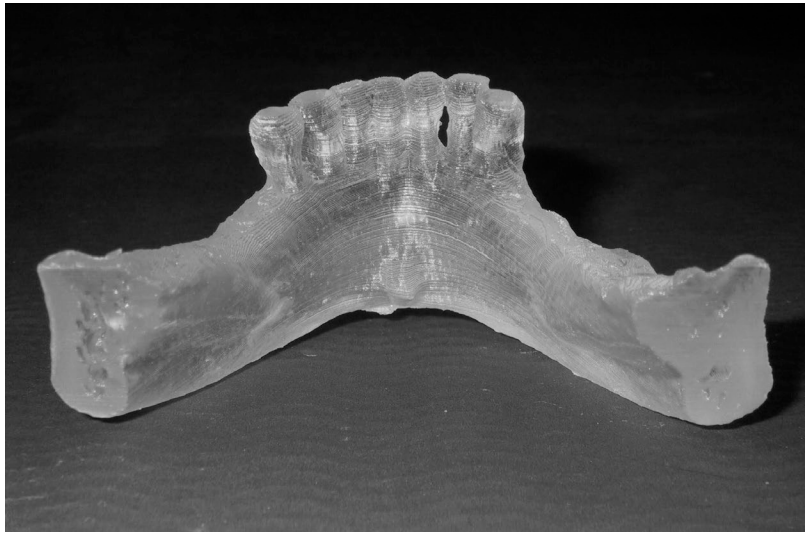
Third Molars

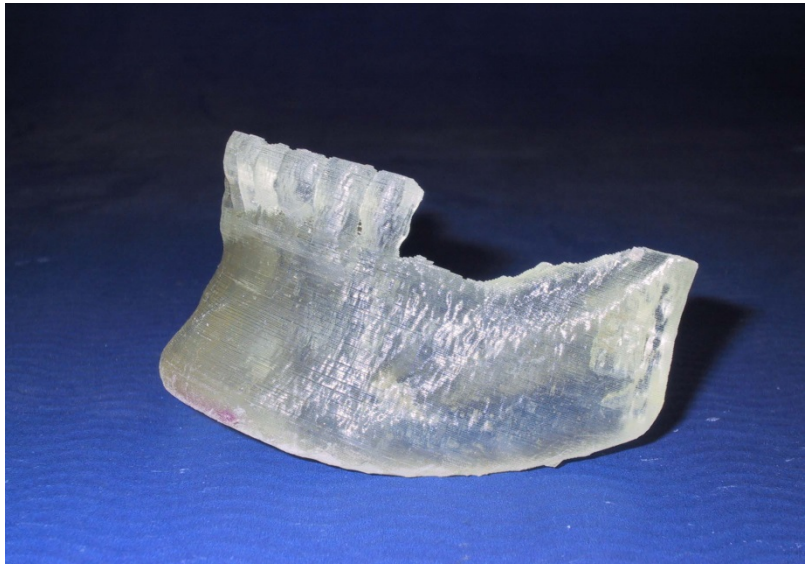


Courtesy of Barry Dace

Fabrication of 3D models

Relies on segmentation





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IDT
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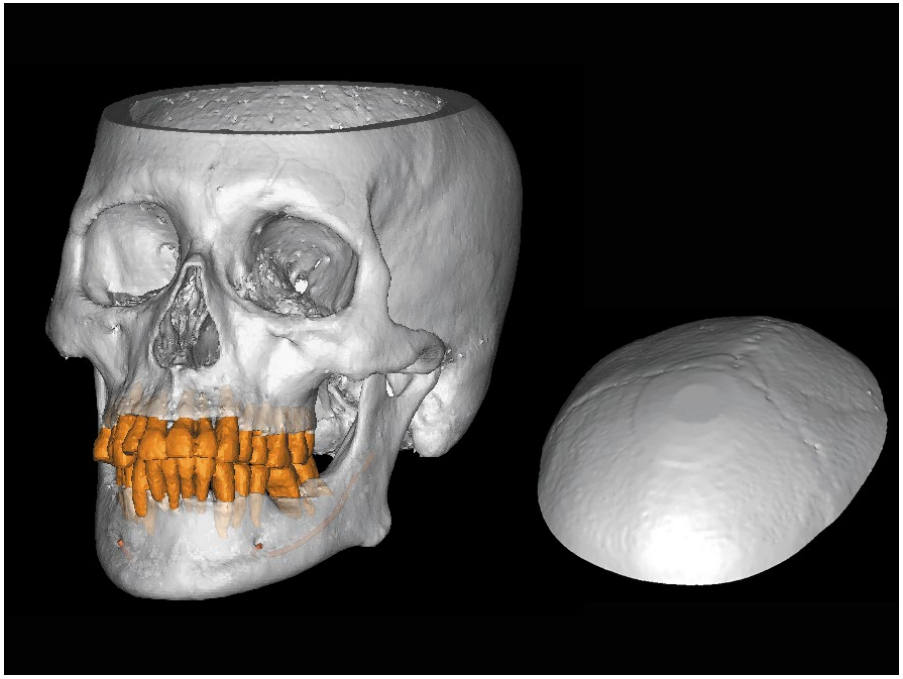

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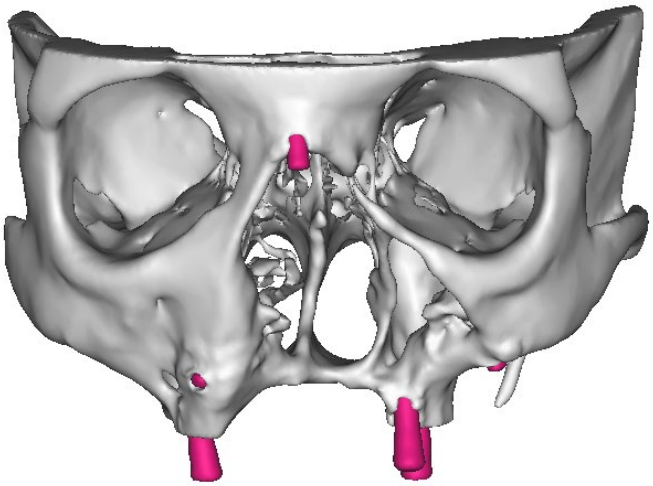
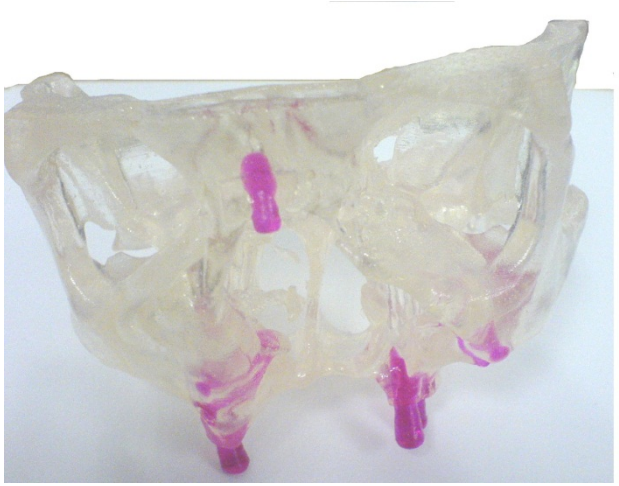
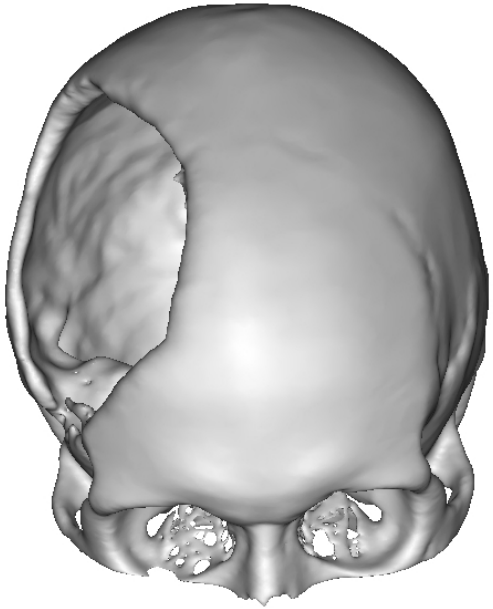
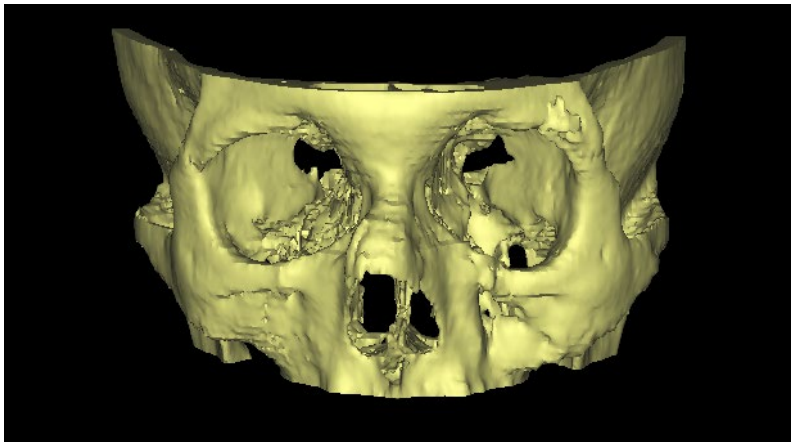


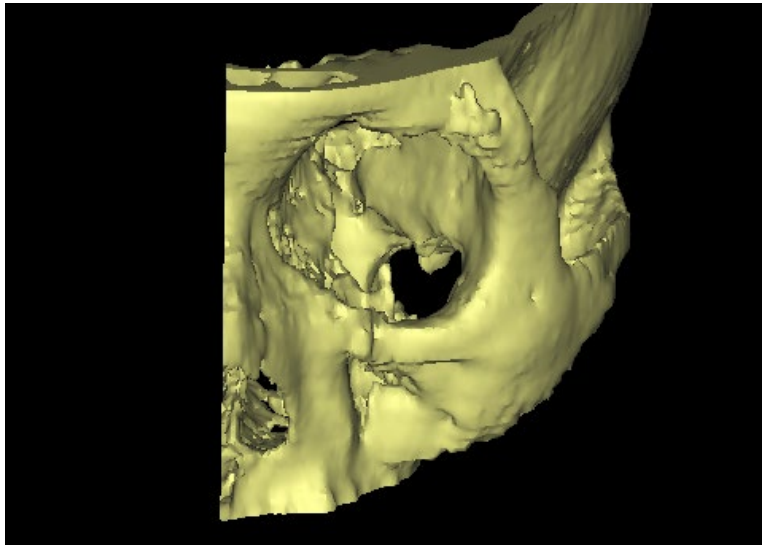




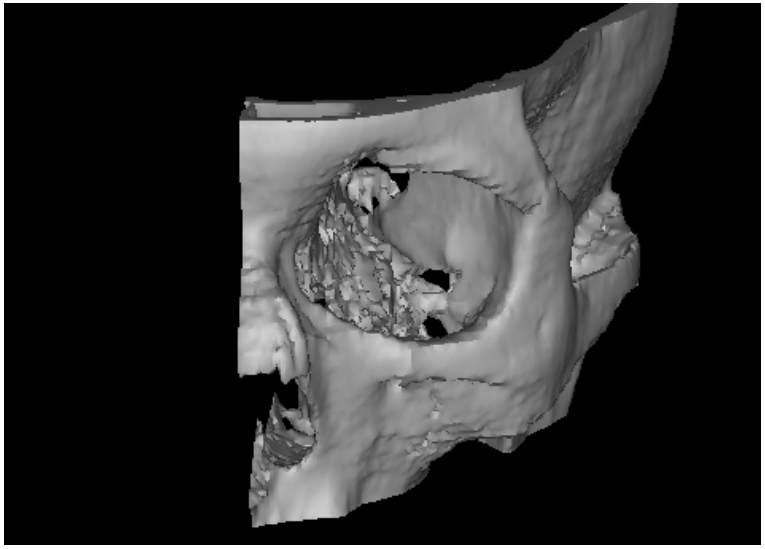
Orbit Implant Case Study



Orbits read in and segmented

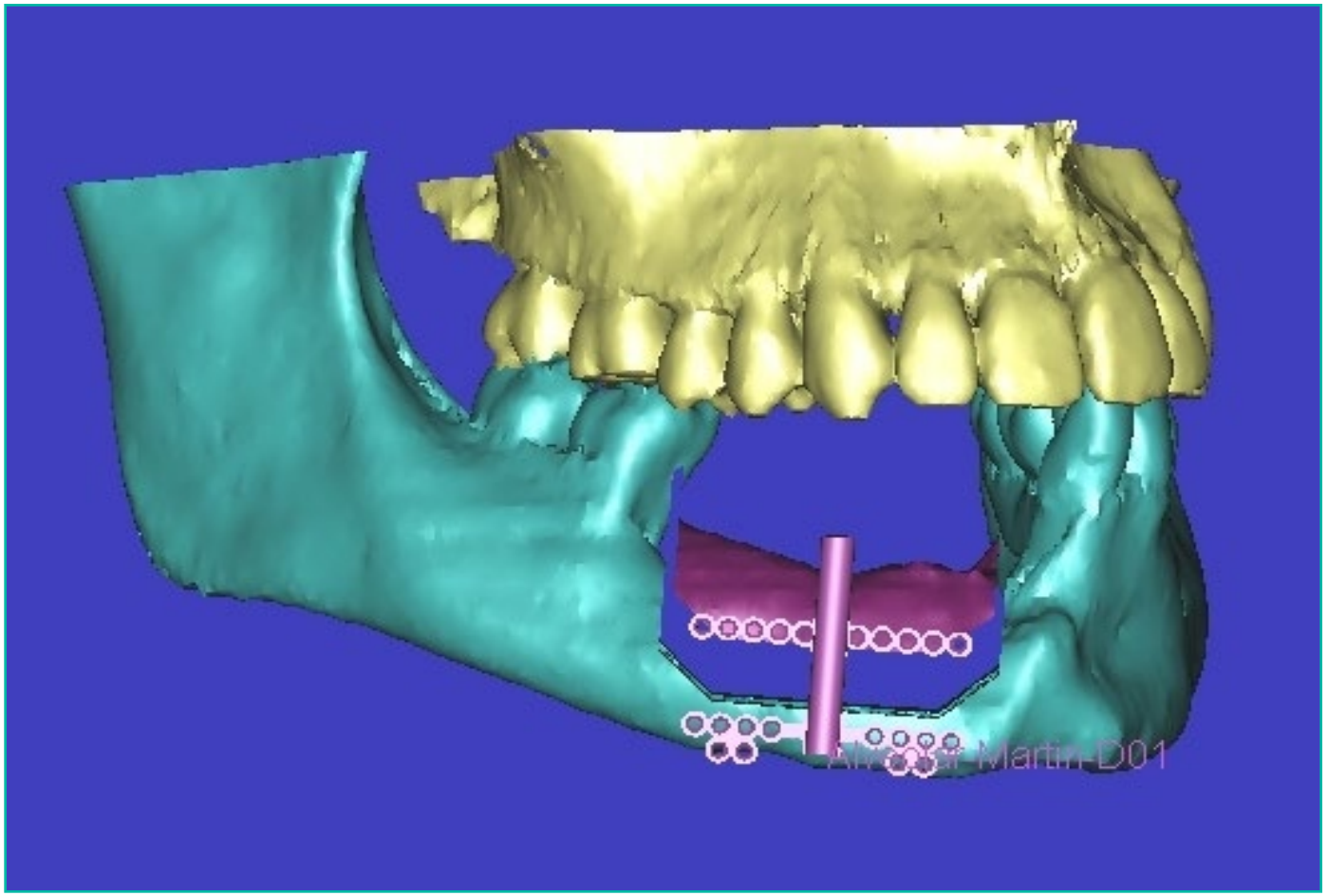


3D cut in half – Bad orbit

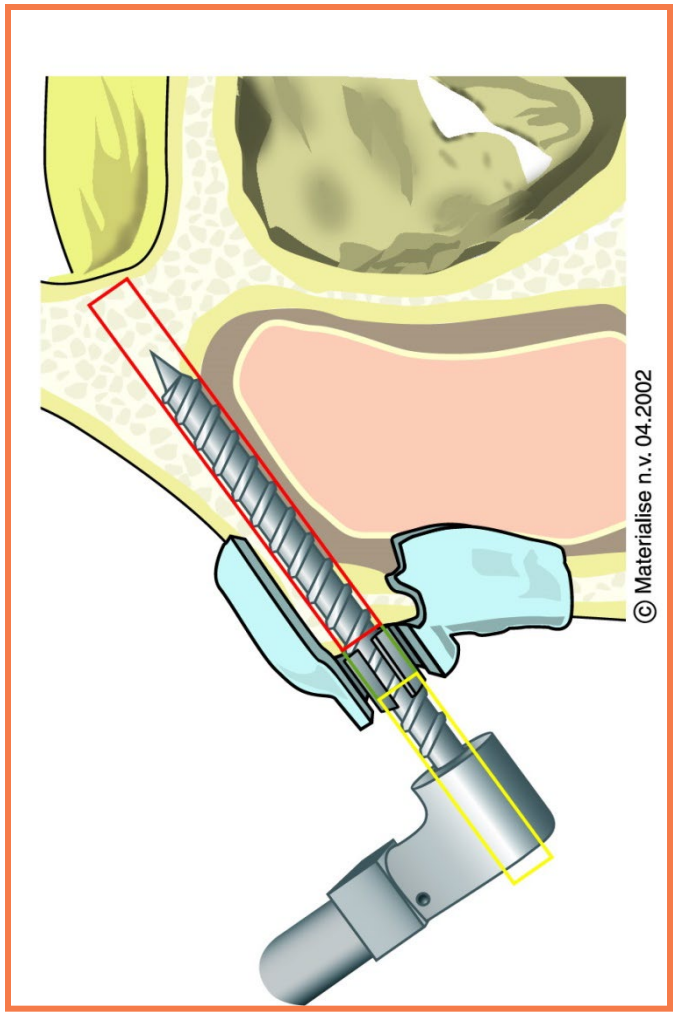


Good orbit is mirrored

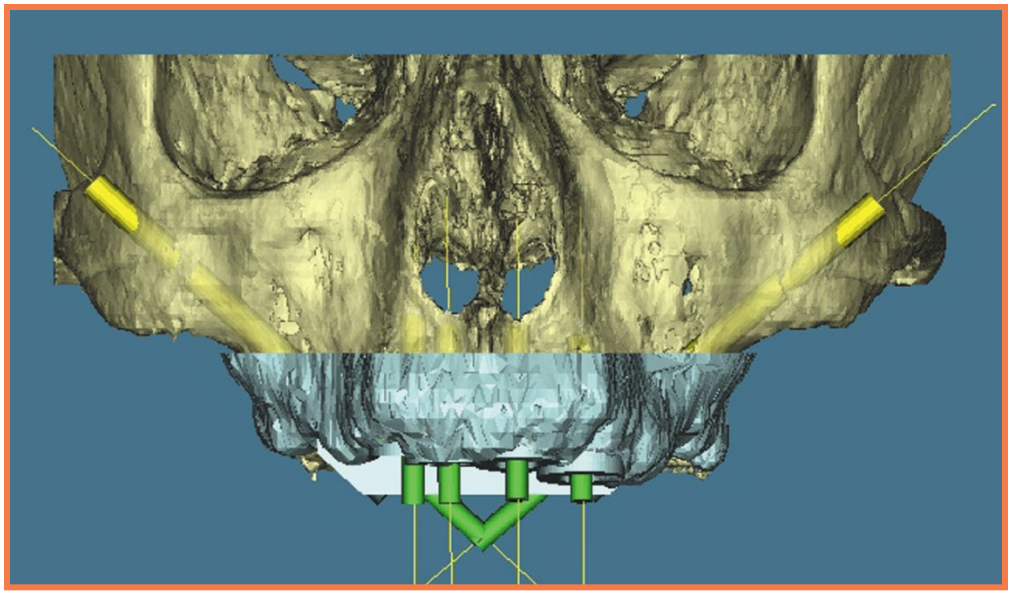
Orthognathic Surgery



SurgiGuides for Special implants



For zygoma Implants



Advantages of CT / CBCT for Dental Implants

- **Accurate length measurements**
  - **bone width and height and length**
- **Freedom from geometric distortion**
- **Diagnostic quality images**
- **3D models and guides**
- **Flapless Surgery**

Preparing your patient for a dental CT / CBCT scans

- **Instruct your patient to stay completely still for the duration of the scan**
- **Instruct them to remove any dentures or jewellery containing metal**
- **Give them something to bite on:**
  - **a wooden tongue depressor**
  - **their own plastic dentures**
  - **a purpose-made scan prosthesis (make sure they know how to insert and wear it)**
- **Provide clear instructions to the person taking the scan.**

Image Diagnostic Technology Ltd
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Tel: +44 (0)20 8819 9158 www.idtscans.com email: info@idtscans.com

Outline of Lectures

- ✔ Introduction / Disclosures
- ✔ Diagnostic Imaging in Dentistry
  - Conventional Radiography
  - CT / CBCT Scans
- ✔ Computer software for planning dental implants
- Radiation Safety
- 3D models and surgical drill guides

Radiation Safety

Anthony Reynolds BA MSc PhD
Registered Clinical Scientist CS03469

Image Diagnostic Technology Ltd.

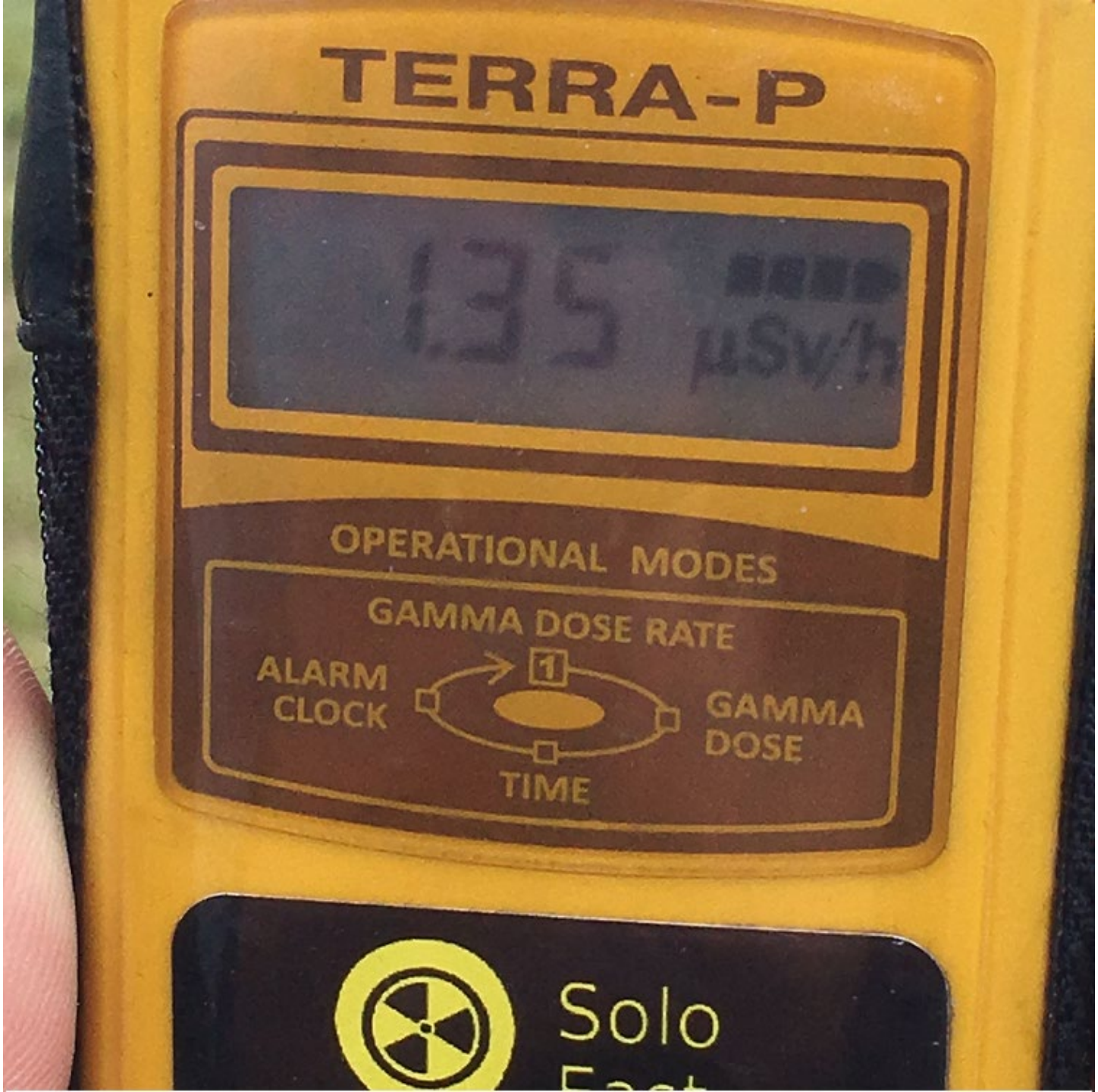
Outline of Lecture

- **Radiation Dose and Risk**
- **Compliance with the Legislation**


ЧОРНОБИЛЬ

26 April 1986

14 June 2017


TERRA-P
1.35
µSv/h
OPERATIONAL MODES
GAMMA DOSE RATE
ALARM CLOCK
1
GAMMA DOSE
TIME
Solo

Dose Rate at Chernobyl (2017)

- 200m from the reactor
- 1.35 microSievert per hour

Background Dose Rate in the UK (Average)

- 0.25 microSievert per hour

Flight from the UK to Chernobyl

- 3 hours x 5 µSv/hr = 15 µSv

Dental x-ray (intraoral)

- 1 microSievert

CBCT scan (both jaws)

- 100 microSievert

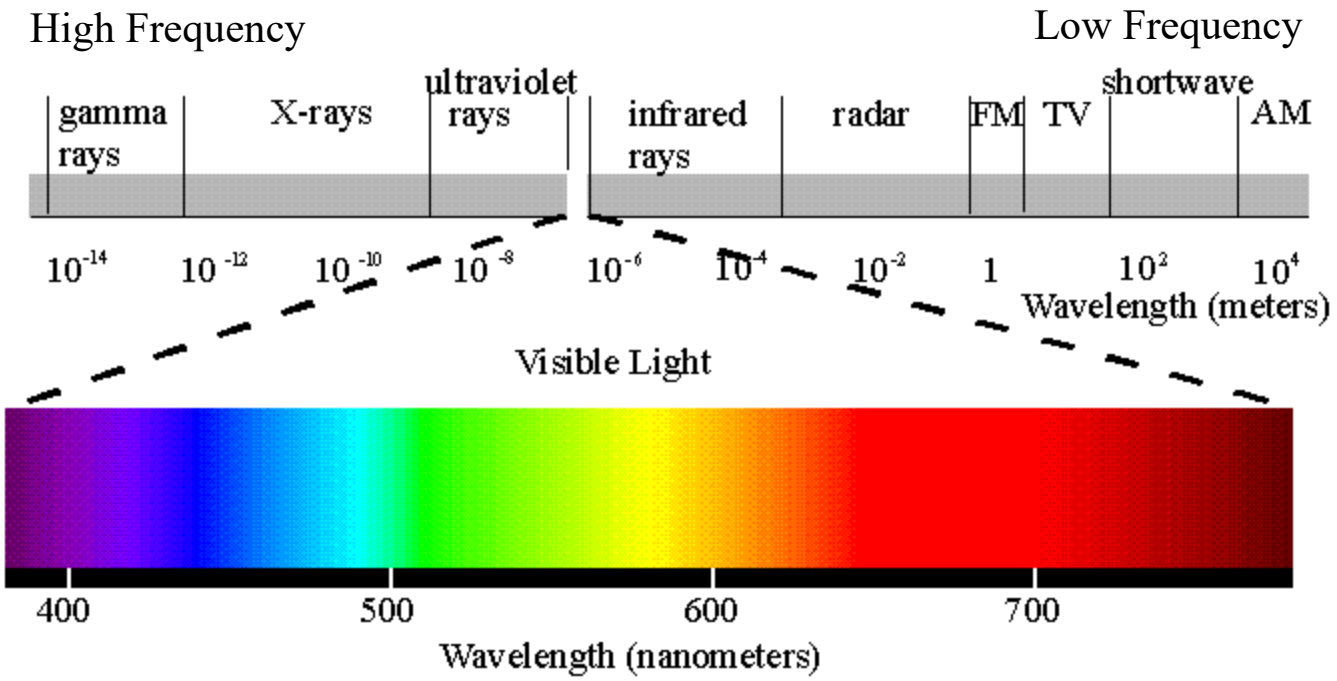
Topics

- **What is radiation?**
- **Sources of radiation**
- **Is radiation harmful?**
- **How can I manage the risk?**

What is Radiation?

- **Energy travelling through space**
- **Sunshine is a familiar example**
  - **A small amount is beneficial**
  - **Too much can be harmful**

The Electro-Magnetic Spectrum

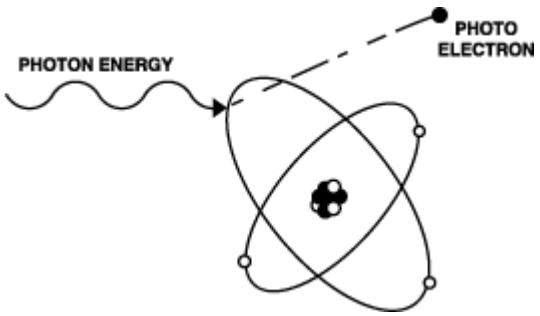


from **http://www.yorku.ca/eye/spectru.htm**

Energy depends on the frequency $E = h\nu$

Gamma Rays and X-Rays

- **Referred to as “Ionising Radiation”**
- **Can disrupt atoms and turn them into positive and negative ions**
- **This can cause damage at molecular level.**

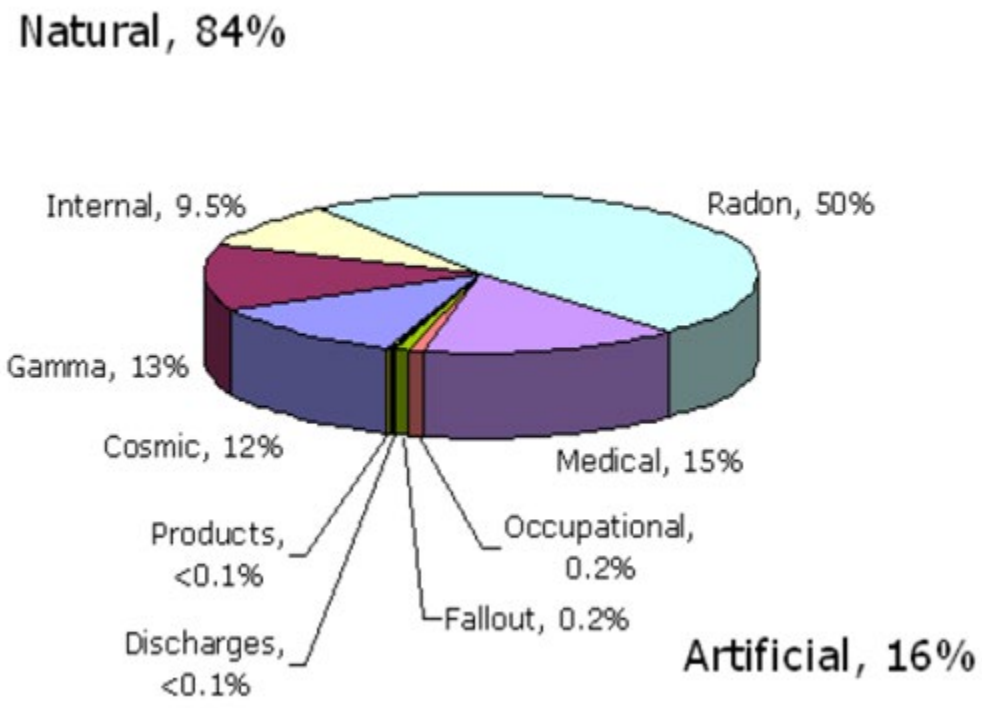


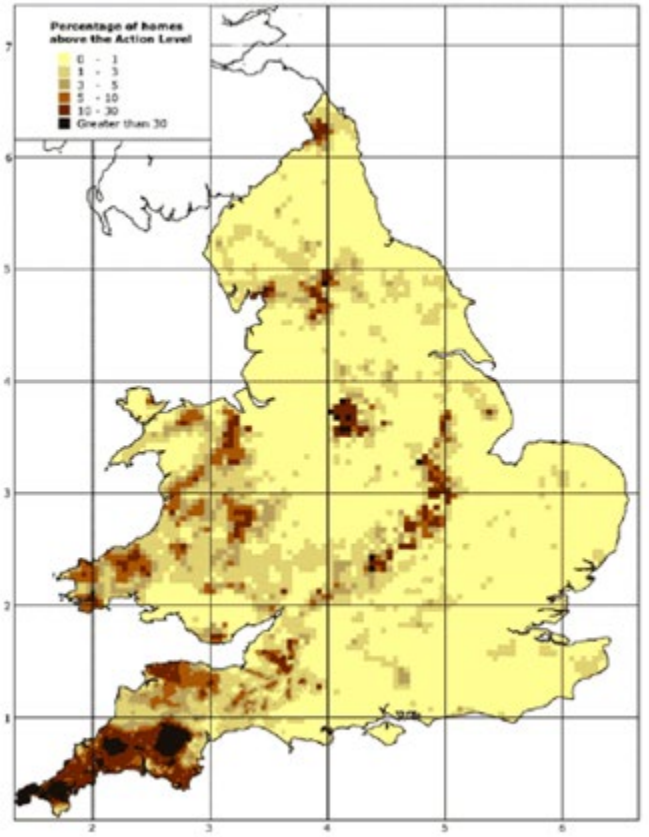
Sources of Ionising Radiation

1. **Environmental (e.g. Radon)**
2. **Cosmic Rays**
3. **Radioactive Isotopes**
   - **inside or outside the body**
   - **natural or man-made**
4. **Medical and Dental x-rays**

The first 3 make up “Background Radiation”
The first 4 make up “Per-Capita Dose”.

Per-Capita Dose in the UK





Background Radiation	**2.2mSv**
Medical and Dental	**0.5mSv**
Average Per-Capita Dose	**2.7mSv per person per year**

Topics

- **What is radiation?**
- **Sources of radiation**
- **Is radiation harmful?**
- **How can I manage the risk?**

Deterministic and Stochastic effects

Deterministic Effects are reproducible

- **severity of the effect increases with the dose**
- **not observed below a threshold dose of about 500mSv**

Stochastic Effects are random

- **the risk (not the severity) increases with the dose**
- **known to occur above 20mSv or so**
- **below about 20mSv we don't know if they occur or not**

Hereditary Effects are random (stochastic) but the incidence in humans is very low.

Deterministic Effects

For a high dose of radiation received over a short period of time, we know that the following effects will occur:

- **radiation sickness: 1-2Gy (whole body dose)**
- **skin erythema: 2-5Gy (local dose)**
- **sterility: 2-3Gy (local dose)**
- **hair loss: 2-5Gy (local dose)**
- **death: 3-5Gy (whole body dose)**

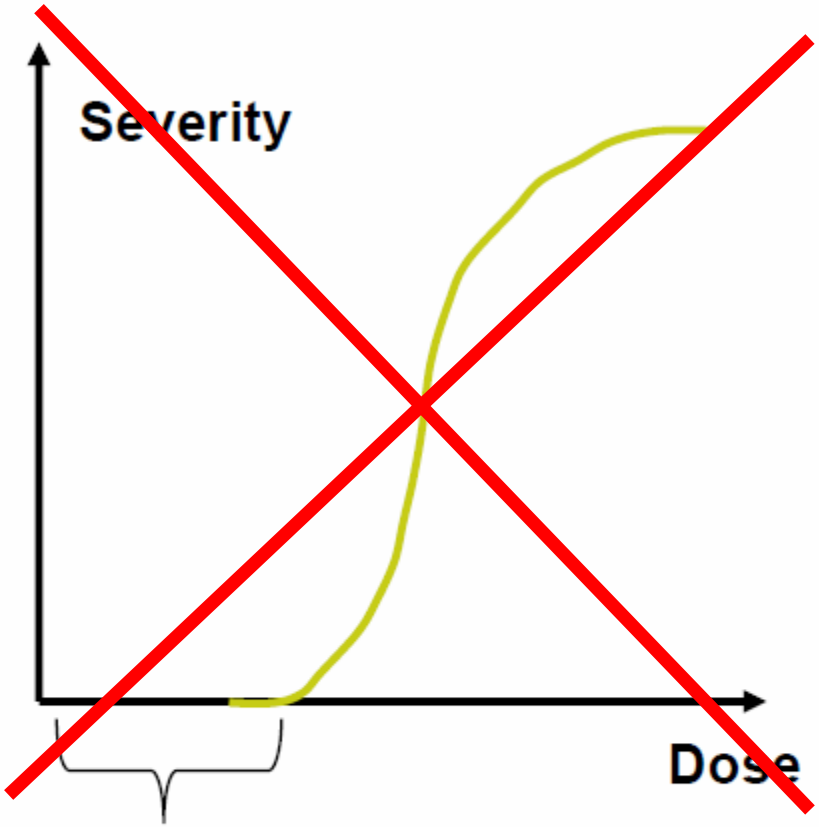
We should never see any of these effects in a dental practice!

Stochastic Effects

- **For a high dose of radiation received over a short period of time, it is very likely (but not certain) that cancer will be induced.**

- **For a low dose of radiation, we think that cancer may be induced (maybe many years after exposure) but we don't know for sure.**

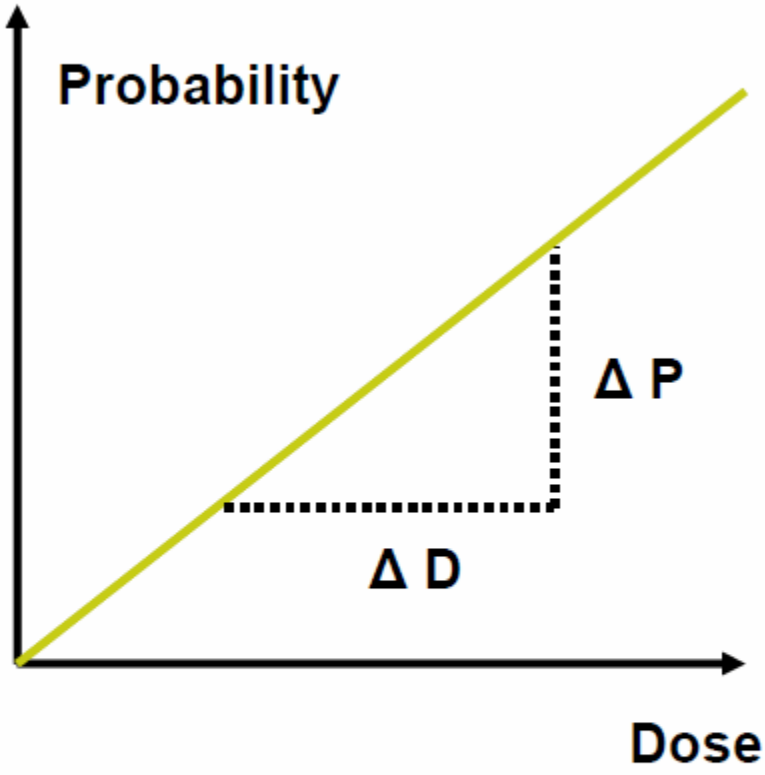
Deterministic Effects



Threshold Dose (about 500 mSv)

Should not see in dental practice!

Stochastic Effects



Risk Factor = Δ P / Δ D

(about 5% per Sievert)

Effects of Chernobyl Disaster

- **28 workers known to have died from Radiation Sickness (deterministic effect)**
- **15 children known to have died from thyroid cancer (stochastic effect)**
- **An additional 4000 may have died from stochastic effects – we don't know for sure.**

Population (years exposed)	Number	Average total in 20 years (mSv)[1]
Liquidators (1986–1987) (high exposed)	240 000	>100
Evacuees (1986)	116 000	>33
Residents SCZs (>555 kBq/m2) (1986–2005)	270 000	>50
Residents low contam. (37 kBq/m2) (1986–2005)	5 000 000	10–20
Natural background	2.4 mSv/year (typical range 1–10, max >20)	48

http://www.who.int/ionizing_radiation/chernobyl/backgrounder/en/

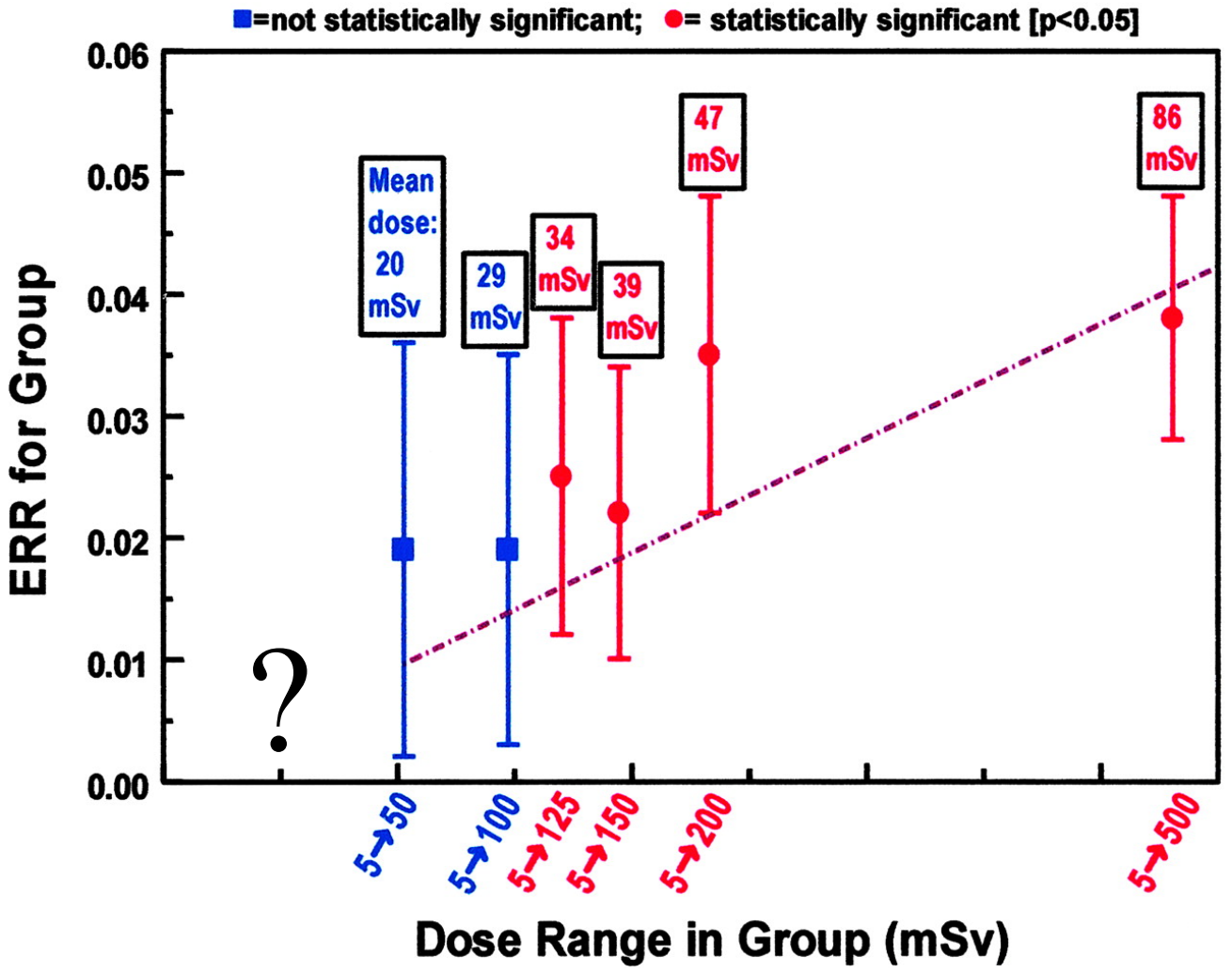
PNAS
Proceedings of the National Academy of Sciences of the United States of America

Cancer risks attributable to low doses of ionizing radiation: Assessing what we really know

David J. Brenner[a,b], Richard Doll[c], Dudley T. Goodhead[d], Eric J. Hall[a], Charles E. Land[e], John B. Little[f], Jay H. Lubin[g], Dale L. Preston[h], R. Julian Preston[i], Jerome S. Puskin[j], Elaine Ron[e], Rainer K. Sachs[k], Jonathan M. Samet[l], Richard B. Setlow[m], and Marco Zaider[n]

Contributed by Richard Doll, August 29, 2003

Estimated excess relative risk (±1 SE) of mortality (1950–1997) from solid cancers among groups of survivors in the LSS cohort of atomic bomb survivors, who were exposed to low doses (<500 mSv) of radiation (2).



Brenner D J et al. PNAS 2003;100:13761-13766

©2003 by National Academy of Sciences

The Linear No-Threshold (LNT) Model

Puts a straight line through the origin

Assumes that the risk of producing cancer is proportional to the dose (no safety threshold)

There is no proof that the LNT model is correct – but it is prudent to use it for Radiation Protection.

The concept of Effective Dose

We know the risks from high doses of radiation

- **e.g. Atom Bomb survivors**

- **Atom Bomb survivors received whole body doses**
- **Dental patients receive doses to a very small region**
- **How can we relate the risks?**

Effective Dose **is a way of describing the dose to a limited region in terms of the whole body dose that would result in the same risk to the patient**

Effective Dose is a measure of risk!

Dose Terminology

Absorbed Dose
Energy absorbed by tissue
(Gray, Gy)

1 Gray (Gy) = 1 Joule per Kilogram (J/Kg)

Equivalent Dose H_T
(Sievert, Sv)

Multiply the Absorbed Dose by the Radiation Weighting factor W_R (= 1 for x-rays) to get H_T
"Local Dose"

Effective Dose E
(Sievert, Sv)

Multiply the Equivalent Dose H_T by the Tissue Weighting factor (W_T) for each organ, and add them up to get the Effective Dose E
"Whole Body Dose"

Annals of the ICRP

PUBLICATION 103

The 2007 Recommendations of the International Commission on Radiological Protection

Editor
J. VALENTIN

PUBLISHED FOR

The International Commission on Radiological Protection

by

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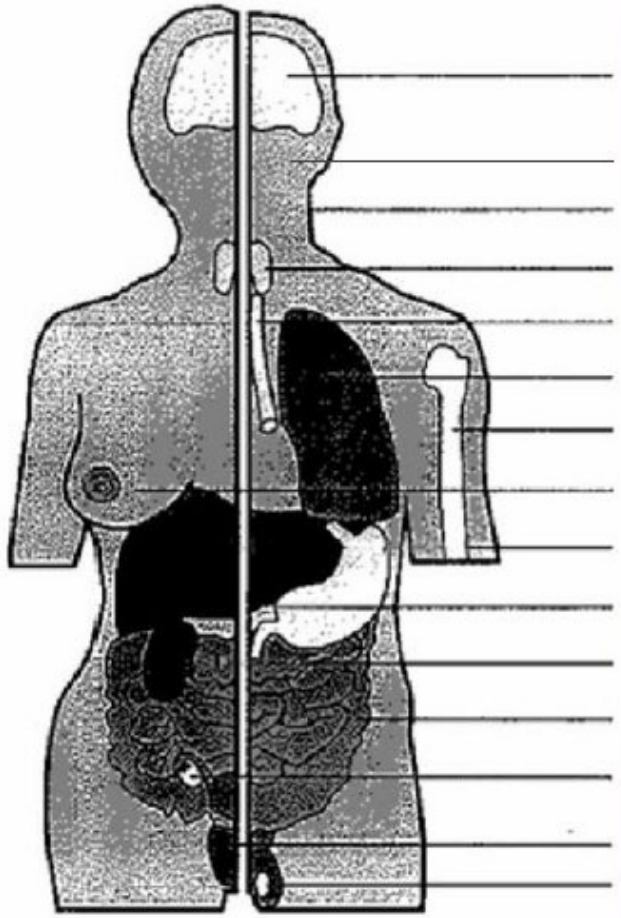
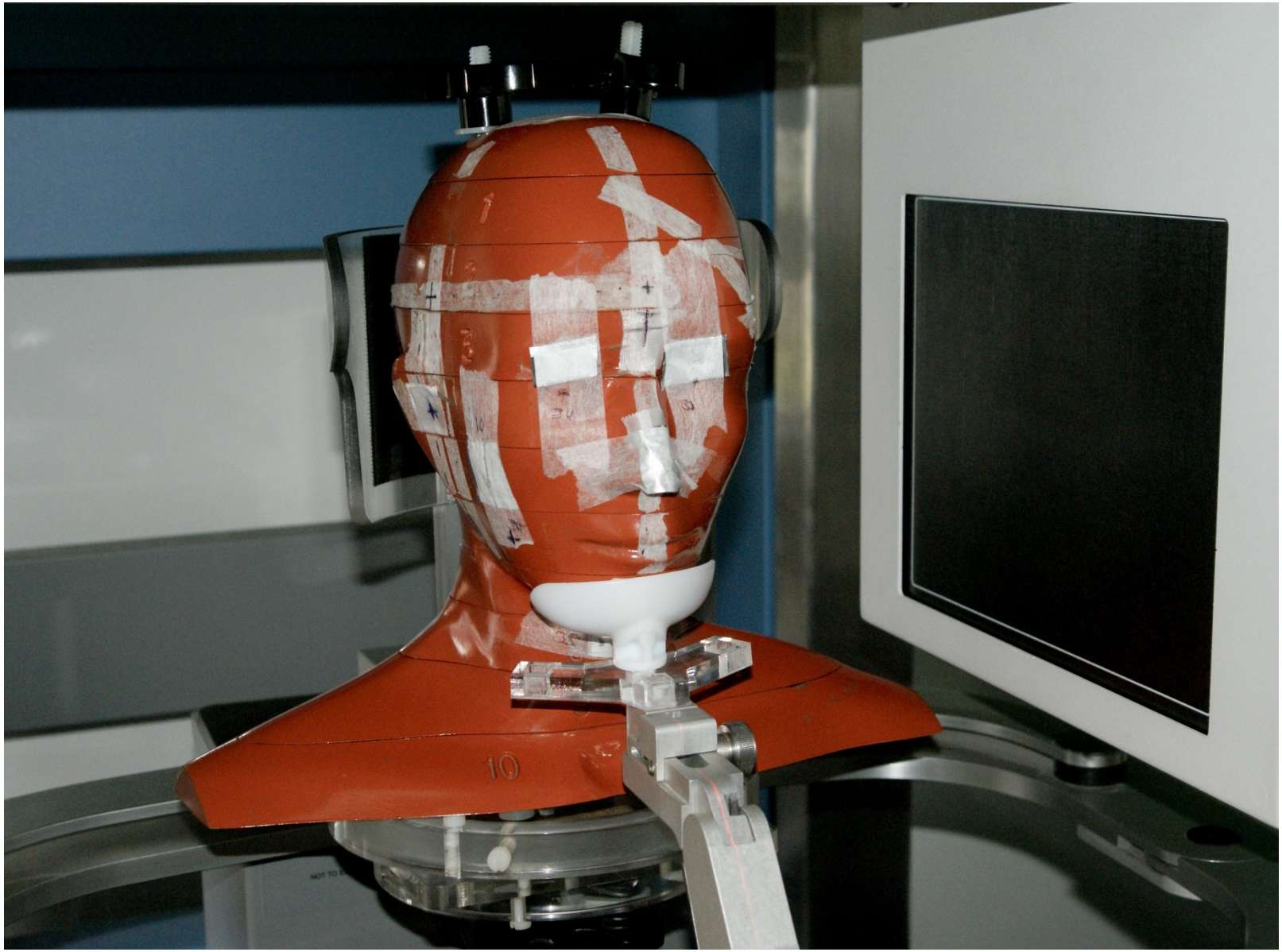


	w_T value ICRP103
Brain	0.01
Salivary glands	0.01
Skin	0.01
Thyroid	0.04
Oesophagus	0.04
Lung	0.12
Red bone marrow	0.12
Breast	0.12
Bone surface	0.01
Liver	0.04
Stomach	0.12
Colon	0.12
Ovary	0.08
Bladder	0.04
Testes	0.08
Remainder	0.12

Tissue Weighting Factors from ICRP 103



More about Effective Dose

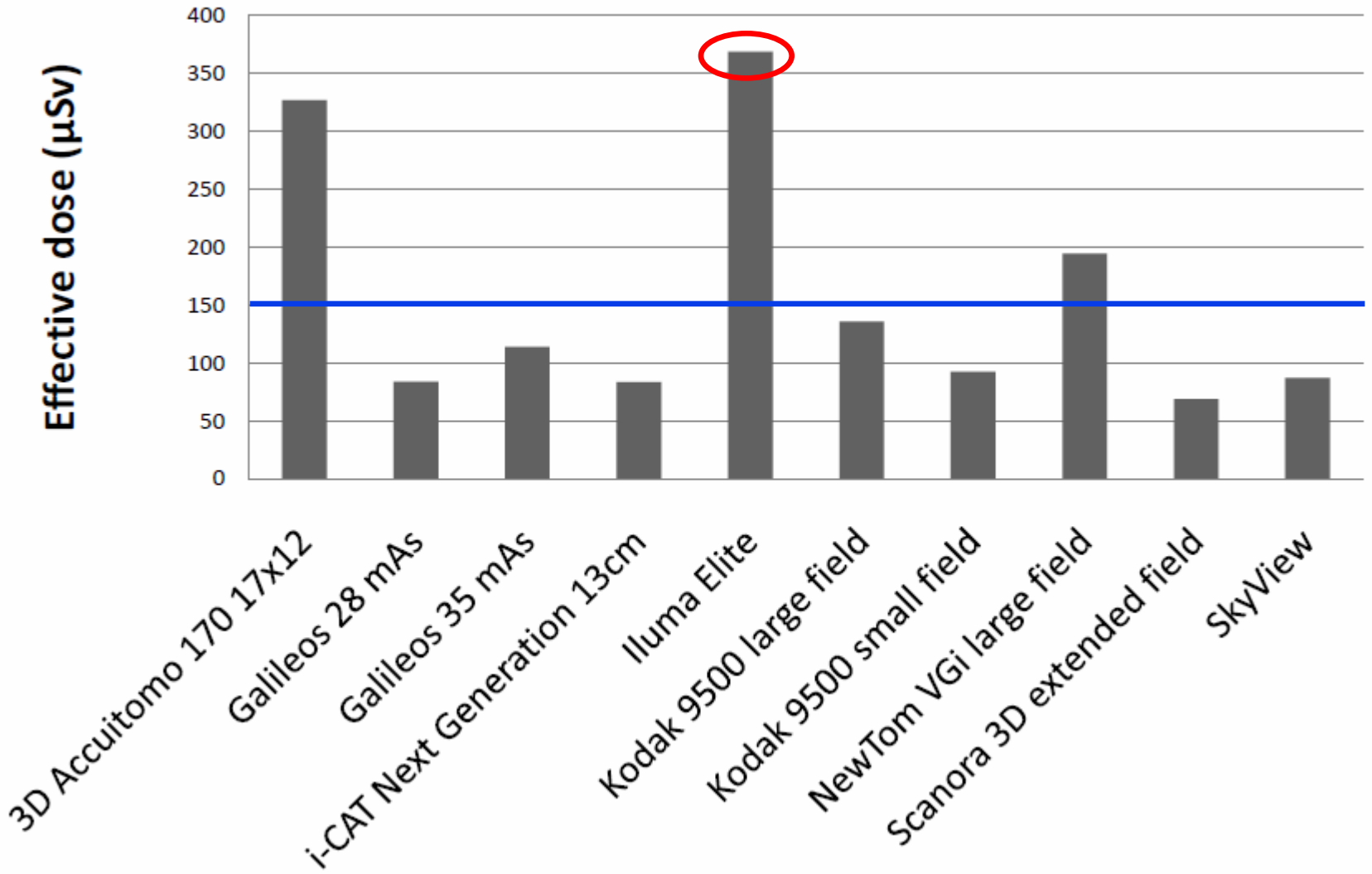
- **The Effective Dose calculation takes the size of the region and the body parts irradiated into account**

- **It's tempting to say "My CBCT scanner might deliver a high Effective Dose, but it's only to a very small region" but this argument is not valid.**

SEDENTEXCT measured Effective Doses for common CBCT scanners and found they were in the range

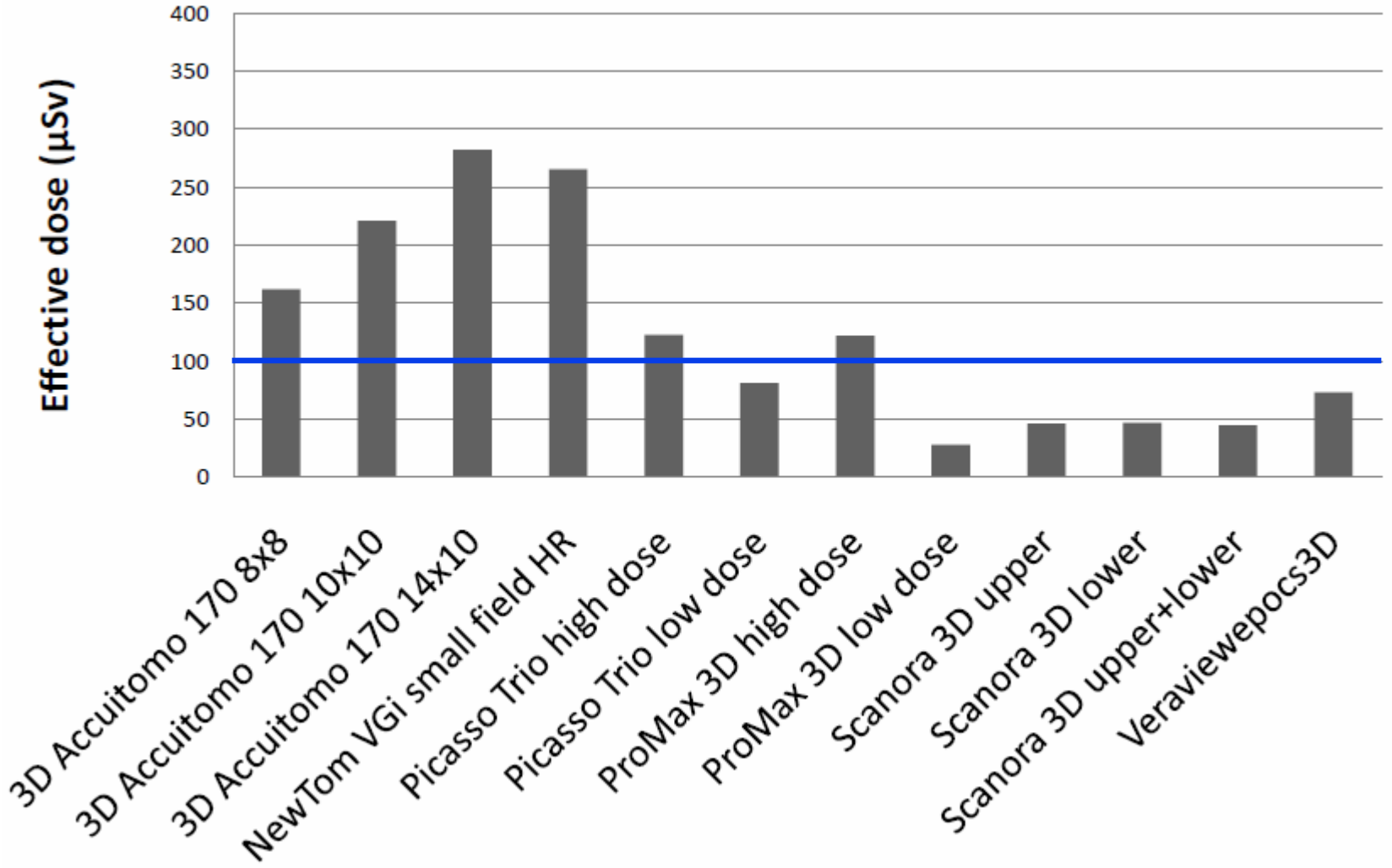
20 microSieverts to 370 microSieverts

Effective dose for large field CBCTs



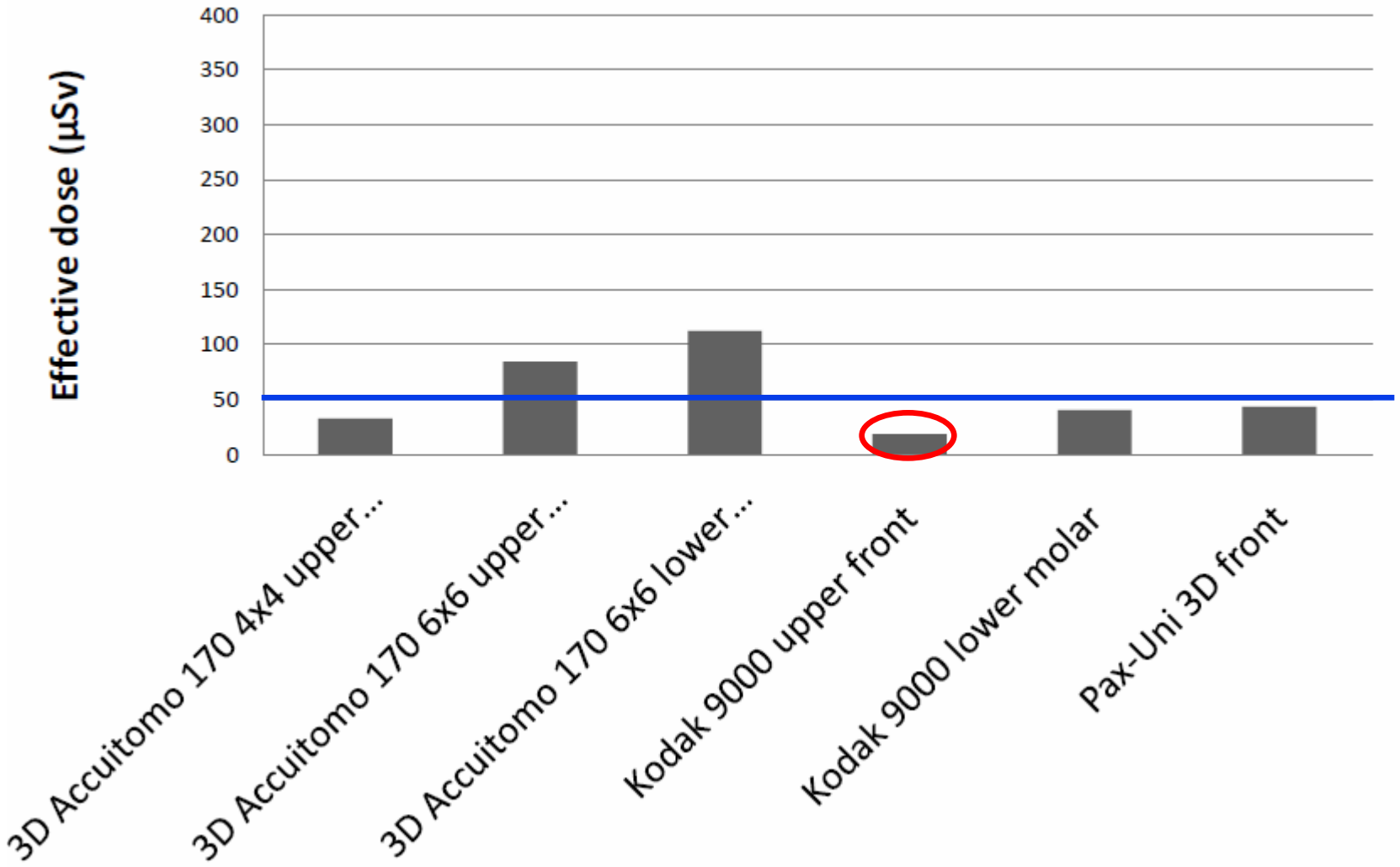
Prof. Ria Bogaerts, Katholieke Universiteit Leuven, March 2011

Effective dose for medium field CBCTs



Prof. Ria Bogaerts, Katholieke Universiteit Leuven, March 2011

Effective dose for small field CBCTs



Prof. Ria Bogaerts, Katholieke Universiteit Leuven, March 2011

Review

E.A.O. guidelines for the use of diagnostic imaging in implant dentistry 2011. A consensus workshop organized by the European Association for Osseointegration at the Medical University of Warsaw

David Harris[1,*], Keith Horner[2], Kerstin Gröndahl[3], Reinhilde Jacobs[4], Ebba Helmrot[3], Goran I. Benic[5], Michael M. Bornstein[6], Andrew Dawood[7] and Marc Quirynen[8]

Article first published online: 20 MAR 2012

DOI: 10.1111/j.1600-0501.2012.02441.x

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Issue

Clinical Oral Implants Research

Volume 23, Issue 11, pages 1243–1253, November 2012

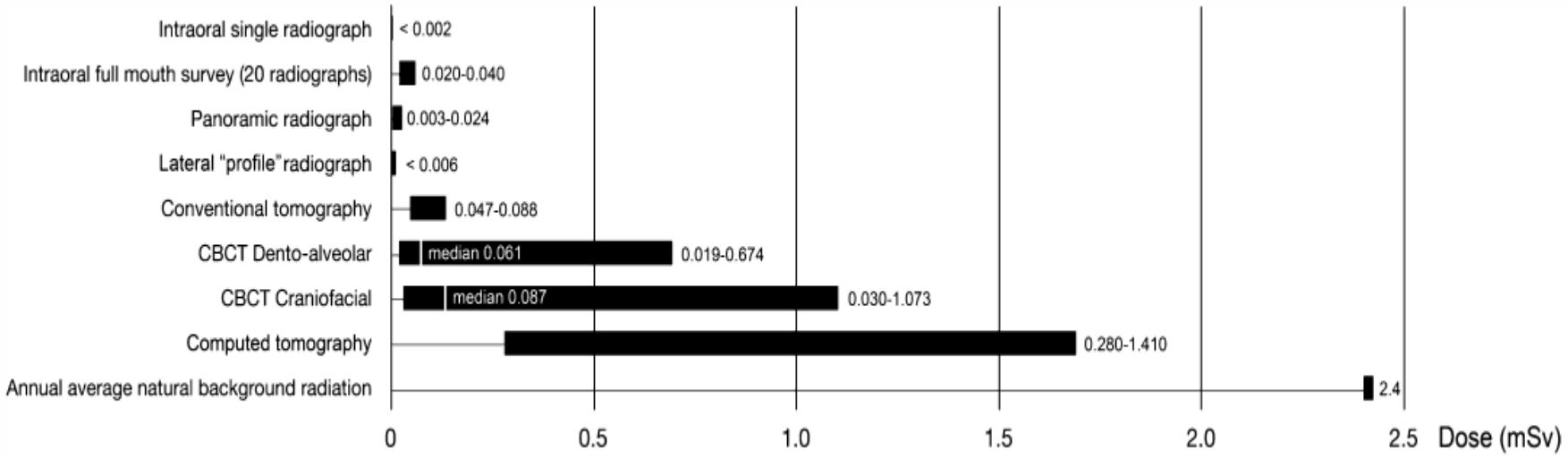

Fig. 1. Ranges of effective dose for the imaging modalities used in implant dentistry.

Typical Doses from Dental X-Rays

	Effective Dose (µSv)
Intraoral (F speed, rectangular collimator)	1 to 2
Intraoral (E speed, round collimator)	3 to 6
Lateral Ceph	5 to 10
Panoramic DPT	3 to 25
Cone Beam CT	20 to 370
Medical CT (using dental protocol)	150 to 1500

Source of exposure	Dose
Dental x-ray	0.005 mSv
100g of Brazil nuts	0.01 mSv
Chest x-ray	0.014 mSv
Transatlantic flight	0.08 mSv
Nuclear power station worker average annual occupational exposure (2010)	0.18 mSv
UK annual average radon dose	1.3 mSv
CT scan of the head	1.4 mSv
UK average annual radiation dose	2.7 mSv
USA average annual radiation dose	6.2 mSv
CT scan of the chest	6.6 mSv
Average annual radon dose to people in Cornwall	7.8 mSv
CT scan of the whole spine	10 mSv
Annual exposure limit for nuclear industry employees	20 mSv
Level at which changes in blood cells can be readily observed	100 mSv
Acute radiation effects including nausea and a reduction in white blood cell count	1000 mSv
Dose of radiation which would kill about half of those receiving it in a month	5000 mSv

https://www.gov.uk/government/publications/ionising-radiation-dose-comparisons/ionising-radiation-dose-comparisons

What is the Risk from an Intraoral x-ray?

- **Assume adult patient, F speed, rectangular collimation**
- **Effective Dose might be 2 microSieverts (worst case)**
- **Risk that patient might develop fatal cancer in 20 years time**

  = 5% (1 in 20) per Sievert (from ICRP103)

  = 1 in 20 million for 1 microSievert

  = 2 in 20 million for 2 microSieverts

  = 1 in 10 million for 2 microSieverts

Health & Safety people would call this a "Negligible Risk"

Cancer: science and society and the communication of risk

Kenneth C Calman

This article is based on the Calum Muir lecture, delivered in Edinburgh in September 1996.

BMJ VOLUME 313 28 SEPTEMBER 1996

Table 2—*Descriptions of risk in relation to the risk of an individual dying (D) in any one year or developing an adverse response (A)*

Term used	Risk range	Example	Risk estimate
High	≥1:100	(A) Transmission to susceptible household contacts of measles and chickenpox[6]	1:1-1:2
		(A) Transmission of HIV from mother to child (Europe)[7]	1:6
		(A) Gastrointestinal effects of antibiotics[8]	1:10-1:20
Moderate	1:100-1:1000	(D) Smoking 10 cigarettes a day[9]	1:200
		(D) All natural causes, age 40[9]	1:850
Low	1:1000-1:10 000	(D) All kinds of violence and poisoning[9]	1:3300
		(D) Influenza[10]	1:5000
		(D) Accident on road[9]	1:8000
Very low	1:10 000-1:100 000	(D) Leukaemia[9]	1:12 000
		(D) Playing soccer[9]	1:25 000
		(D) Accident at home[9]	1:26 000
		(D) Accident at work[9]	1:43 000
		(D) Homicide[9]	1:100 000
Minimal	1:100 000-1:1 000 000	(D) Accident on railway[9]	1:500 000
		(A) Vaccination associated polio[10]	1:1 000 000
Negligible	≤1:1 000 000	(D) Hit by lightning[9]	1:10 000 000
		(D) Release of radiation by nuclear power station[9]	1:10 000 000

What is the Risk from a CBCT scan?

- **Assume adult patient, dento-alveolar scan, both jaws**
- **Effective Dose might be 100 microSieverts (worst case)**
- **Risk that patient might develop fatal cancer in 20 years time**

  = 5% (1 in 20) per Sievert (from ICRP103)

  = 1 in 20 million for 1 microSv

  = 100 in 20 million for 100 microSv

  = 1 in 200,000 (roughly) for CBCT scan

Health & Safety people would call this a "Minimal Risk"

*** If your patient is a child the risk is 3x more**

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		(D) Playing soccer[9]	1:25 000
		(D) Accident at home[9]	1:26 000
		(D) Accident at work[9]	1:43 000
		(D) Homicide[9]	1:100 000
Minimal	1:100 000-1:1 000 000	(D) Accident on railway[9]	1:500 000
		(A) Vaccination associated polio[10]	1:1 000 000
Negligible	≤1:1 000 000	(D) Hit by lightning[9]	1:10 000 000
		(D) Release of radiation by nuclear power station[9]	1:10 000 000

Typical Risks from Dental X-Rays

	Effective Dose (µSv)	Risk
Intraoral (F speed, rect coll)	1 to 2	
Intraoral (E speed, round coll)	3 to 6	
Lateral Ceph	5 to 10	
Panoramic	3 to 25	
Cone Beam CT	20 to 370	
Medical CT (using dental protocol)	150 to 1500	

Typical Risks from Dental X-Rays

	Effective Dose (µSv)	Risk	
Intraoral (F speed, rect coll)	1 to 2	< 1 in 10 million	Negligible
Intraoral (E speed, round coll)	3 to 6	< 1 in 3.3 million	Negligible
Lateral Ceph	5 to 10	< 1 in 2 million	Negligible
Panoramic	3 to 25	1 in 6.7 million to 1 in 800 thousand	Negligible to Minimal
Cone Beam CT	20 to 370	1 in 1 million to 1 in 50 thousand	Mimimal to Very Low
Medical CT (using dental protocol)	150 to 1500	1 in 130 thousand to 1 in 13 thousand	Very Low

Risk varies with Age

Age group (years)	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 risk

5% per Sievert at age 30

RADIATION PROTECTION N° 172 A report prepared by the SEDENTEXCT project 2011

www.sedentexct.eu

Justification

(balancing the benefits against the risks)

Risk

- **Exposure to ionising radiation**
- **Might induce a cancer**
- **Might induce a hereditary defect**

Benefit

- **Accurately pre-plan dental implant treatment**
- **Less risk of damaging a critical structure**
- **Reduce operating time**
- **Improved aesthetic results**

Clinical

Decision

Implant Surgery Complications: Etiology and Treatment

Kelly Misch, DDS,* and Hom-Lay Wang, DDS, MSD, PhD†

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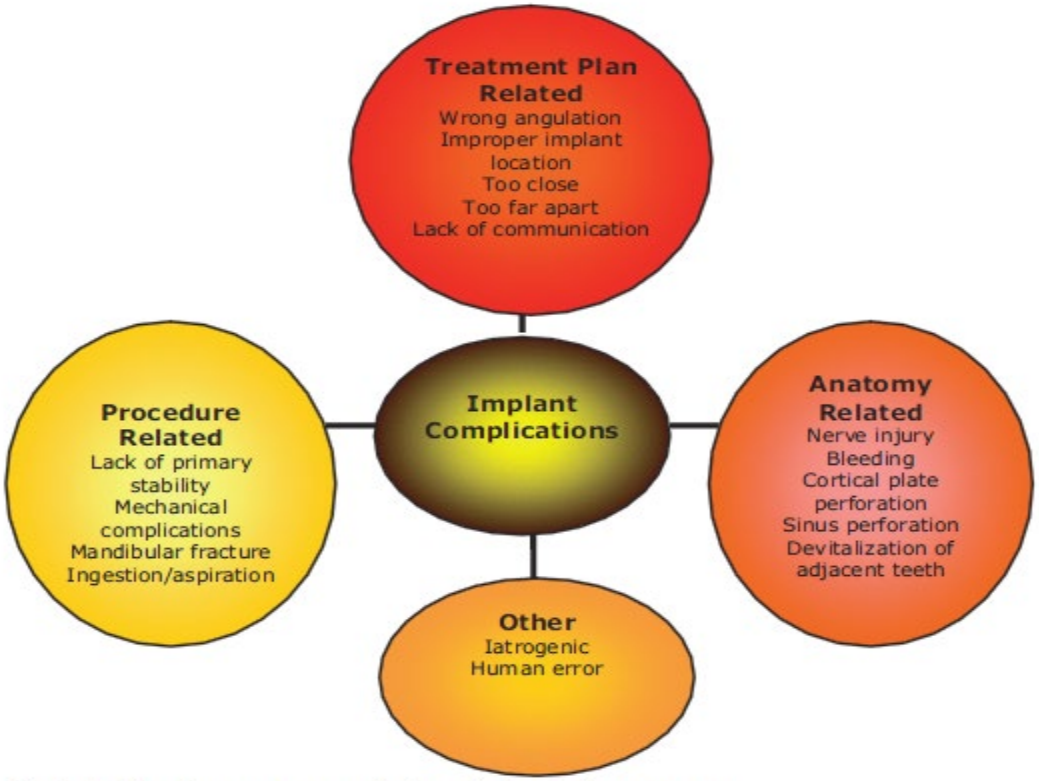
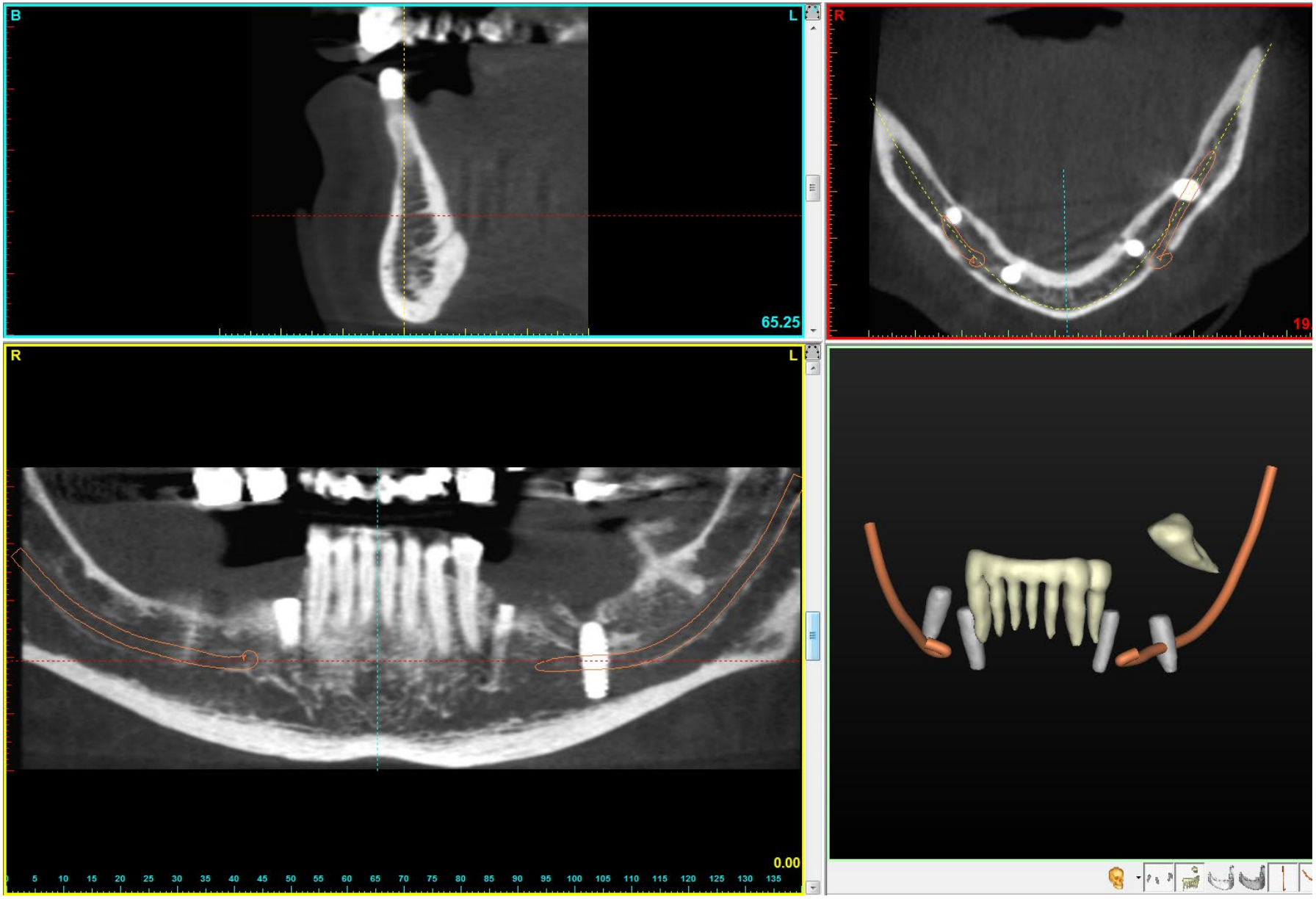


Fig. 1. Outline of common complications during implant surgery.

The Risk of Not Having a CBCT Scan



Take the CBCT Scan first, do the surgery second (not the other way around)!

If everyone in the UK had a dental CBCT scan every year ...

- ***There might be 160 extra cancer deaths per year***
  (if LNT is correct)

- ***Compared to 155,000 cancer deaths from other causes***

UK Mortality 2002: Cancers which contribute one per cent or more to total cancer mortality

Lung	33,600	(22%)
Bowel	16,220	(10%)
Breast	12,930	(8%)
Prostate	9,940	(6%)
Oesophagus	7,250	(5%)
Pancreas	6,880	(4%)
Stomach	6,360	(4%)
Bladder	4,910	(3%)
Non-Hodgkin's lymphoma	4,750	(3%)
Ovary	4,690	(3%)
Leukaemia	4,310	(3%)
Brain and CNS	3,370	(2%)
Kidney	3,360	(2%)
Head and neck	3,000	(2%)
Multiple myeloma	2,600	(2%)
Liver	2,510	(2%)
Mesothelioma	1,760	(1%)
Malignant melanoma	1,640	(1%)
Cervix	1,120	(1%)
Body of Uterus	1,070	(1%)
Other	22,910	(15%)
Persons: all malignant neoplasms	155,180	(100%)

http://www.cancerresearchuk.org/aboutcancer/statistics/mortality

Outline of Lecture

✔**Radiation Dose and Risk**

- **Compliance with the Legislation**

Annals of the ICRP

PUBLICATION 103

The 2007 Recommendations of the International Commission on Radiological Protection

Editor
J. VALENTIN

PUBLISHED FOR

The International Commission on Radiological Protection

by

ELSEVIER

Framework for Radiation Protection

- **Based on the Recommendations of the International Commission for Radiation Protection (ICRP)**
  - **an advisory body with no formal powers**
- **European Directives for Radiation Safety**
- **National Legislation**
  - **England, Scotland, Wales, Northern Ireland**
- **Local Rules / Written Procedures at each hospital or dental practice**
- **Each healthcare professional has an individual responsibility**

European Directives for Radiation Safety

- **Basic Safety Standards Directive**
  - **96/29/Euratom of 13 May 1996**
- **Medical Exposure Directive**
  - **97/43/Euratom of 30 June 1997**

Both Replaced by

- **Basic Safety Standards Directive (revised)**
  - **2013/59/Euratom of 5 December 2013**
  - **National legislation to be enacted by 5 February 2018**

Transposition of BSSD into UK Law

Radiation Safety for Workers and the Public

- **Ionisation Radiations Regulations 1999 – "IRR99"**
- **Enforced by Health and Safety Executive**
- **Revised legislation "IRR 2017" came into force on 6 February 2018.**

Radiation Safety for Patients

- **Ionising Radiation (Medical Exposure) Regulations 2000 (amended in 2006 and 2011) – "IR(ME)R 2000"**
- **Enforced by Care Quality Commission (CQC)**
- **Revised legislation "IR(ME)R 2017" came into force on 6 February 2018.**

Legislation versus Guidelines – what's the Difference?

"Legislation" refers to Criminal Law

- **Example: it is an offence not to register with the Health and Safety Executive (HSE) if you are working with x-rays**

"Guidelines" refer to Best Practice and are often relevant in Civil Law

- **Can I defend myself if a patient sues me?**
- **What if I'm investigated by the General Dental Council (GDC)?**

You won't go to jail for not complying with the Guidelines, but compliance puts you in a stronger position.

IRR 2017 - New System of Authorisation

- **Under IRR 2017 employers have to notify HSE in advance of commencing work with ionising radiation.**

- **Graded system (based on level of risk):**
  - **Notification: work with radionuclides**
  - **Registration: work with radiation generators including x-ray tubes. Costs £25 to register (for all sites under one Employer).**
  - **Consent: administering radiopharmaceuticals to patients (costs £25 per Employer)**

- **Employers (e.g. dental practice owners) had to register and pay £25 fee by 5 February 2018.**

- **If you should have registered but haven't already done so you can register online here: https://services.hse.gov.uk/bssd/**

IRR 2017 - New System of Authorisation

- **Employers (e.g. dental practice owners) had to register and pay £25 fee by 5 February 2018.**
- **Must re-register (and pay a new fee) after a material change (such as change of Employer's name or address)**
- **Associates (working at someone else's practice and following the owner's rules and regulations) don't have to register.**

Risk Assessment

A Risk Assessment is required before commencing new activities involving ionising radiation.

1. **Look for the hazards (sources of radiation)**
2. **Decide who may be harmed and how (staff, public)**
3. **Decide if existing control measures (shielding, warning signs) are adequate or if more are needed**
4. **Record the findings of the Risk Assessment**
5. **Review the Assessment periodically (e.g. once per year) and revise if necessary.**

Sources of Radiation

- **Primary Beam**
  - only the patient should be exposed to the primary beam.
- **Tube Leakage**
  - must be less than 1mGy/hour at 1 meter
  - tests are performed to ensure this.
- **Scattered Radiation**
  - radiation scattered from the patient
  - staff can protect themselves through Distance, Shielding, Time.

Staff Protection

Based on 3 principles:

- **Distance**
  - **the further you are from the source the less radiation you receive**
  - **follows Inverse Square Law ($1/d^2$)**
- **Shielding**
  - **fixed (built into the walls)**
  - **a mobile shield**
  - **protective equipment (e.g. lead apron for staff)**
- **Time**
  - **shorter exposure to radiation results in less dose.**

Staff are present 8 hours a day so it is vital to protect them.

Hierarchy of Control Measures

Control Measures should be considered in this order:

1. **Engineering Controls**
   - **Beam collimation, shielding, warning devices**
2. **Systems of Work**
   - **Controlled Areas**
   - **Local Rules**
3. **Personal Protective Equipment (should be a last resort)**
   - **Lead aprons**

Protecting Members of the Public

- **Adequate shielding needs to be built into the walls, ceilings, floors, doors, windows of rooms containing x-ray equipment**
  - **if you have windows in the doors make sure they contain lead**
- **Think carefully about the best locations for waiting rooms, toilets etc**
- **Think how to prevent members of the public from walking into a Controlled Area**
  - **warning signs**
  - **radiographer stands at the door**
  - **good building design ensuring the public have no reason to walk past a Controlled Area.**

Dose Limits for Workers and the Public

Annual Dose limits (mSv)			
	Adults (over 18 yrs)	Trainee (under 18 yrs)	Other persons
Whole body	20	6	1
Lens of the eye	150	50	15
Skin	500	150	50
Hands etc.	500	150	50
Women of reproductive capacity 13 mSv averaged over the abdomen in any consecutive 3 months			

IRR 2017: Dose Limit to Lens of Eye is now 20mSv/year for Adults and 15mSv/year for Trainees/Other Persons

Classified Persons

Employees must be "classified" if they are likely to receive:

- **An Effective Dose of more than 6mSv per year, or**
- **An Equivalent Dose to lens of eye of more than 15mSv per year, or**
- **An Equivalent Dose to extremities of more than 150mSv per year (skin, hands, forearms, feet or ankles)**

If they are Classified they must have

- **An appointed doctor**
- **A radiation passbook if they work in another Employer's controlled environment.**

People who work in dental practices are not normally "Classified"!

Local Rules

Work in a Controlled Area must be carried out according to Local Rules

Local Rules should be on display in each room where x-ray equipment is used

Employees must read Local Rules and sign an undertaking that they have been read.

Some dental practices put the Local Rules on their website.

Radiation Protection Advisor

- **Dental Practices must appoint a suitable RPA**
- **Must consult RPA to ensure observance of IRR 2017**
- **RPA should review radiation safety for each new x-ray installation and at least every 3 years for existing installations**
  - **e.g. risk assessment**
  - **is there adequate shielding**
  - **designation of controlled areas**
  - **training of operators**
  - **local rules / written procedures**

Radiation Protection Advisor

- **RPA is generally a physicist with certification from HSE-approved Assessing Body**
- **Usually an outside consultant**
- **Should be available for consultation (otherwise, get a different one)**
- **A list of RPAs is available at www.rpa2000.org.uk**

Radiation Protection Supervisor (RPS)

- **Where work is subject to Local Rules, employer must appoint a Radiation Protection Supervisor (RPS)**
- **Usually a member of staff who can command authority (e.g. a dentist)**
- **Should be trained to have knowledge of the Regulations and understand the precautions to be taken**
- **Legal responsibility remains with the employer.**

Outside Workers

An Outside Worker is someone who carries out work in the Controlled Area of an Employer other than their own

- **Includes service engineers, cleaners, contractors etc**
- **May include Agency Staff e.g. radiographers**
- **Now includes both Classified and Non-Classified workers (used to be just Classified workers)**
- **You are responsible for their safety**
- **In the case of an engineer you can hand responsibility over temporarily through a Handover Procedure.**

RADIATION CONTROLLED AREA AND EQUIPMENT HANDOVER FORM

Part 1: CUSTOMER – Handover of controlled area and equipment to Company Representative

FACILITY / DEPARTMENT:	CONTROLLED AREA / ROOM: EQUIPMENT:	
COMPANY CARRYING OUT WORK:	ID SEEN: YES ☐ / NO ☐	CALL REFERENCE NO:
REASON FOR HANDOVER:		
IDENTIFY KNOWN HAZARDS WITH CONTROLLED AREA OR EQUIPMENT:		

Customer: As an authorised representative of the customer, I hereby hand over the controlled area and equipment as above. Information has been exchanged to enable appropriate risk assessment to be made.	**Company:** As an authorised representative of the company, I accept responsibility of the controlled area and equipment for the reason stated above. Risk assessment will be made using the information provided and company procedures followed.

Customer Representative:	Signature:	Company Representative:	Signature:
Date:	Time:	Date:	Time:

Part 2: COMPANY REPRESENTATIVE – Handover of controlled area and equipment to customer

Please tick all applicable categories of work carried out.

	CATEGORY OF WORK	DETAILS
☐	Routine service	
☐	Fault diagnosis / repair	
☐	Installation of part(s)	
☐	Upgrade / Modification	Hardware ☐ / Software ☐
☐	Incident response	
☐	Hazard Notice response	
☐	Clinical protocol changes	
☐	Other	

Could this work have implications for radiation safety or patient dose or image quality? *Tick all boxes that apply.*

☐ Shielding	☐ Interlocks / exposure termination	☐ Safety features / warning devices
☐ Beam quality / filtration / grid	☐ Collimation / alignment / field sizes	☐ Detector dose / dose indicator
☐ Dose curve / protocol	☐ Patient dose / dose rate / AEC	☐ Imaging quality / processing
☐ DAP / skin dose indicator	☐ Mechanical / Electronic / Scale Cal.	☐ Other - please specify:
☐ None of the above	See visit/service report for details.	

1. Equipment is OPERATIONAL following work as indicated above and on the visit/service report. ☐
2. Equipment is PARTIALLY OPERATIONAL limitations may exist, refer to visit/service report. ☐
3. Equipment is NOT OPERATIONAL and MUST NOT BE USED. ☐

Company Representative:	Signature:	Customer representative:	Signature:
Date:	Time:	Date:	Time:

Part 3: CUSTOMER – Returning equipment to use

I confirm that I have been authorised as a competent customer representative ☐

I confirm the above company provided information and associated service report have been reviewed and carried out appropriate checks in accordance with the Ionising Radiation Regulations. I confirm all required local procedures have been completed.

1. I am satisfied that the equipment is in a satisfactory condition for use in medical exposure. ☐
2. I am NOT satisfied that the equipment is satisfactory for use in medical exposure. ☐

Reason:

Actions Taken:

Customer Representative:	Signature:	Date:	Time:

AXREM ASSOCIATION OF HEALTHCARE TECHNOLOGY PROVIDERS FOR IMAGING, RADIOTHERAPY & CARE
AXREM, Rotherwick House, 3 Thomas More Street, London E1W 1YZ

Ionising Radiation (Medical Exposure) Regulations 2017

Ionising Radiation (Medical Exposure) Regulations 2000 (amended in 2006 and 2011) – "IR(ME)R 2000"

- **Medical exposures (e.g. patients)**
- **Enforced by Care Quality Commission www.cqc.org.uk**
- **In Northern Ireland: enforced by Regulation and Quality Improvement Authority www.rqia.org.uk**

IR(ME)R 2000 was replaced by IR(ME)R 2017.

Principles of Patient Protection

- **Justification** **(benefits must outweigh the risks)**
- **Optimisation** **(keep doses As Low As Reasonably Practicable)**
  (consistent with the intended diagnostic purpose)
- **Limitation**
  ~~**(20 mSv per year for Classified Persons)**~~
  ~~**(1 mSv per year for members of the public)**~~
  (no dose limits for medical exposures)
  (must set limits for research programs)
  (must set limits for carers and comforters)

Before taking radiographs

- **Is the radiograph necessary?**
- **Is adequate clinical information available?**
- **Do we understand the referrer's objectives?**
- **Can the exposure be justified?**

Before taking radiographs

- **Do we have the correct patient?**
  - **Name**
  - **Address**
  - **Date of Birth**
  - **Pregnancy status**
- **Exposing the wrong patient is automatically notifiable to Care Quality Commission (CQC)**
- **Check the problem area with the patient before the exposure.**

Optimisation

(keeping doses as low as practicable, consistent with the intended purpose)

Want to Optimise

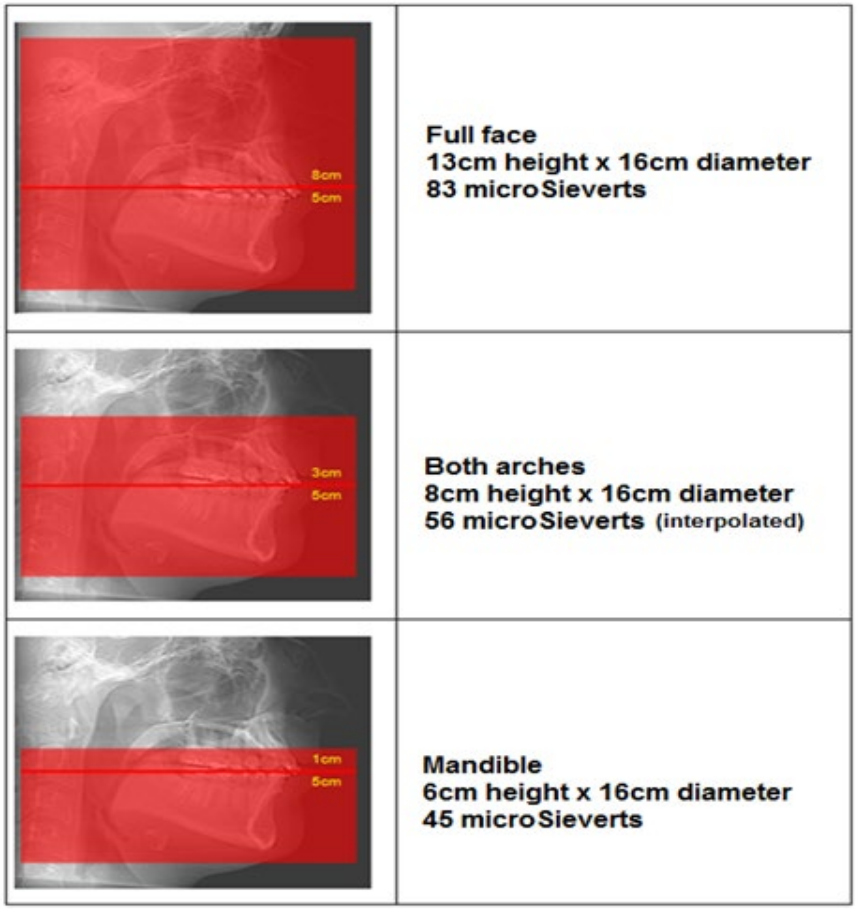
$$\frac{\textbf{Benefit to Patient*}}{\textbf{Risk to Patient}}$$

*** not to the dentist!**

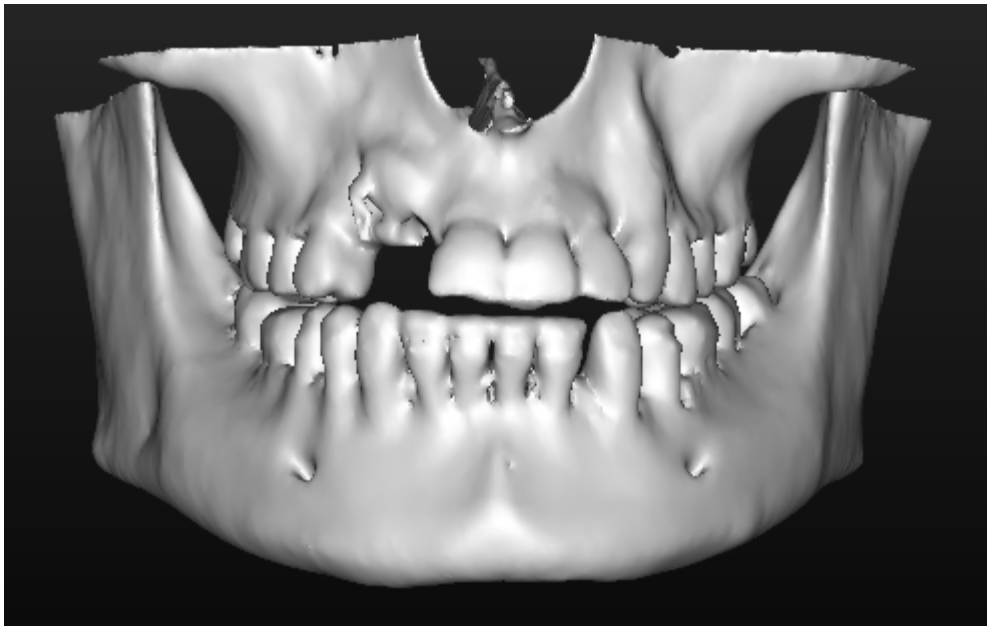
How to Optimise CBCT Scans

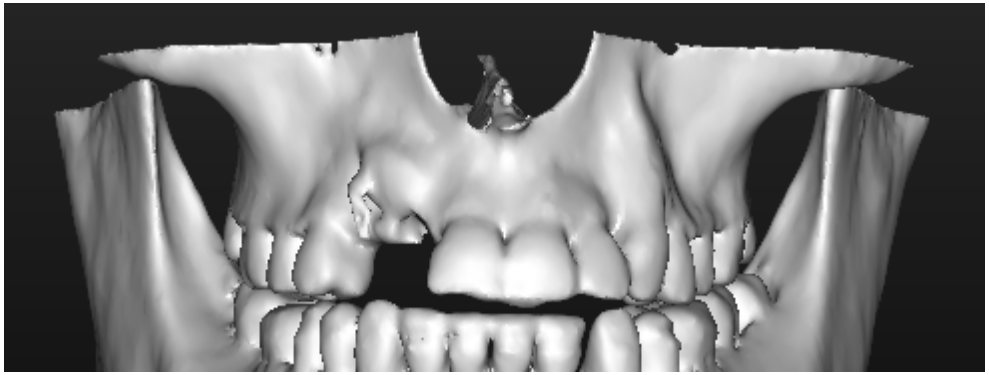
1. **Reduce the Height (vertical collimation)**

Reduces the risk without loss of benefit in most cases.

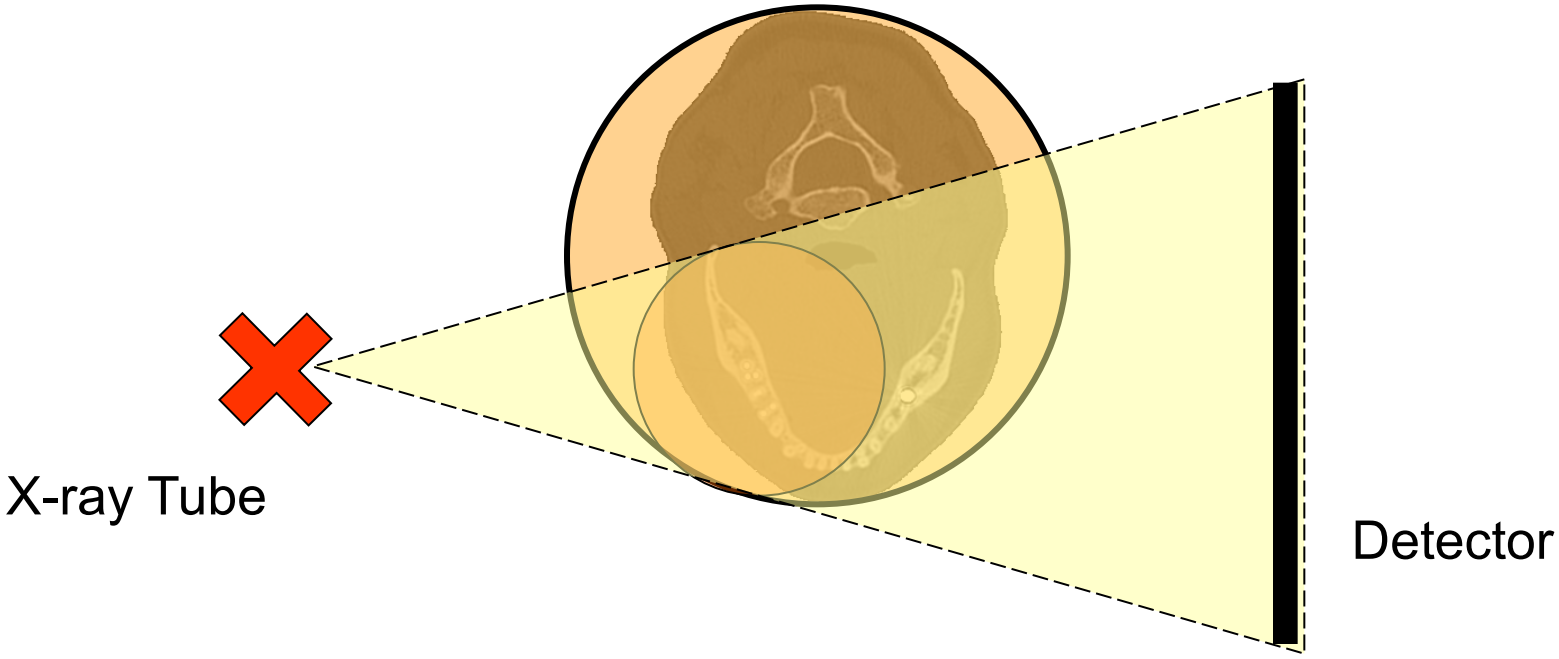


Absorbed Dose outside primary beam is effectively zero

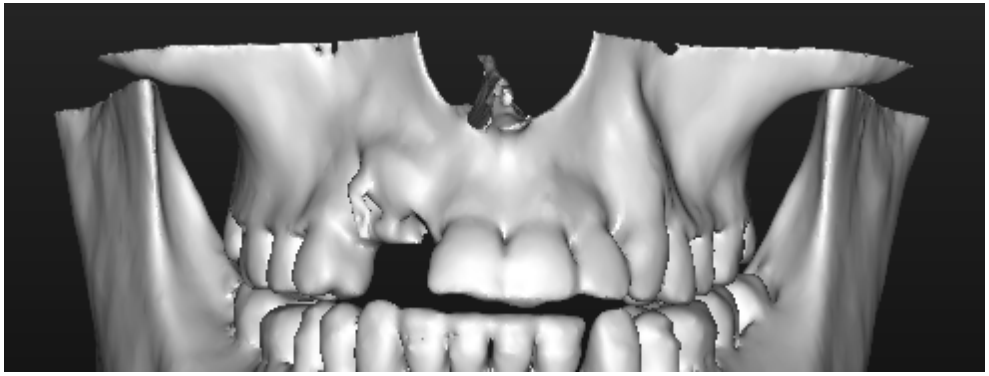




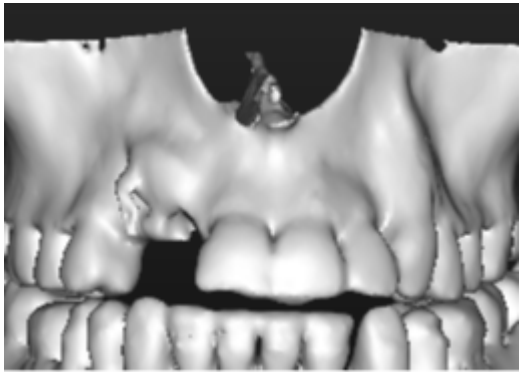
2. Reduce the Diameter (horizontal collimation)



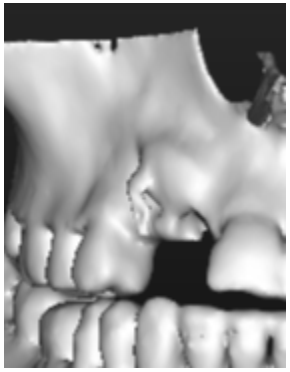
- **Absorbed Dose outside primary beam is not zero (about 50% from SEDENTEXCT measurements)**
- **There may be some loss of benefit**



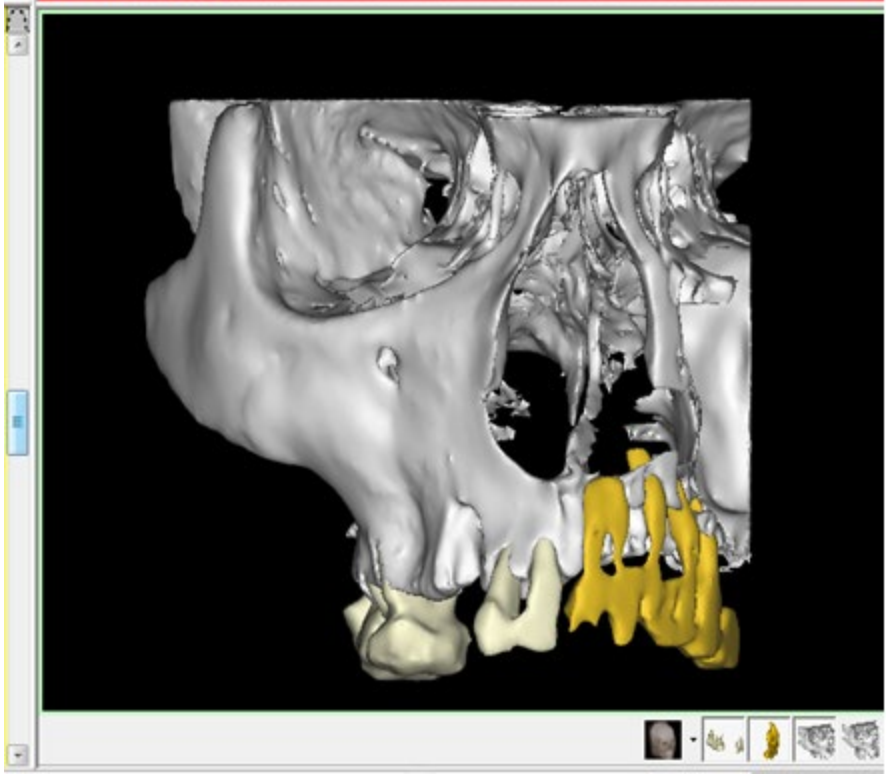
16cm diameter



8cm diameter



4cm diameter



The Absorbed Dose to the left side of the patient is not zero

(it's maybe around 50% of the Absorbed Dose to the right side).

Position the patient to get the maximum information for the same radiation dose.

Optimisation of CBCT Scans

3. **Reduce the mAs (tube current, scan time)**

- **Reducing the mAs may have a negative impact on image quality**

- **On some CBCT scanners, the voxel size is linked to the mAs.**

Duty Holders under IR(ME)R 2017

(may be one and the same person)

The Employer

- **provides a framework of policies and procedures**

The Referrer (“Prescriber” in most EU countries)

- **must supply sufficient clinical information to allow the exposure to be justified**

The Practitioner

- **is responsible for justifying the exposure in terms of benefits versus risks**

The Operator

- **is responsible for carrying it out safely.**

Employer

The Employer is the legal person responsible for compliance with IRR 2017 and IR(ME)R 2017.

The Employer could be:

- **An NHS Trust**
- **The owner of a dental practice**
- **The owner of an x-ray repair and servicing company**
- **etc.**

The Employer must create a framework for Radiation Protection through written policies and procedures.

Practitioner

- **Practitioner must decide if the exposure is justified (i.e. the benefits must outweigh the risks)**
- **Must take into account the objectives of the exposure and the characteristics of the patient**
- **Is there another way to obtain the required information?**
- **What do the Referral Guidelines say?**
- **Urgency of the procedure (e.g. pregnant women may prefer to postpone it).**

Evaluating the Results

- **The Practitioner must put procedures in place to ensure that a clinical evaluation of the outcome of the exposure is carried out and recorded**
- **If it is known, prior to the exposure, that no clinical evaluation will occur then the procedure cannot be justified and the exposure must not take place**
- **If exposure will not change the patient's management it cannot be justified and must not take place.**

Referrer

- ***Referrers*** **may prescribe (request) x-ray examinations.**
- **They must be registered health care professionals.**
- **They must provide sufficient clinical information to substantiate the need for an x-ray examination.**
- **A history and clinical examination of the patient is essential prior to any request for an exposure.**
- **Previous x-ray examinations should also be investigated**
- **“Routine” x-rays are not allowed.**

Operator

- ***Operators*** **are responsible for carrying out the exposure safely.**
- **They should ensure the dose from the exposure is as low as reasonably practicable and consistent with the intended diagnostic purpose**
  - ***dose should not be so low as to give non-diagnostic images***
- **There should be written protocols in place for each type of examination**
- **If the dose is above the Diagnostic Reference Levels (DRL) the reason should be recorded.**

Diagnostic Reference Levels

- **DRLs are dose levels which are not expected to be exceeded for standard procedures**
  (they are not Dose Limits – they are guidelines)

- **Local DRLs should be set for each type of x-ray procedure**

- **Local DRLs should not normally exceed National DRLs.**

Diagnostic Reference Levels

- **For intra-orals the National DRL is 1.7 mGy in the UK (entrance dose)**

- **For DPTs the National DRL is 67 mGy.cm^2 for children and 93 mGy.cm^2 for adults (Dose Area Product, DAP)**

- **We don't have a National DRL for CBCT yet.**

Informed Consent

Wherever practical and prior to an exposure, the patient must be provided with information relating to benefits and risks.

- **For dental radiography, leaflets in the waiting room would meet this requirement in practice.**

Medical Physics Expert (MPE)

Under IRR 2017 dental practices have to appoint an RPA

Under IR(ME)R 2017 they have to appoint an MPE (who will often be the same person):

- **MPE to be available for consultation on Optimisation**
- **Give advice on radiological equipment**
- **Setting of local DRLs**
- **Establish and maintain QA programme**

A list of RPAs and MPEs is available at www.rpa2000.org.uk

Installation of New X-Ray Equipment

(or major repairs to existing equipment)

- **Installer must perform “critical examination”**
- **Dentist’s RPA/MPE should advise on whether results of critical examination are acceptable**

Critical Examination

- **Must be performed before first use or after a major repair**
- **Evaluation of safety features**
- **Responsibility of the installer/repairer**
- **Performed by engineer or physicist**
- **Evaluation of shielding and radiation protection**
- **Evaluation of warning signals**
- **Evaluation of exposure controls**
- **Acceptable functioning of cut-out switches etc**
- **Report should be kept with equipment records.**

Automated Dose Reporting

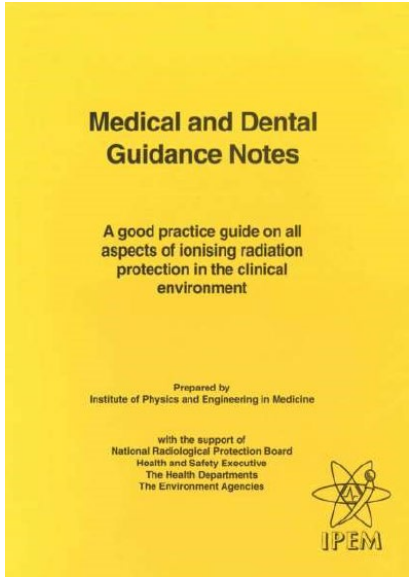
CT/CBCT equipment installed after 5 Feb 2018 must have the capacity to transfer all dose related parameters to the patient's exposure record.

Acceptance Testing

- **Ensures equipment meets its specifications**
- **Responsibility of the purchaser**
- **Performed by Radiation Protection Advisor (RPA) or Medical Physics Expert (MPE)**
- **Provides a baseline for Quality Control tests.**

Routine QC Tests

- **Monthly tests can be performed by the Operator**
- **Annual tests should be performed by RPA or MPE**
- **Follow manufacturer's instructions for QC tests**
- **See also Medical and Dental Guidance Notes (2002)**



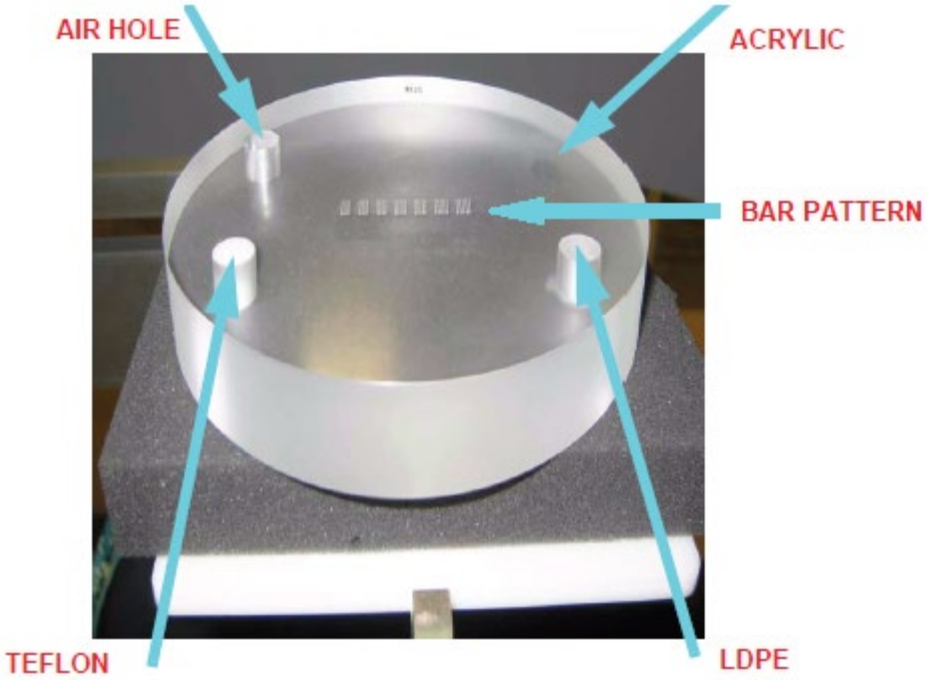
£20 from Institute of Physics and Engineering in Medicine (IPEM)

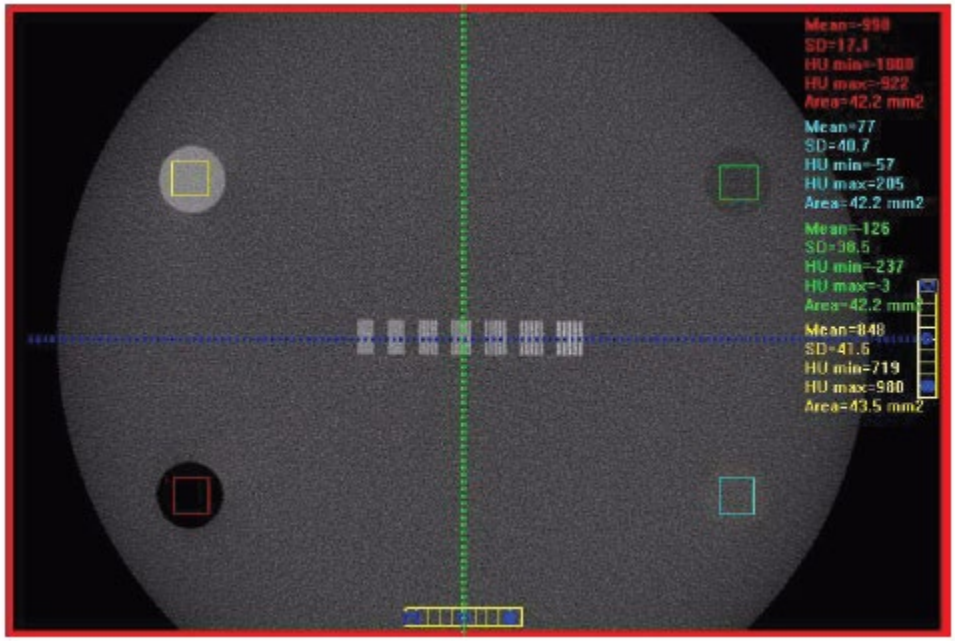
https://www.ipem.ac.uk/ScientificJournalsPublications/MedicalandDentalGuidanceNotes.aspx

Monthly Tests

example: i-CAT 17-19 CBCT Scanner

- **Scan the supplied QC phantom using the recommended settings**
- **Follow the manufacturer's instructions to measure density of inserts and number of line pairs visible**
- **Measure the distance to check geometrical accuracy**

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SD=17.1
HU min=-1000
HU max=-922
Area=42.2 mm2
Mean=77
SD=40.7
HU min=-57
HU max=205
Area=42.2 mm2
Mean=-126
SD=38.5
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HU max=-3
Area=42.2 mm2
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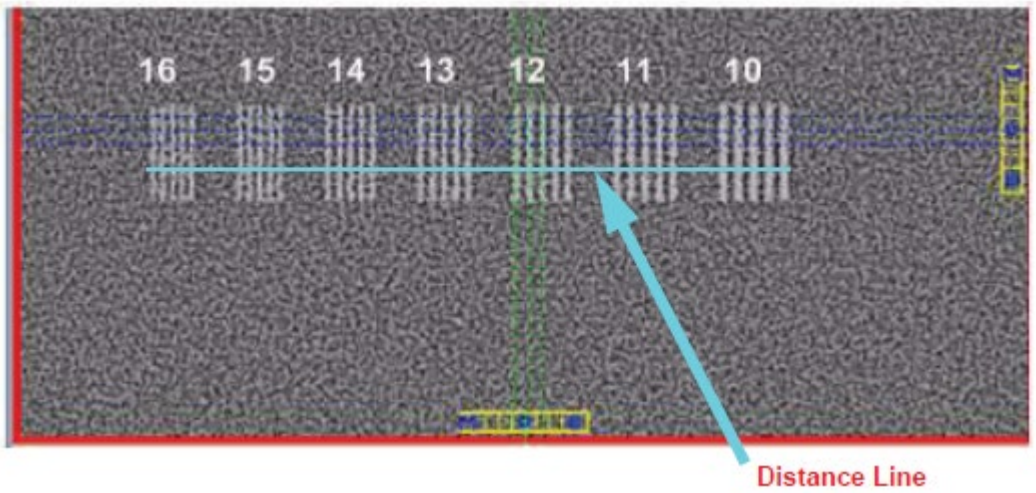
SD=41.6
HU min=719
HU max=980
Area=43.5 mm2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Distance Line

Recommended Annual Tests

- **Usually performed by RPA or MPE**
- **Is radiation output within specs?**
- **Is tube voltage (kVp) within specs?**
- **Tube Current (mA) accuracy**
- **Timer (s) accuracy**
- **Half value layer**
- **Tube leakage**
- **Focal spot size**
- **Collimation accuracy**
- **Tube stability & mechanical safety**

Accidental or Unintended Exposures

- **“Significant events” (including near misses) must be analysed, recorded and reported**
- **Includes equipment or procedural failures**
- **Duty of candour to disclose “clinically significant” events to patient, referrer, practitioner**
- **If not in patient’s best interests to inform patient then representatives must be informed instead.**

Guidance on investigation and notification of medical exposures much greater than intended.

16 January 2017

Table 1 – Examples of unintended medical exposures that require notification

All Modalities	**When to notify (what constitutes an exposure much greater than intended)**
Wrong patient exposed	All cases – regardless of dose
Wrong examination including incorrect body part or modality.	When the total exposure is at least 20 times greater than the intended dose.
Low dose examinations, where the intended dose is less than 0.5mSv, to include DEXA, skull, dentition, chest, in-vitro nuclear medicine	

https://www.cqc.org.uk/guidance-providers/ionising-radiation/reporting-irmer-incidents

Due Diligence

- **“In any proceedings against any person for an offence consisting of the contravention of these Regulations it is a defence for that person to show that the person took all reasonable steps and exercised all due diligence to avoid committing the offence”**
- **Document everything!**

Training Requirements – IRR 2017 and IR(ME)R 2017

- **Employers must maintain an up-to-date record of training, available for inspection, with date and nature of training recorded.**

Practitioner Training

Practitioners **must have received adequate training both in radiation safety and clinical aspects (e.g. selection criteria)**

- ***for dentists this would normally be a degree course***
- ***must keep up to date with CPD***

Operator Training

Operators **must have received adequate training specific to the tasks that they undertake**

- ***dental nurses, hygienists, therapists etc required to take x-rays would normally require the Certificate in Dental Radiography or equivalent***
- ***must receive training on practical aspects of operating the equipment***
- ***must keep up to date with CPD***

Referrer Training

There are no specific requirements in IR(ME)R 2017 for Referrer training, however, many people believe that training of Referrers would be beneficial, especially for Dental CBCT.

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http://dmfr.birjournals.org

SHORT COMMUNICATION

Basic training requirements for the use of dental CBCT by dentists: a position paper prepared by the European Academy of DentoMaxilloFacial Radiology

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https://www.rcseng.ac.uk/education-and-exams/courses/

Friday 15 March 2019 £300

Dental CBCT Course for Referrers

Cone Beam Computed Tomography (CBCT) is increasingly common in hospital and general dental practice. This course is based on the Level 1 training criteria published in the latest European EADMFR guidelines. Upon completion participants will have fulfilled their legal and ethical responsibilities.

The course is hosted by the RCS and the British Society of Dental and Maxillofacial Radiology and is delivered by experienced consultant dental maxillofacial radiologists.

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Saturday 16 March 2019 £450

Basics of Dentoalveolar CBCT Interpretation

This hands-on course is designed to train dentists to interpret and write reports on CBCT scans limited to dento-alveolar regions. The course content is modified from the "Level 2" training criteria published in the latest European guidelines.

This course is jointly hosted by the British Society of Dental and Maxillofacial Radiology (BSDMFR) and the Royal College of Surgeons of England and is delivered by experienced consultant dental maxillofacial radiologists.

KING'S College LONDON

Dental Cone Beam CT Radiological Interpretation PG Cert

Online Course

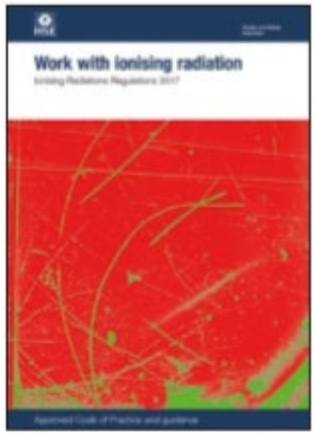
https://www.kcl.ac.uk/study/postgraduate/taught-courses/dental-cone-beam-ct-radiological-interpretation-pg-cert.aspx

Radiology Reports

- **IR(ME)R 2017 requires a *clinical evaluation* of the outcome of each exposure (other than for carers and comforters) and that this must be *recorded.***
- **There is no legal requirement to send the images to a Radiologist for reporting**
- **If you have received sufficient training, it is good practice to report on the images yourself**
- **If you haven't received sufficient training, or if you suspect pathology may be present, it is good practice to send the images to a Specialist in Dental and Maxillofacial Radiology for a Report.**

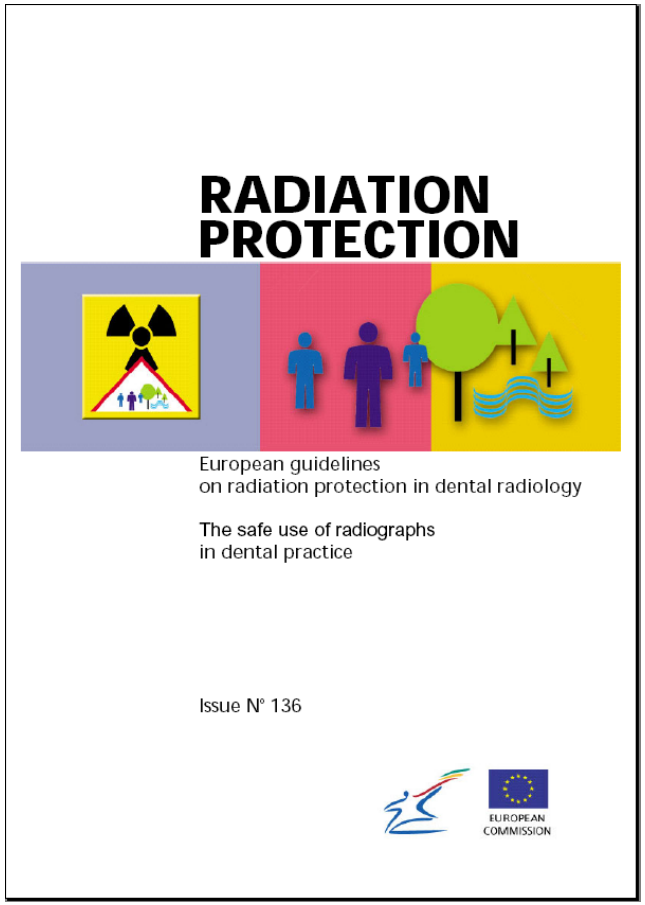
Guidance Documents (UK)

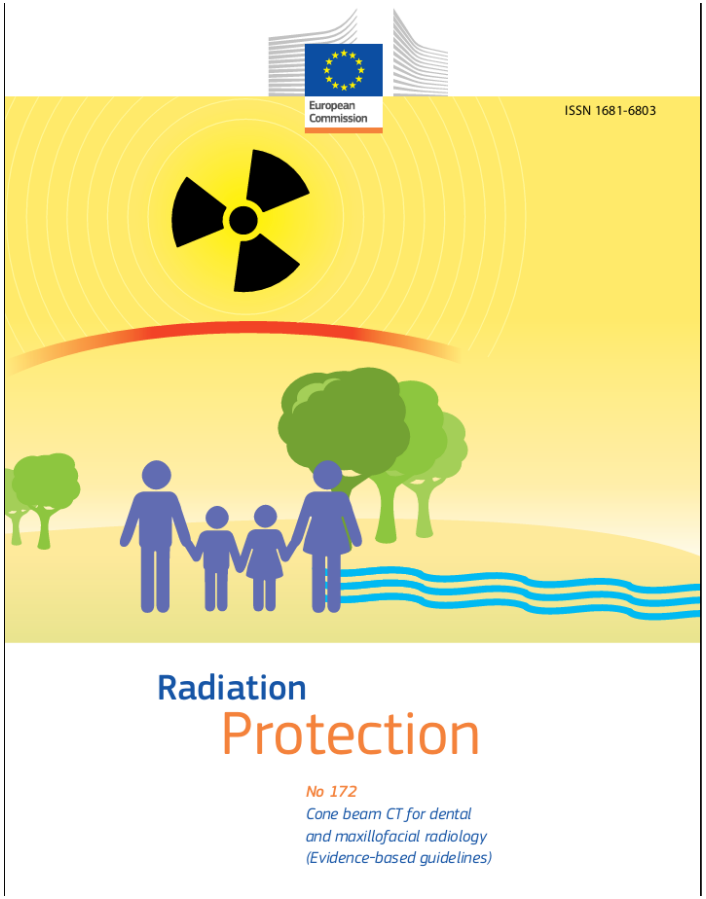
- **New Approved Code of Practice L121 (costs £27)**
  www.hse.gov.uk/pubns/priced/l121.pdf
- **Revised Medical and Dental Guidance Notes – to be published.**
- **Guidance Notes for Dental Practitioners on the Safe Use of X-Ray Equipment – PHE updates planned.**
- **IR(ME)R Companion Guide – to be published.**
- **IR(ME)R 2017 legislation is available here:**
  www.legislation.gov.uk/uksi/2017/1322/contents/made



L121 (Second edition)
Published 2018

Guidance Documents (Europe)





http://europa.eu.int/comm/energy/nuclear/radioprotection/publication/doc/136_en.pdf

The End

Thank you for listening.