Image Diagnostic Technology Ltd

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Tel: +44 20 8819 9158 www.idtscans.com email: info@idtscans.com

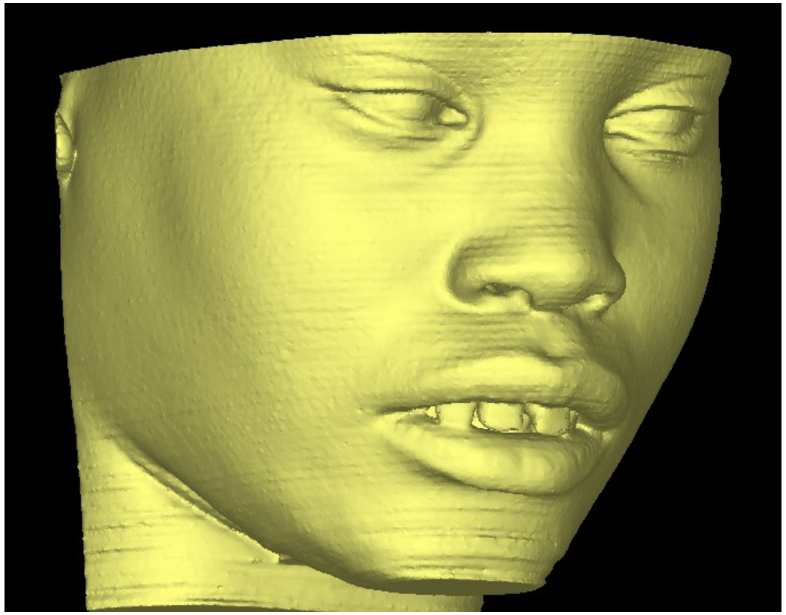
The Science Behind CBCT

Anthony Reynolds BA MSc PhD
Registered Clinical Scientist CS03469
Medical Physics Expert ICPM 877781

Image Diagnostic Technology Ltd.

Who or what is IDT?

Image Diagnostic Technology Ltd aka “IDT Scans”



Specialises in:

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

38,000 scans processed since 1991

www.idtscans.com

Support

Please click on the links to access the Support pages:

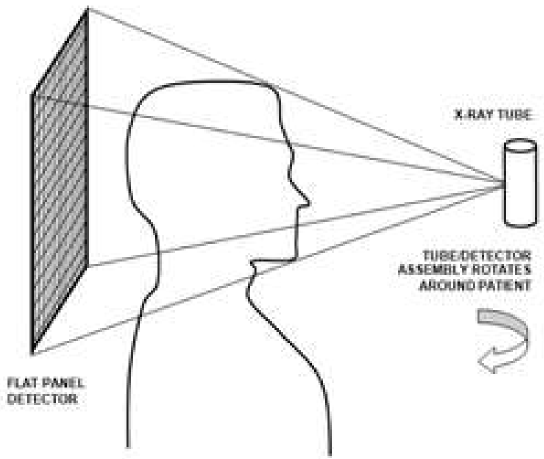
- Frequently Asked Questions
- For the Patient
- For the Dentist
- For the Imaging Centre
- Software
- Publications
- Lecture Slides
- DICOM Uploader
- SFTP Secure File Transfer Protocol
- Dental CT View
- Remote Help

Outline of Presentation

✔ **Introduction**
- **Principles of CBCT Imaging**
- **CBCT Image Acquisition and Processing**
- **Radiation Physics in relation to CBCT**
- **Dose and Risk**

Cone Beam Computed Tomography (CBCT)

Cone Beam CT Scanners:



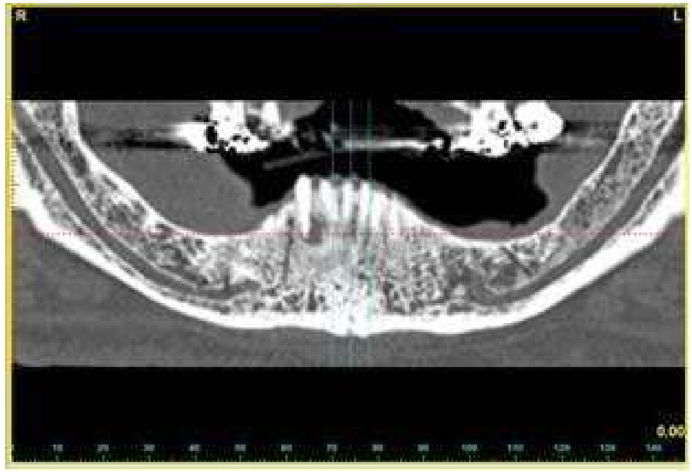
- **Cone beam geometry**
- **Rotate relatively slowly**
- **Modest radiation dose (20 to 200µSv)**
- **Cover a large volume with a single rotation**
- **Acquire data as 2-D projections which are reconstructed into a 3-D volume**

Medical CT versus Dental CBCT:

Medical CT:
- **Better contrast**
- **Less noise**

Dental CBCT:
- **Better resolution**
- **Lower dose**

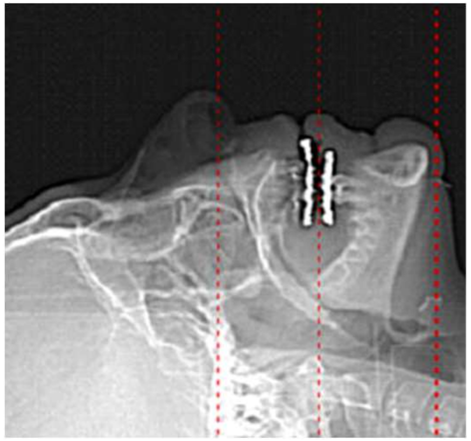
Image Quality



GE LightSpeed Medical CT

i-CAT CBCT

Why is the Dose Lower with CBCT?



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 medical CT "brain scan".

(Review Paper)

ELSEVIER SAUNDERS

THE DENTAL CLINICS OF NORTH AMERICA

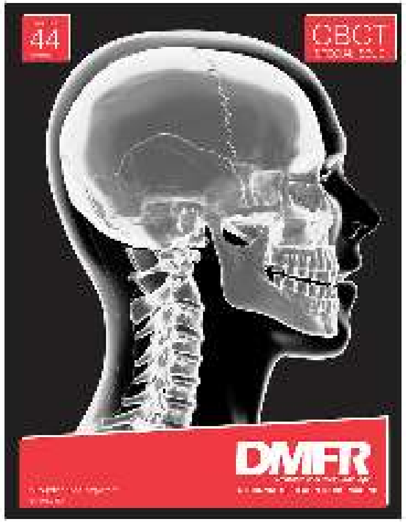
Dent Clin N Am 52 (2008) 707–730

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]

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

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



DentoMaxilloFacial Radiology

CBCT Special Issue

VOLUME 44, ISSUE 1, 2015

Dentomaxillofacial Radiology (2015) 44, 20140224

birpublications.org/dmfr

CBCT SPECIAL ISSUE: REVIEW ARTICLE

Technical aspects of dental CBCT: state of the art

[1]R Pauwels, [2]K Araki, [3]J H Siewerdsen and [4]S S Thongvigitmanee

[1]*Department of Radiology, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand;* [2]*Department of Oral Diagnostic Sciences, Showa University School of Dentistry, Tokyo, Japan;* [3]*Department of Biomedical Engineering The I-STAR Laboratory, Johns Hopkins University, Baltimore, MD, USA;* [4]*X-Ray CT and Medical Imaging Laboratory, Biomedical Electronics and Systems Development Unit, National Electronics and Computer Technology Center, National Science and Technology Development Agency, Pathumthani, Thailand*

Physica Medica 88 (2021) 193–217

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journal homepage: www.elsevier.com/locate/ejmp

ELSEVIER

Review paper

Dental cone beam CT: An updated review

Touko Kaasalainen[a,*], Marja Ekholm[b,c], Teemu Siiskonen[d], Mika Kortesniemi[a]

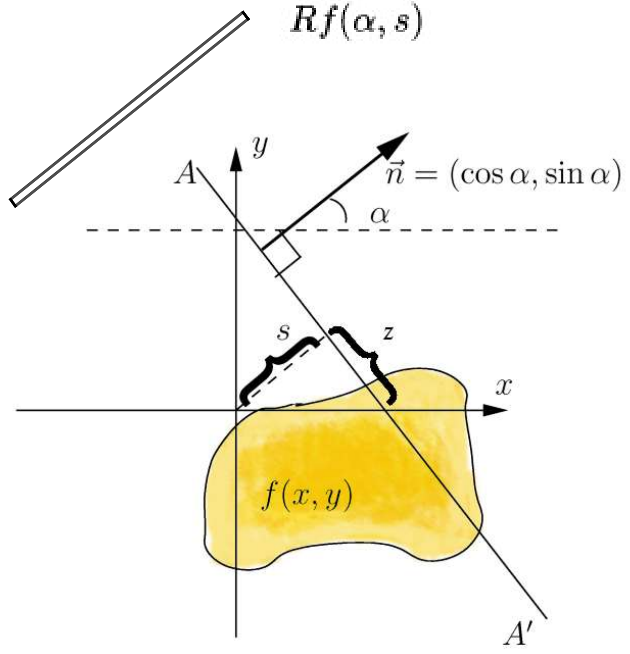
[a] HUS Diagnostic Center, Radiology, Helsinki University and Helsinki University Hospital, P.O. Box 340, Haartmaninkatu 4, 00290 Helsinki, Finland

[b] Institute of Dentistry, University of Turku, Lemminkäisenkatu 2, 20520 Turku, Finland

[c] South West Finland Imaging Center, Turku University Hospital, Lemminkäisenkatu 2, 20520 Turku, Finland

[d] Radiation Practices Regulation, Radiation and Nuclear Safety Authority - STUK, P.O. Box 14, FI-00881 Helsinki, Finland

How CT works… Radon 1917



Radon Transform

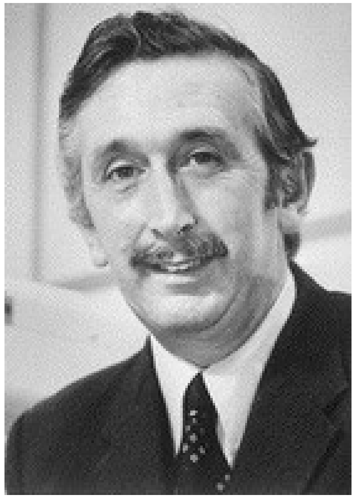
$$Rf(\alpha, s) = \int_{-\infty}^{\infty} f\big((z\sin\alpha + s\cos\alpha), (-z\cos\alpha + s\sin\alpha)\big)\, dz$$

Inverse Transform

$$f(\mathbf{x}) = \int_0^{\pi} (\mathcal{R}f(\cdot,\theta) * h)(\langle \mathbf{x}, \mathbf{n}_\theta \rangle)\, d\theta$$

Radon, Johan (1917) "On the determination of functions from their integral values along certain manifolds" *(in German)*, *Reports on the Proceedings of the Royal Saxonian Academy of Sciences at Leipzig* **69**, 262-277.

How CT works… *Hounsfield 1973*

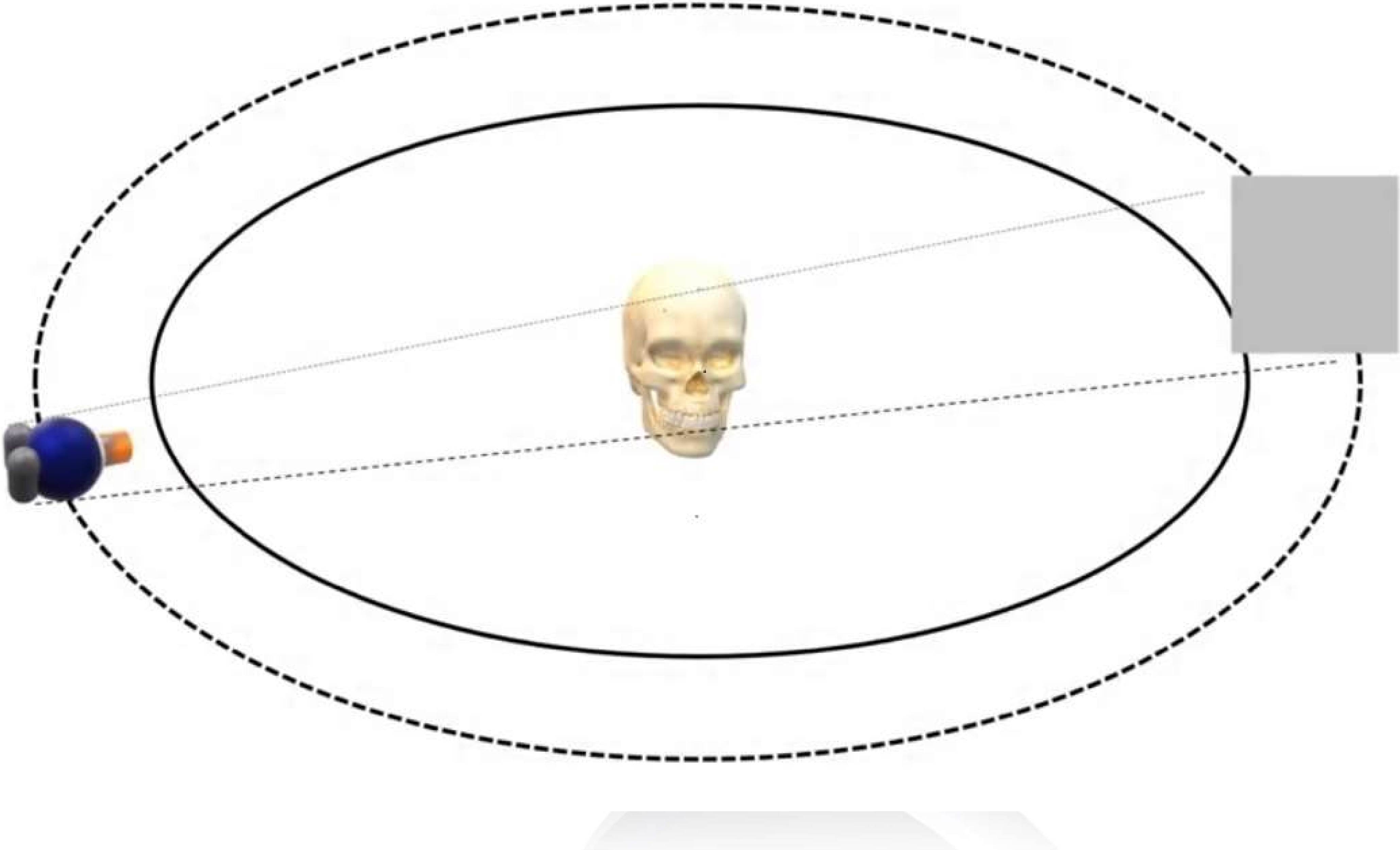


Godfrey Hounsfield

Allan Cormack

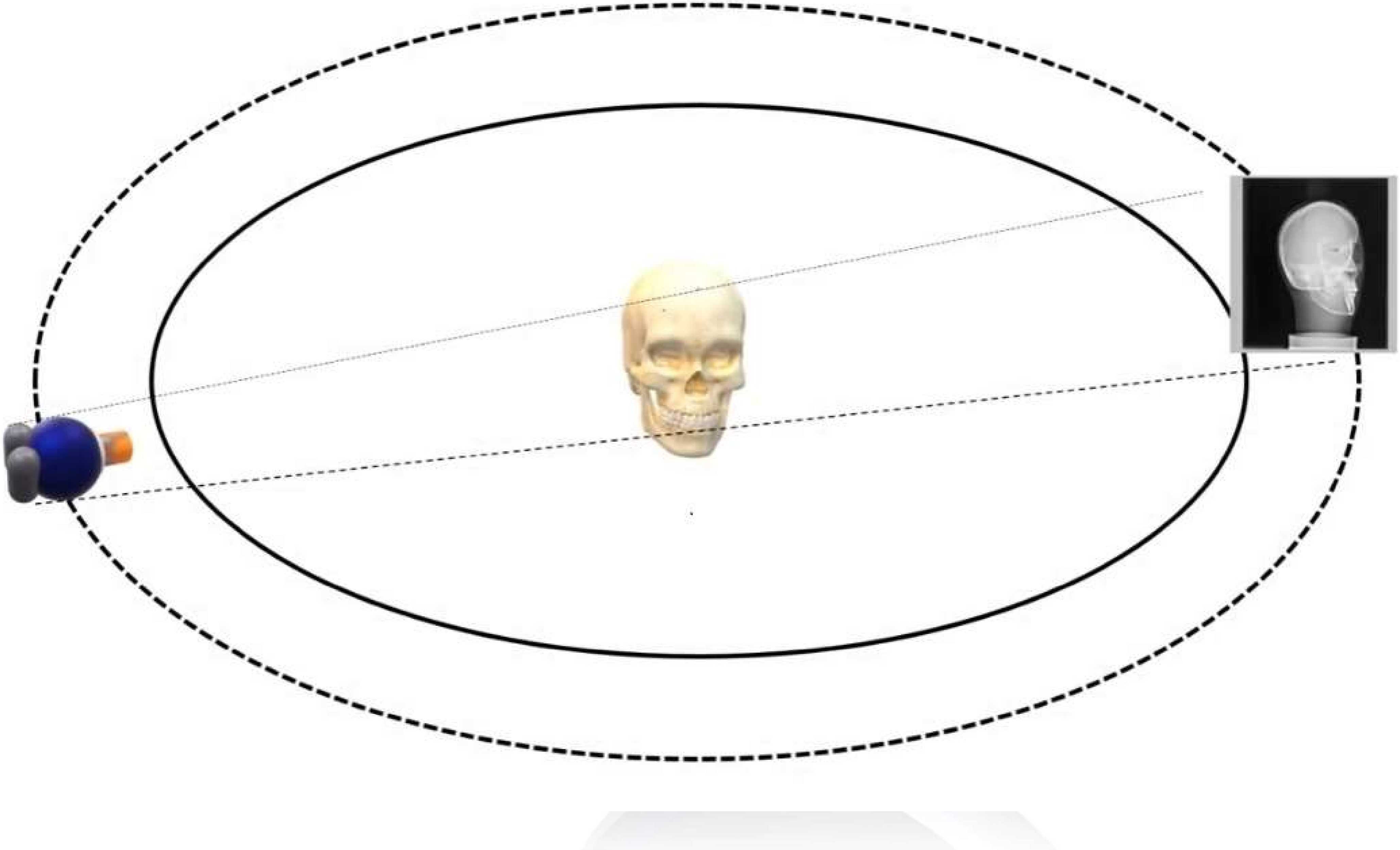
Nobel prize in Medicine, 1979

CBCT



cone-beam CT (CBCT)
patient sitting or standing

Acknowledgements to
Maxwell Dziku



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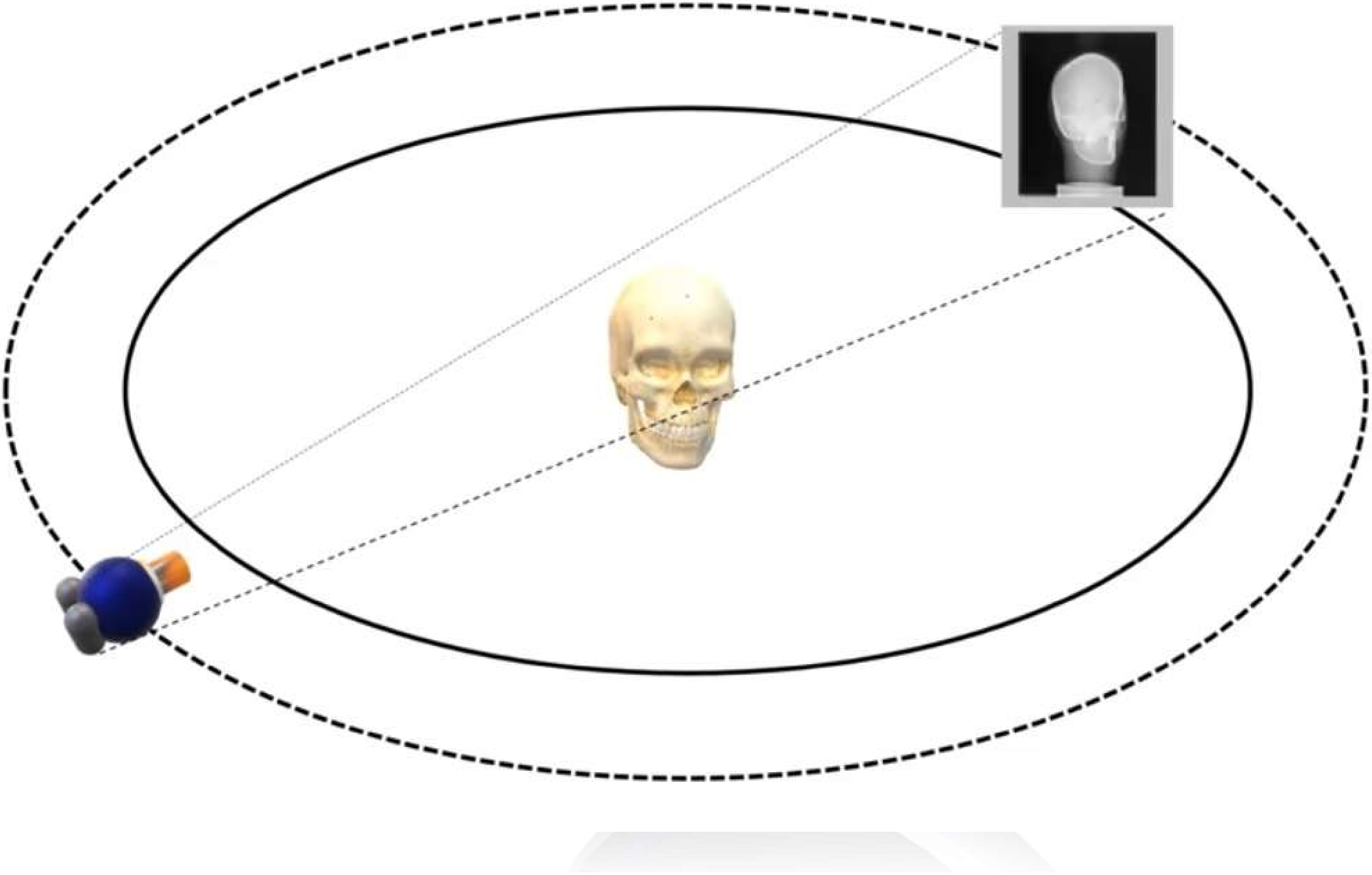

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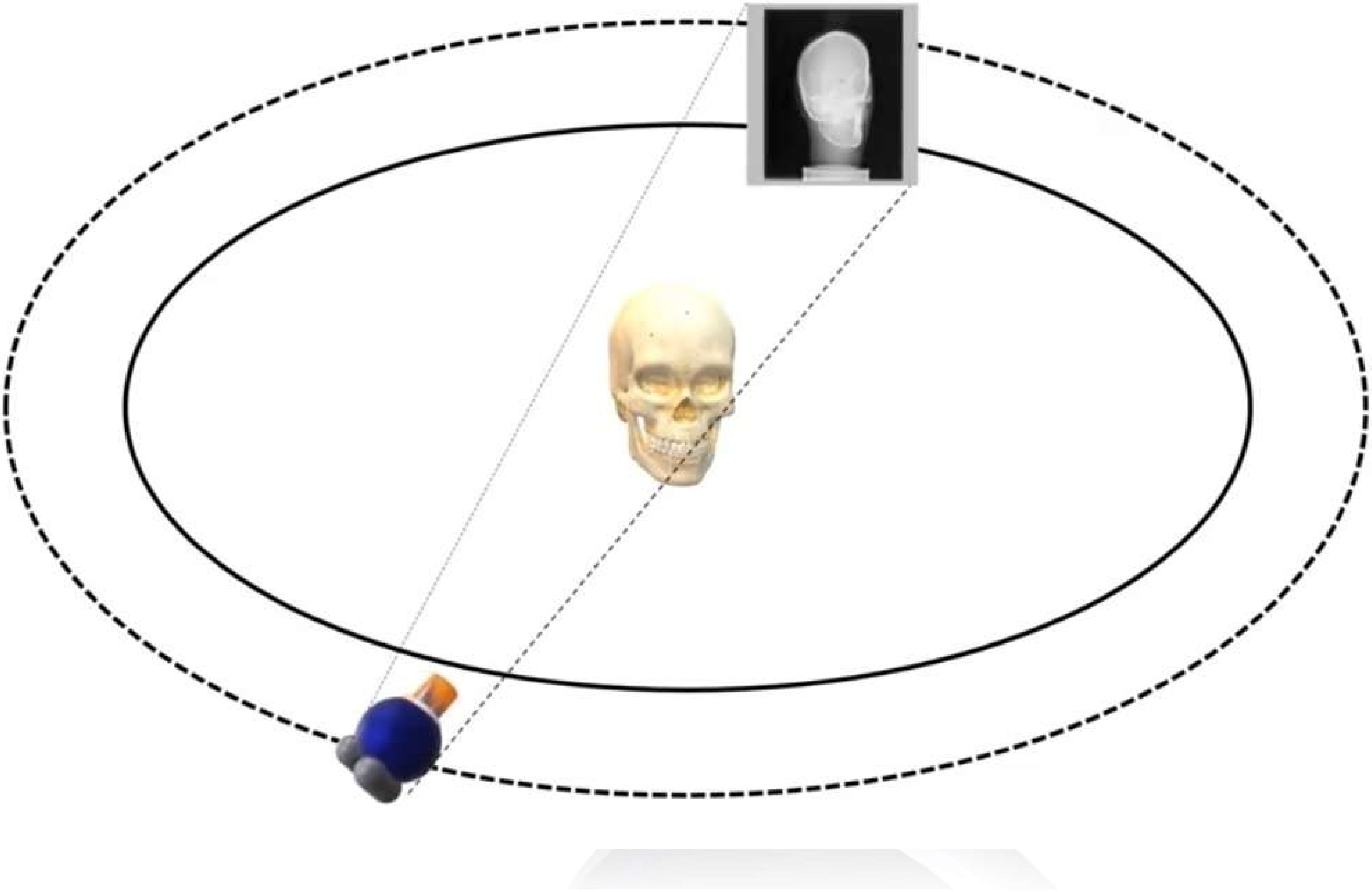

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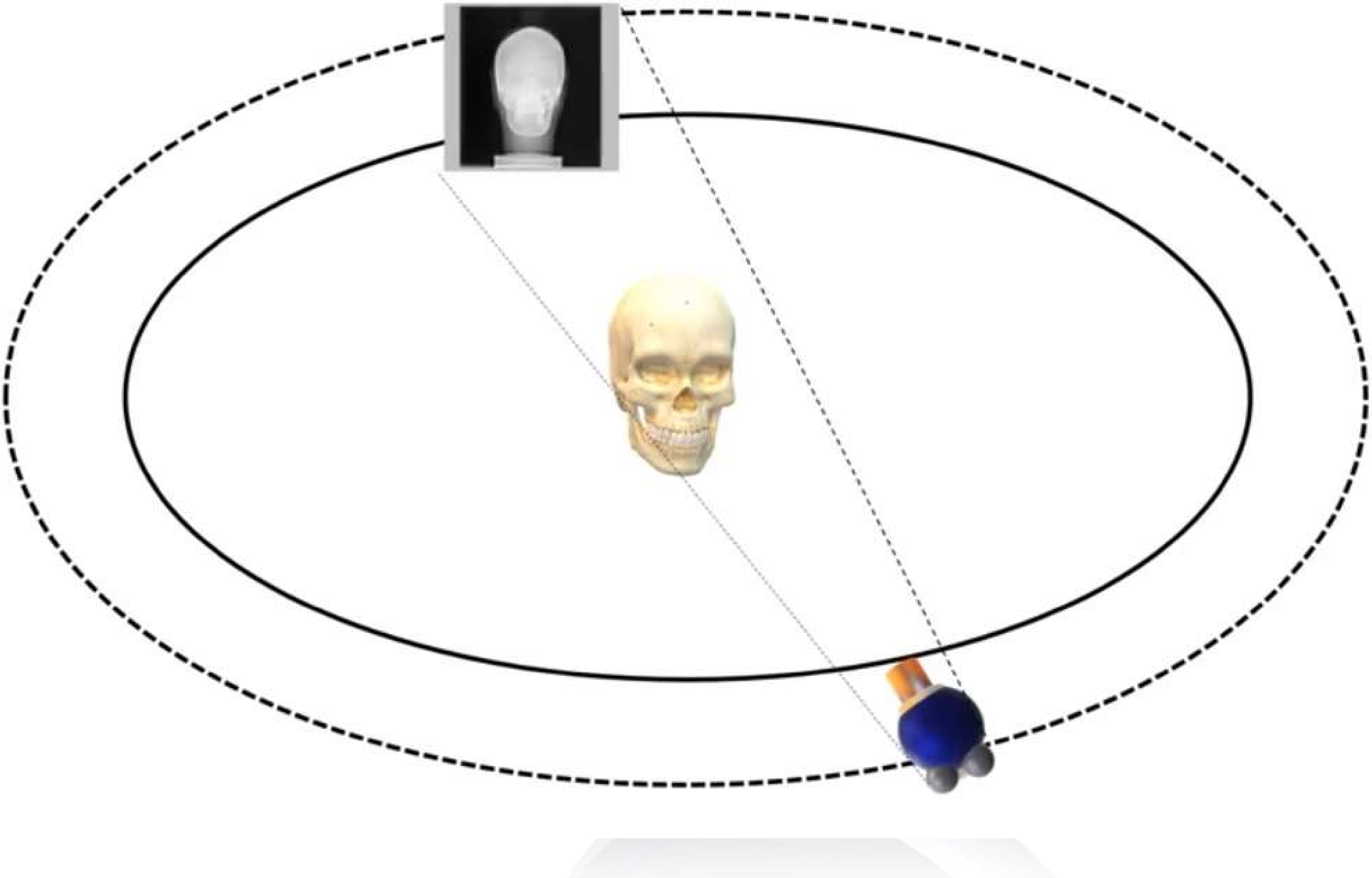

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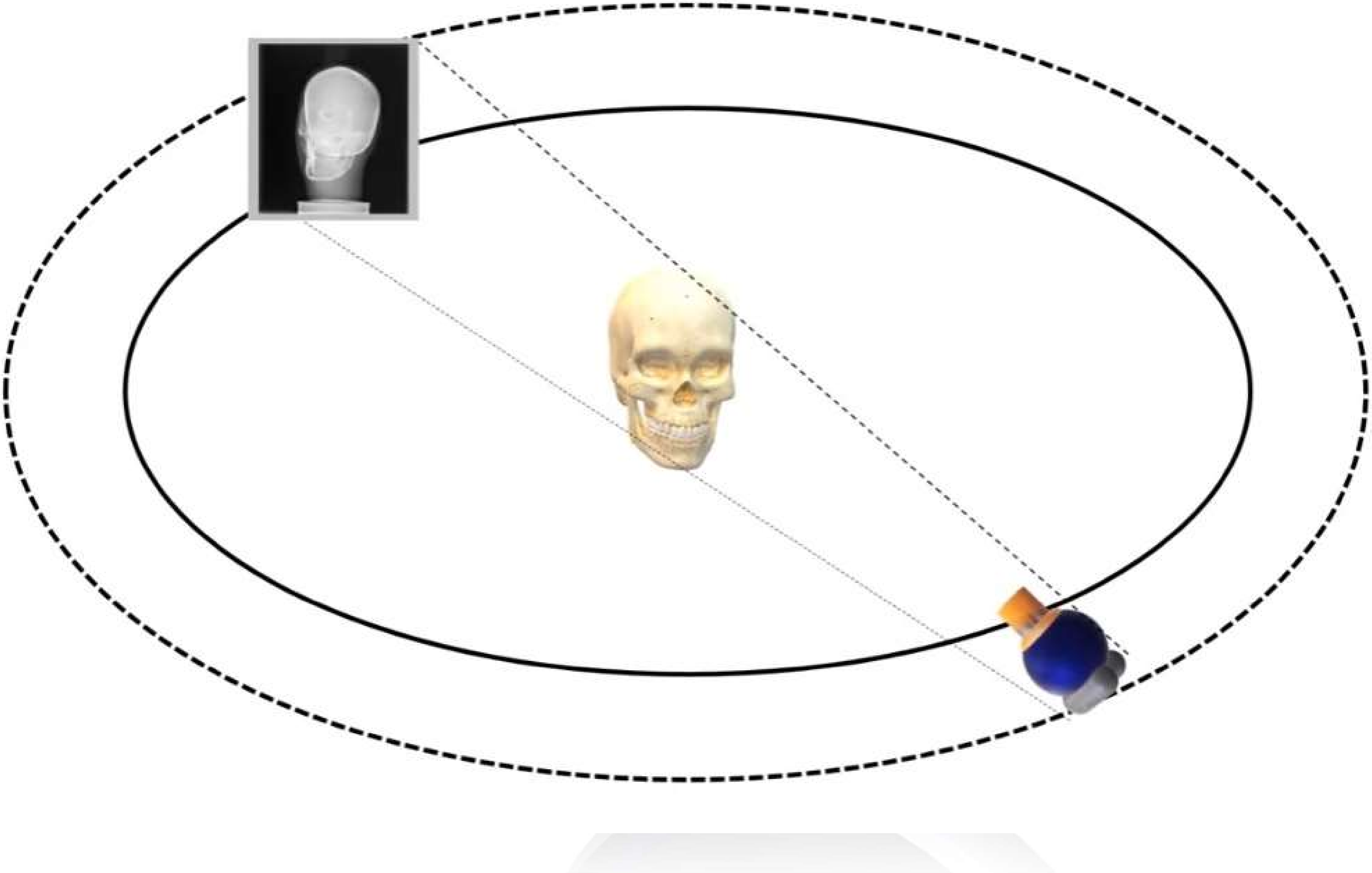

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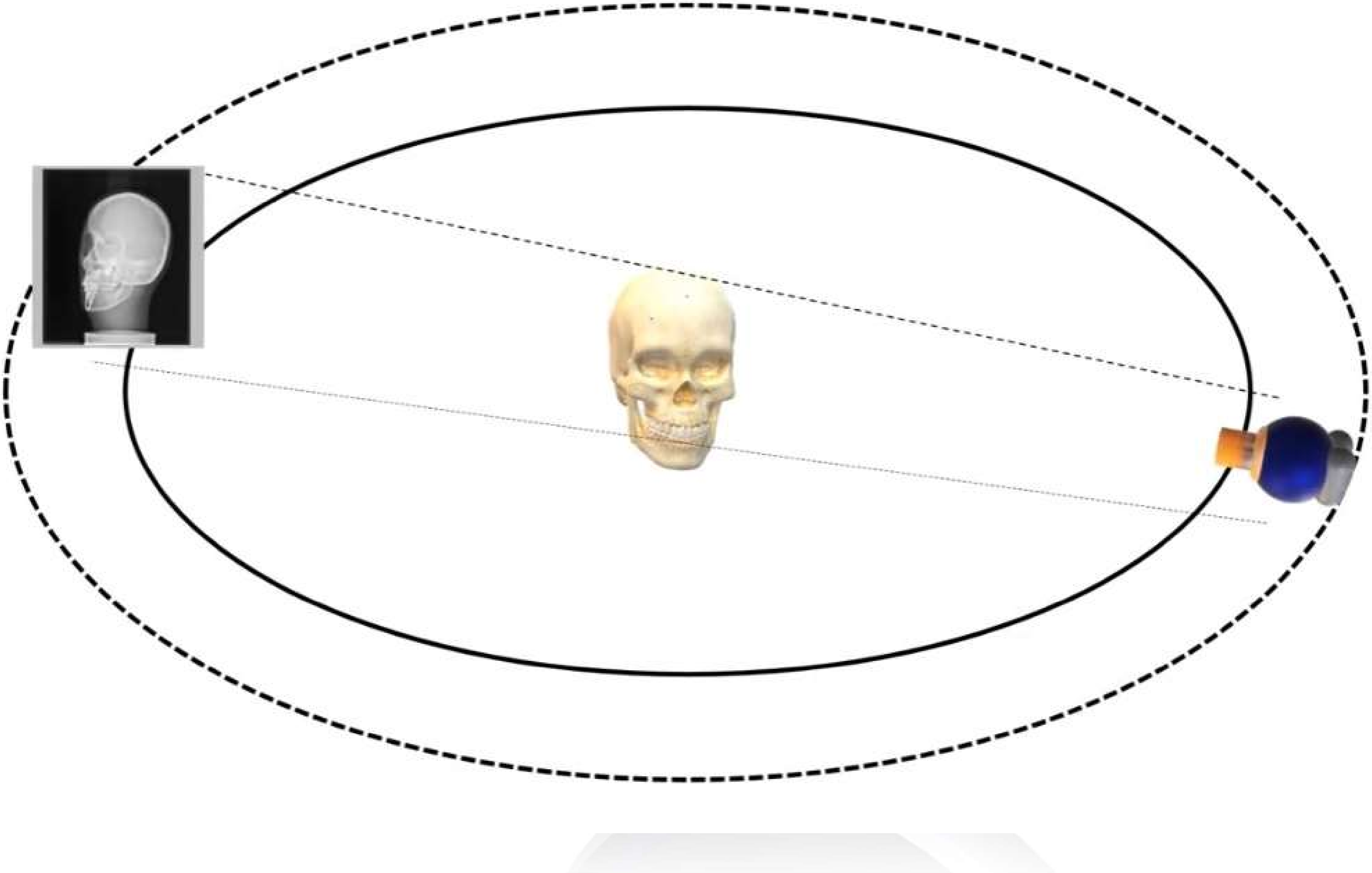
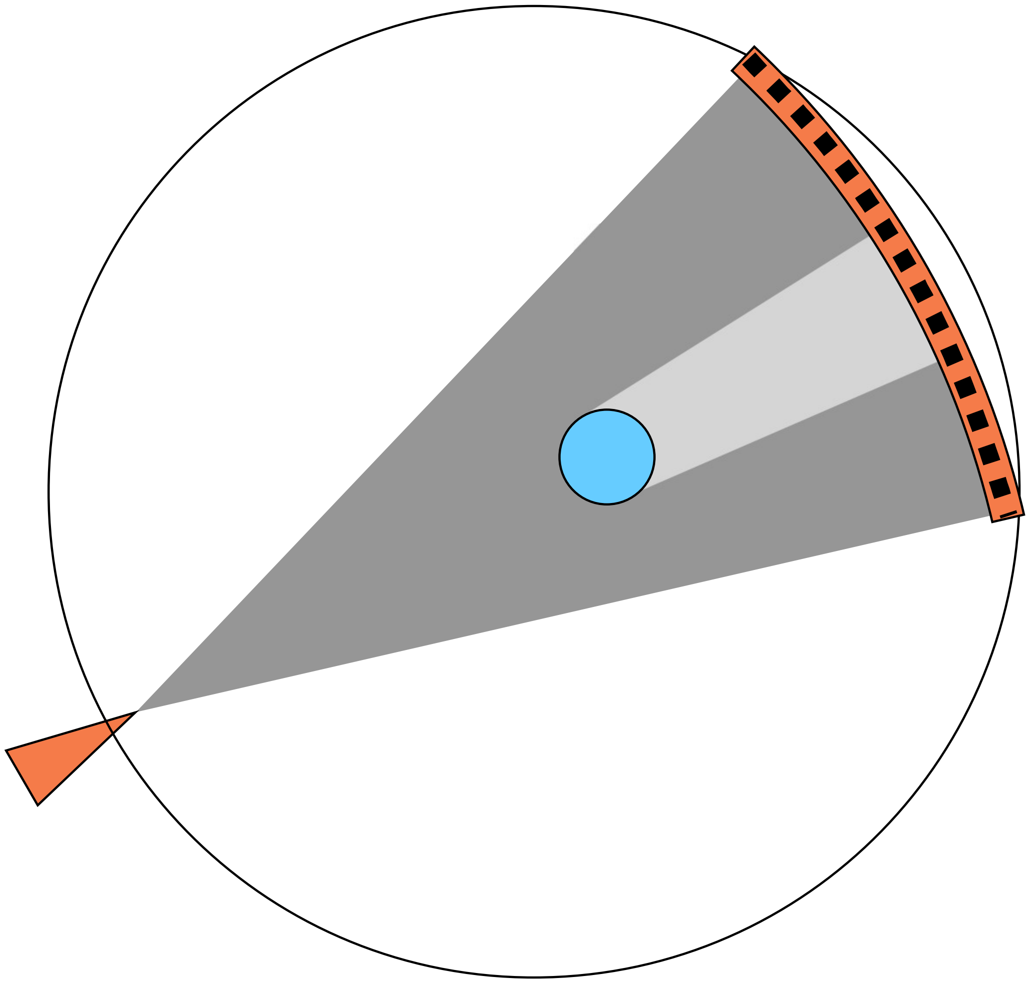


cone-beam CT (CBCT)
patient sitting or standing

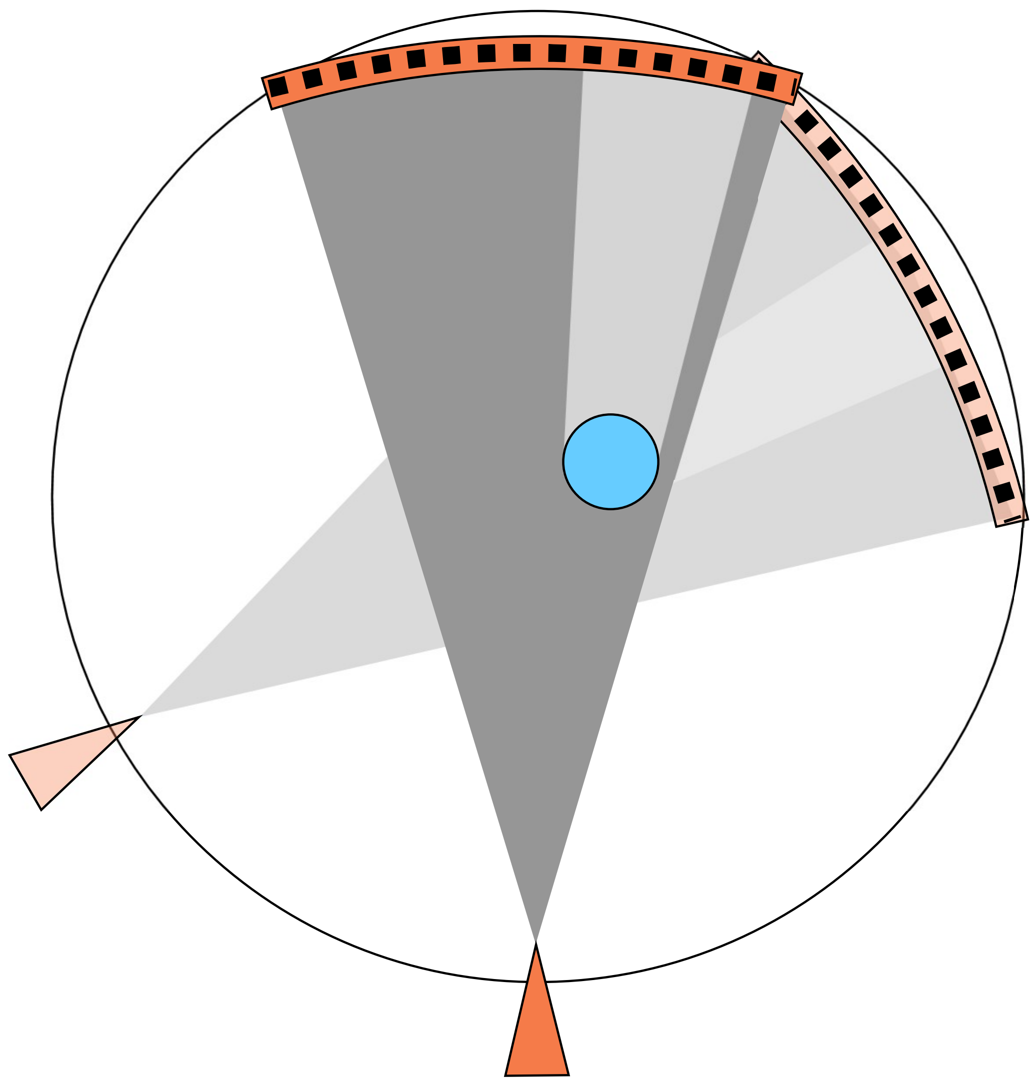
Acknowledgements to
Maxwell Dziku

acquisition



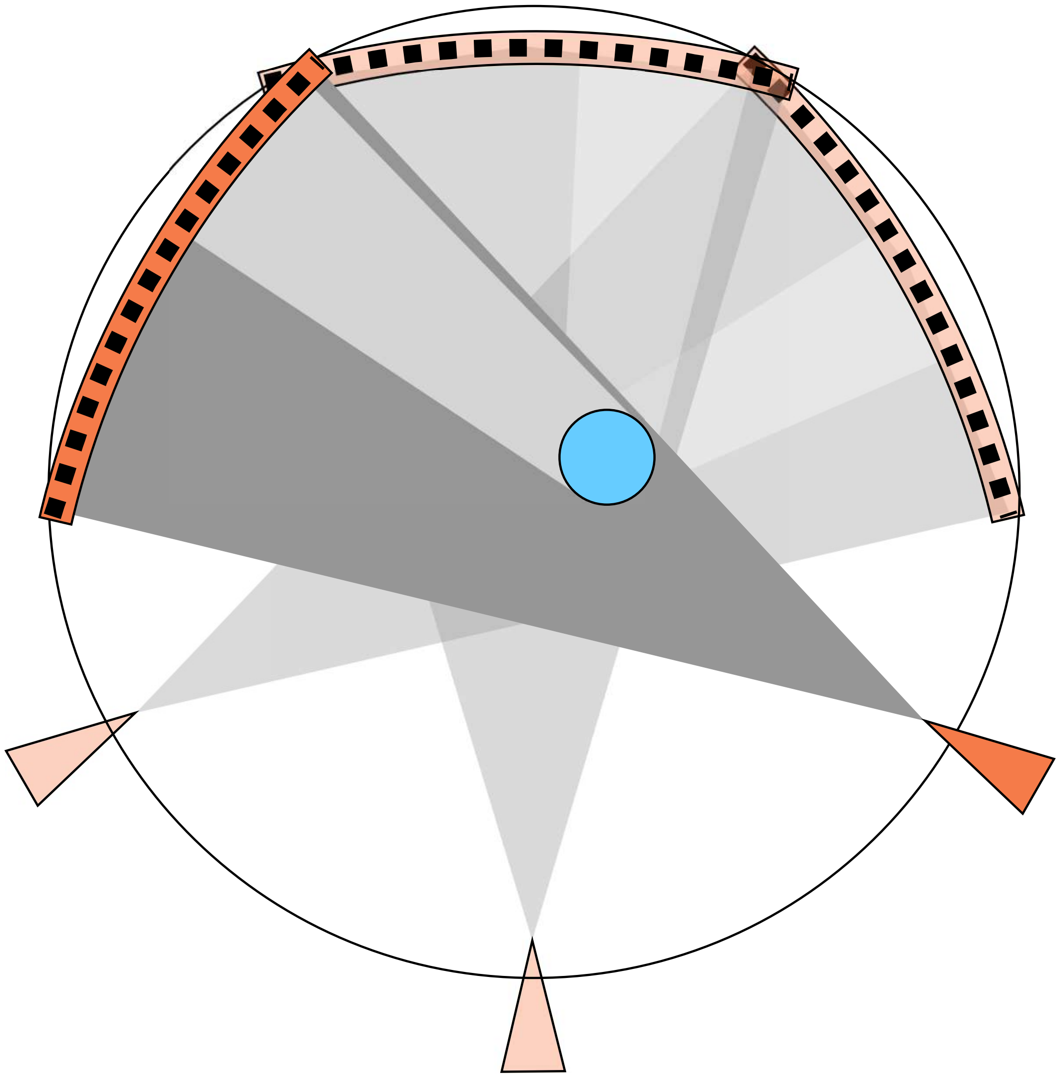
Animation courtesy of
Demetrios J. Halazonetis

acquisition



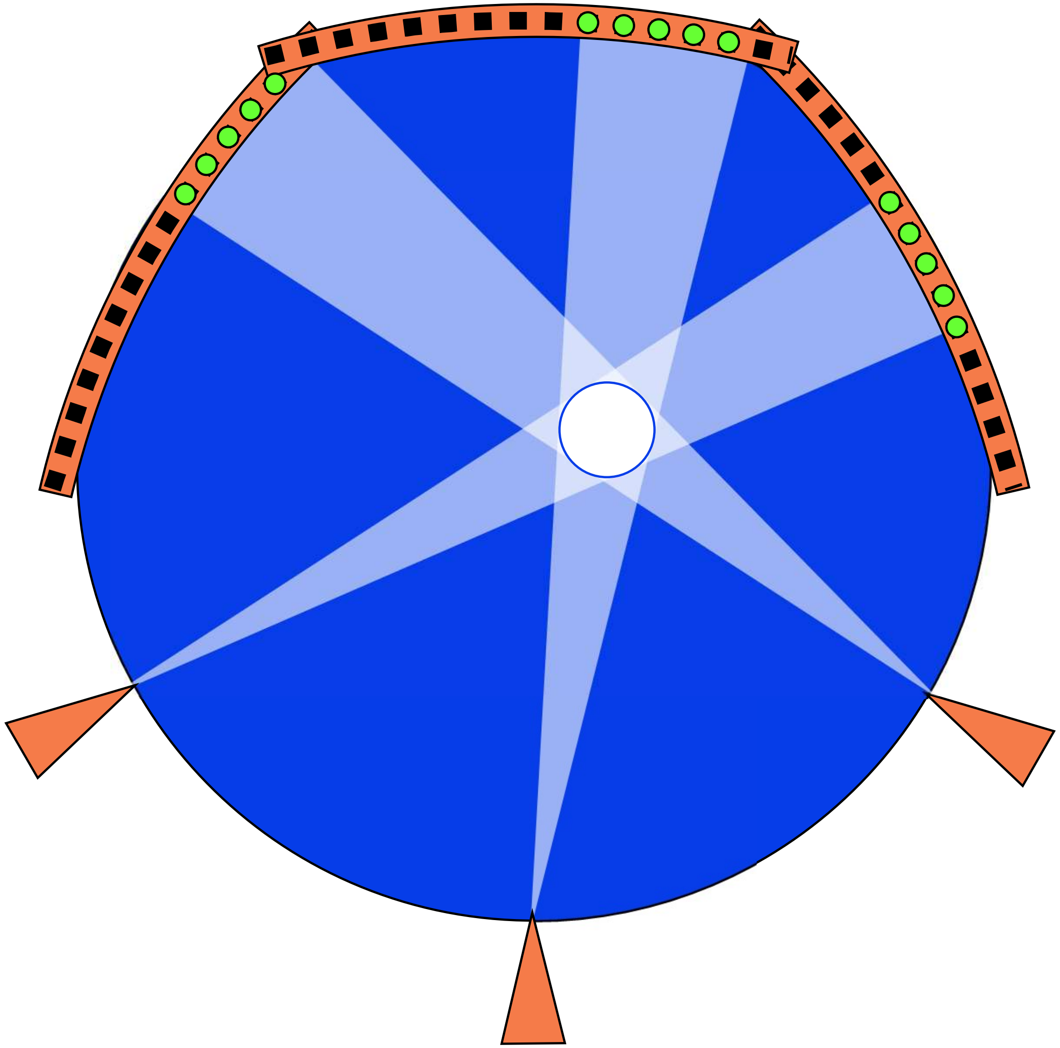
Animation courtesy of Demetrios J. Halazonetis

acquisition



Animation courtesy of
Demetrios J. Halazonetis

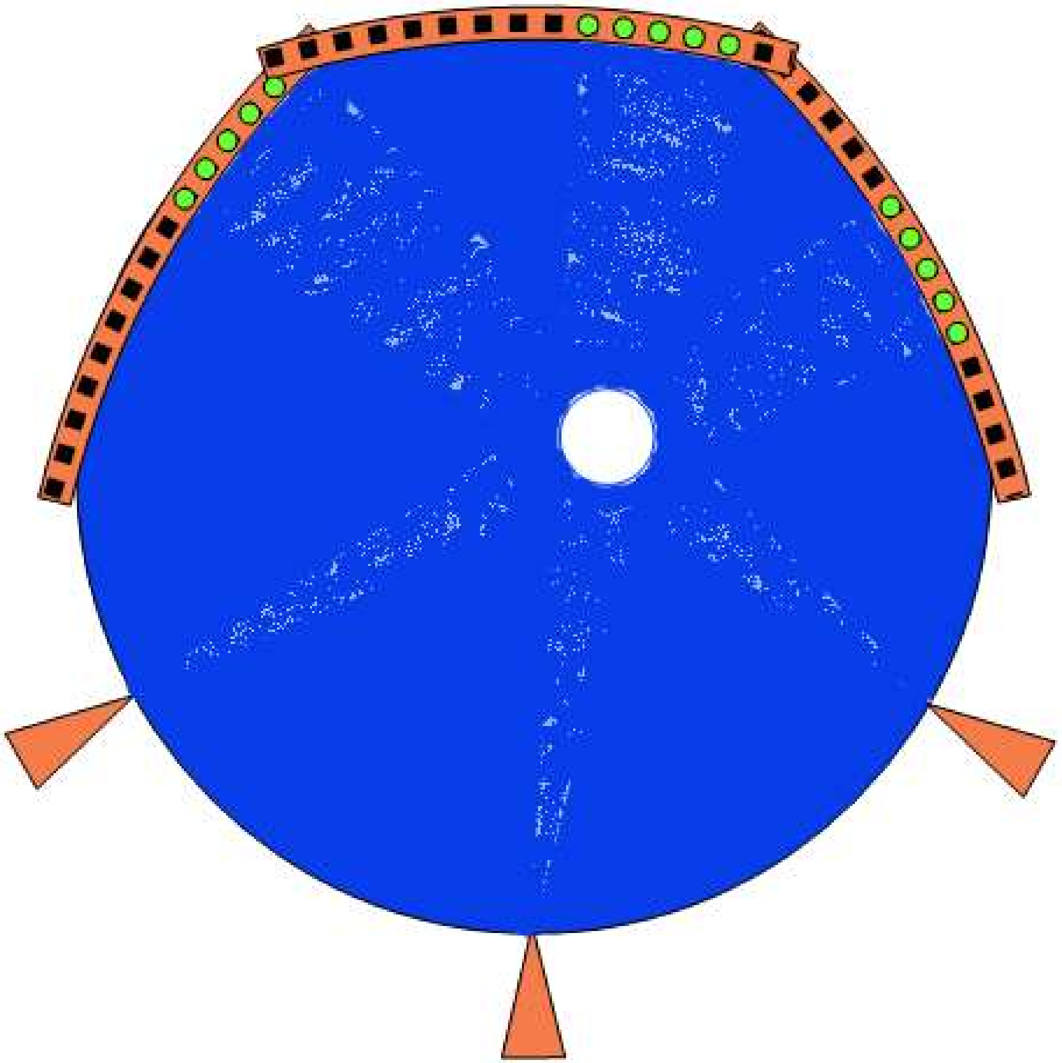
Reconstruction – filtered backprojection



Back Projection

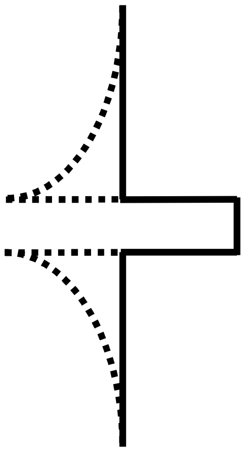
Animation courtesy of Demetrios J. Halazonetis

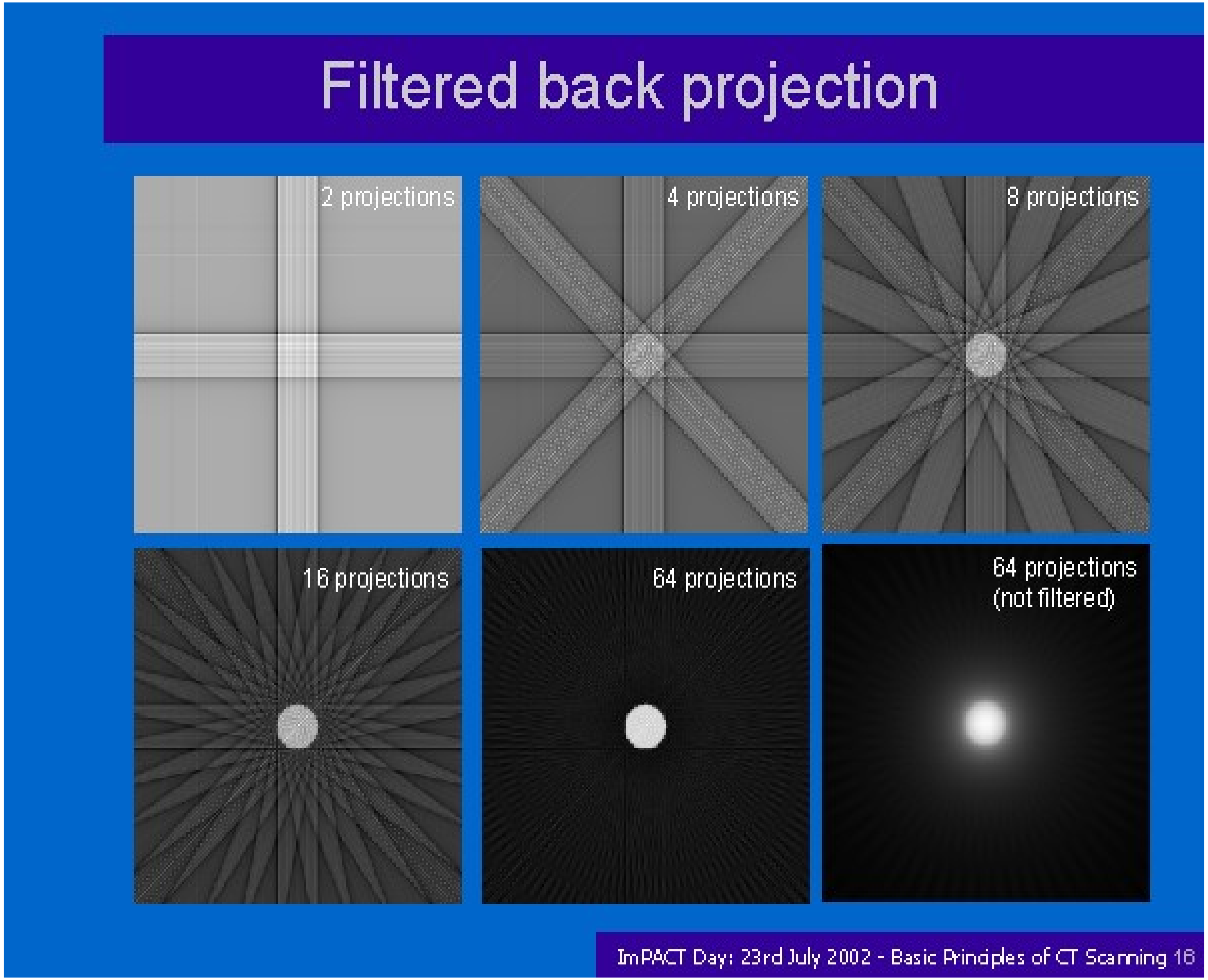
Reconstruction – filtered backprojection



Filtered Back Projection

Animation courtesy of Demetrios J. Halazonetis

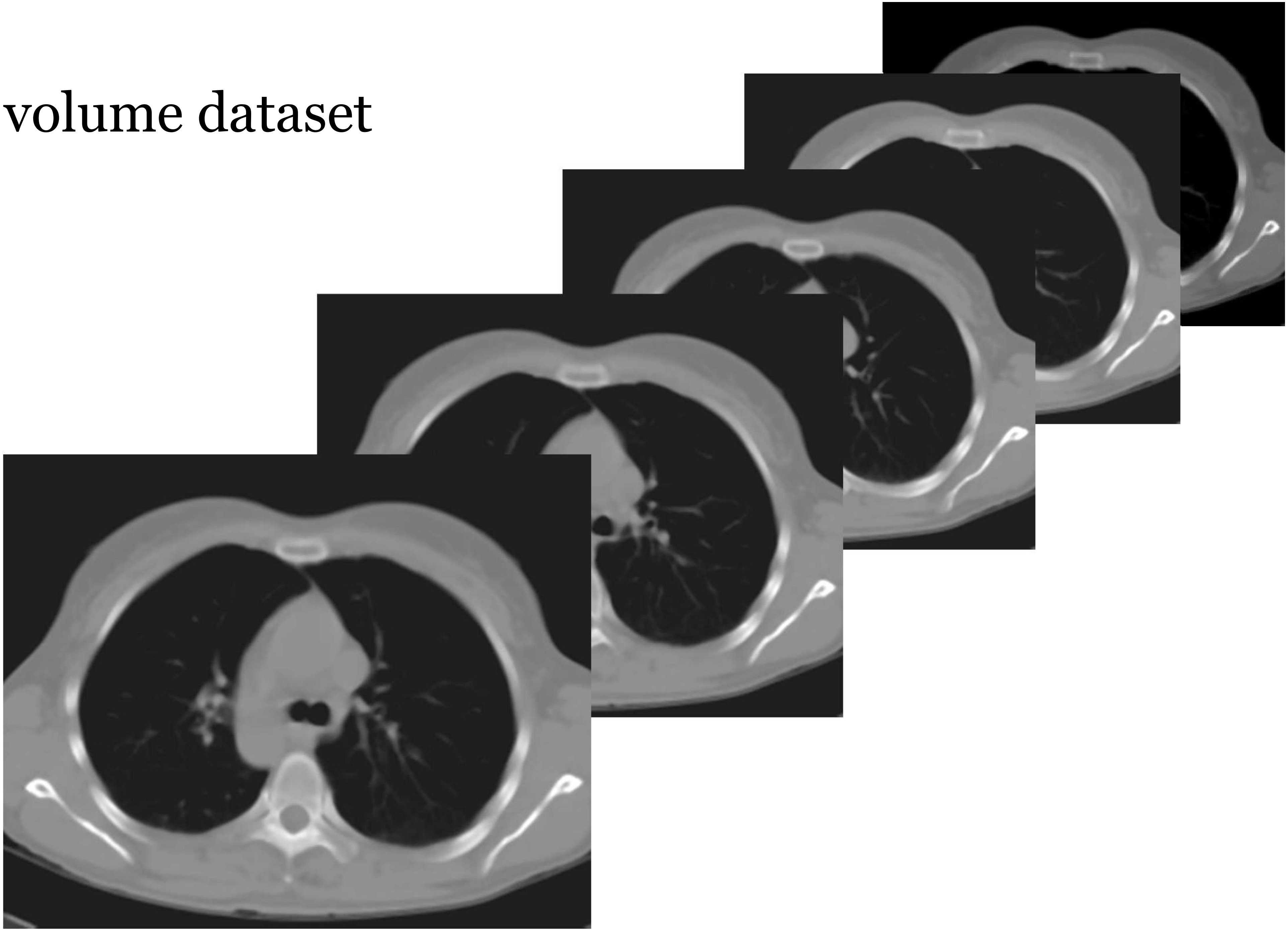




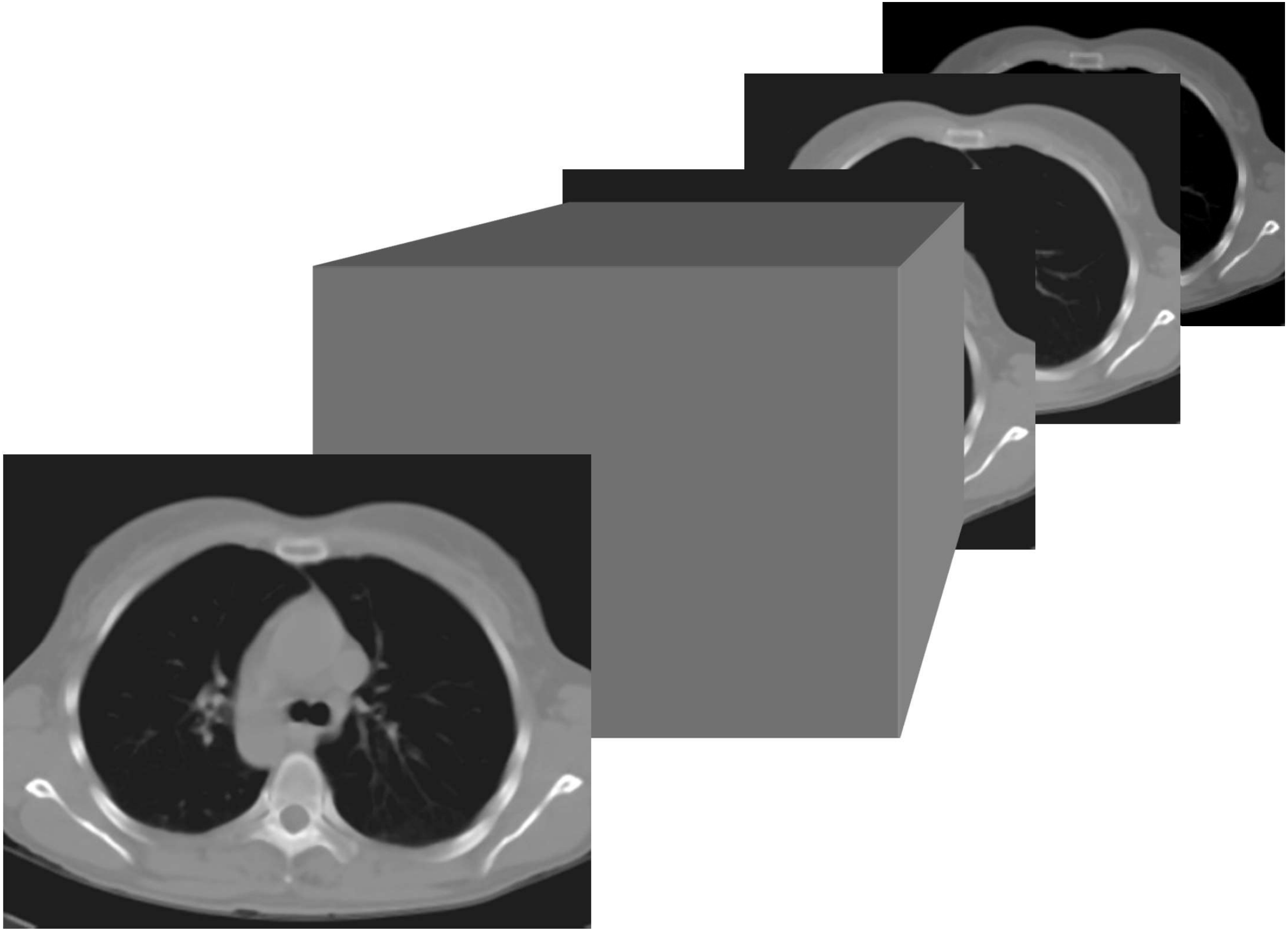
Also known as: "Convolution & Back Projection"

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

volume dataset

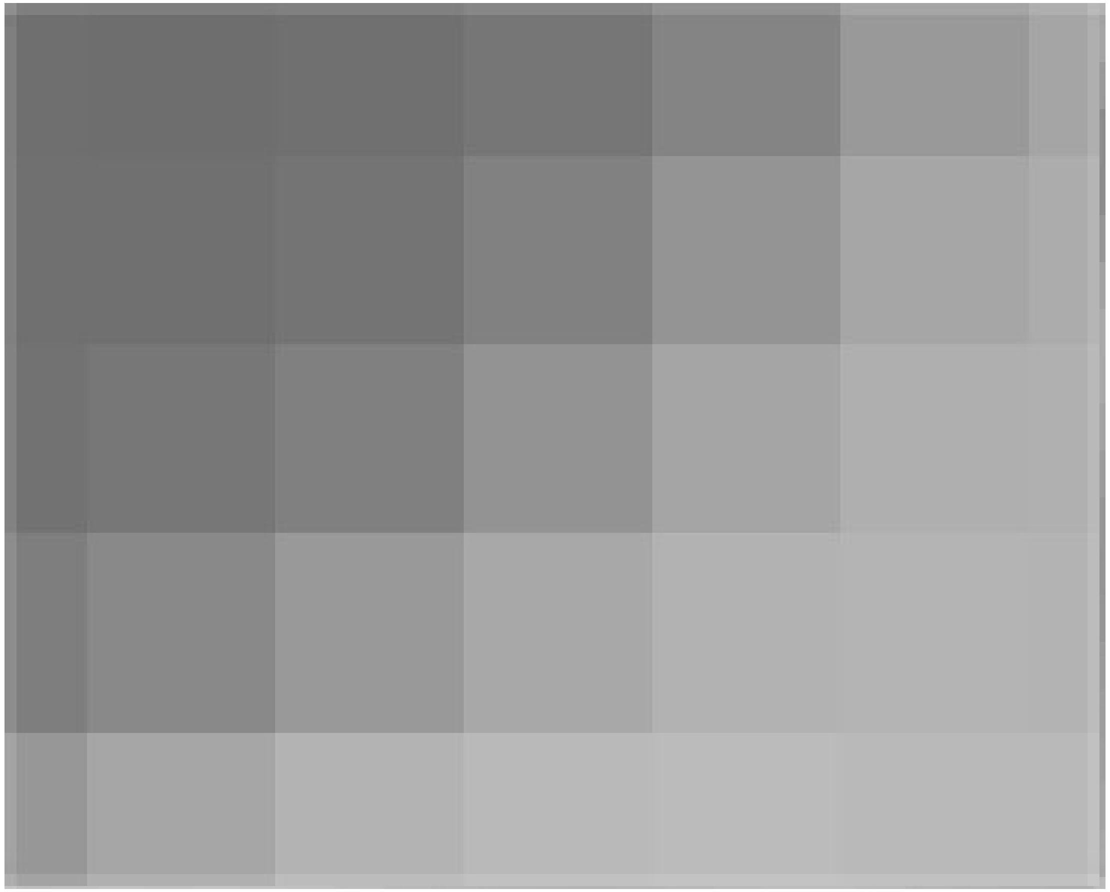


Animation courtesy of Demetrios J. Halazonetis

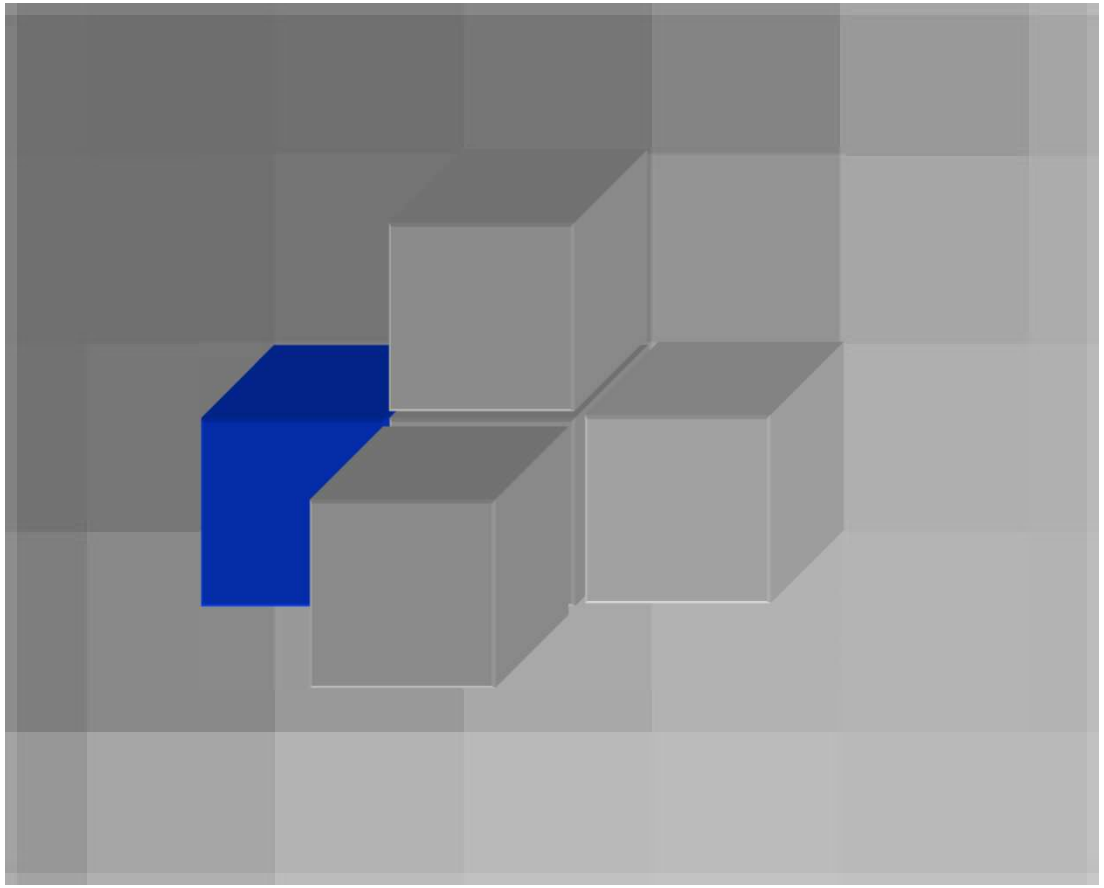


Animation courtesy of
Demetrios J. Halazonetis

Pixels (**Pic**ture **el**ements)

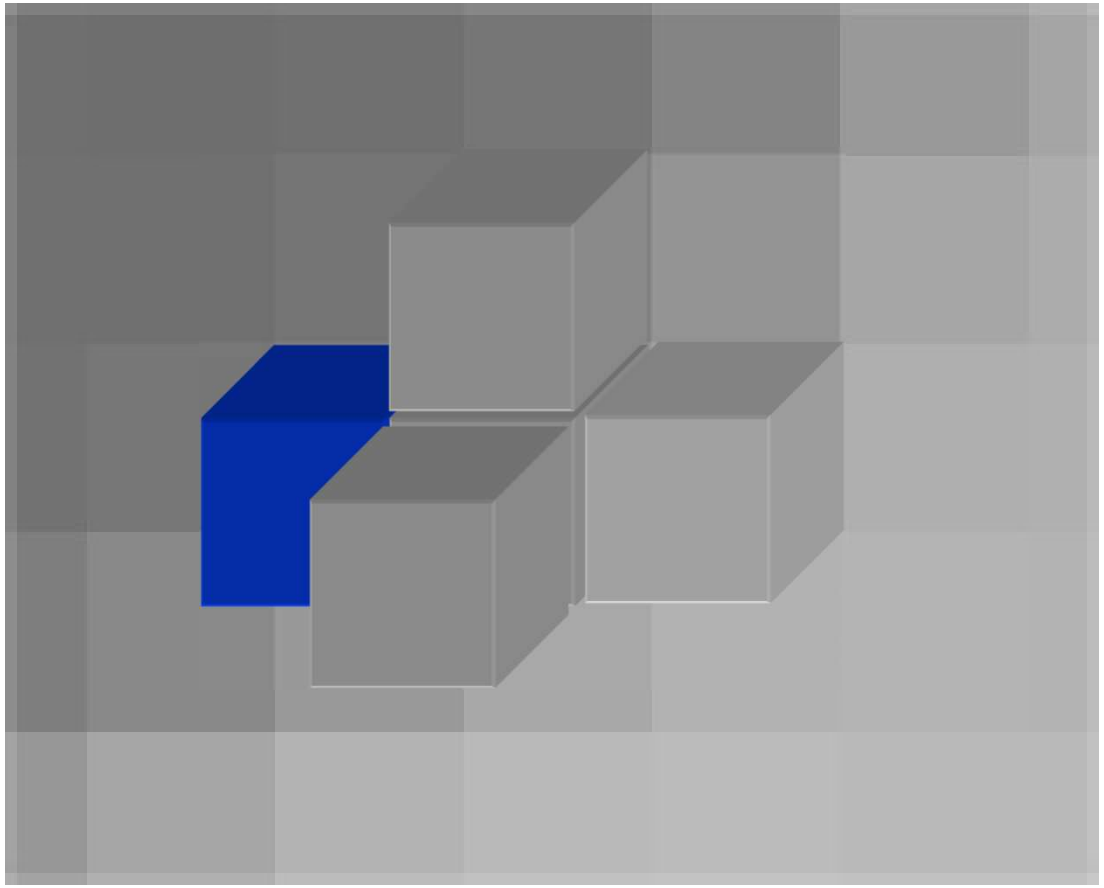


Animation courtesy of Demetrios J. Halazonetis



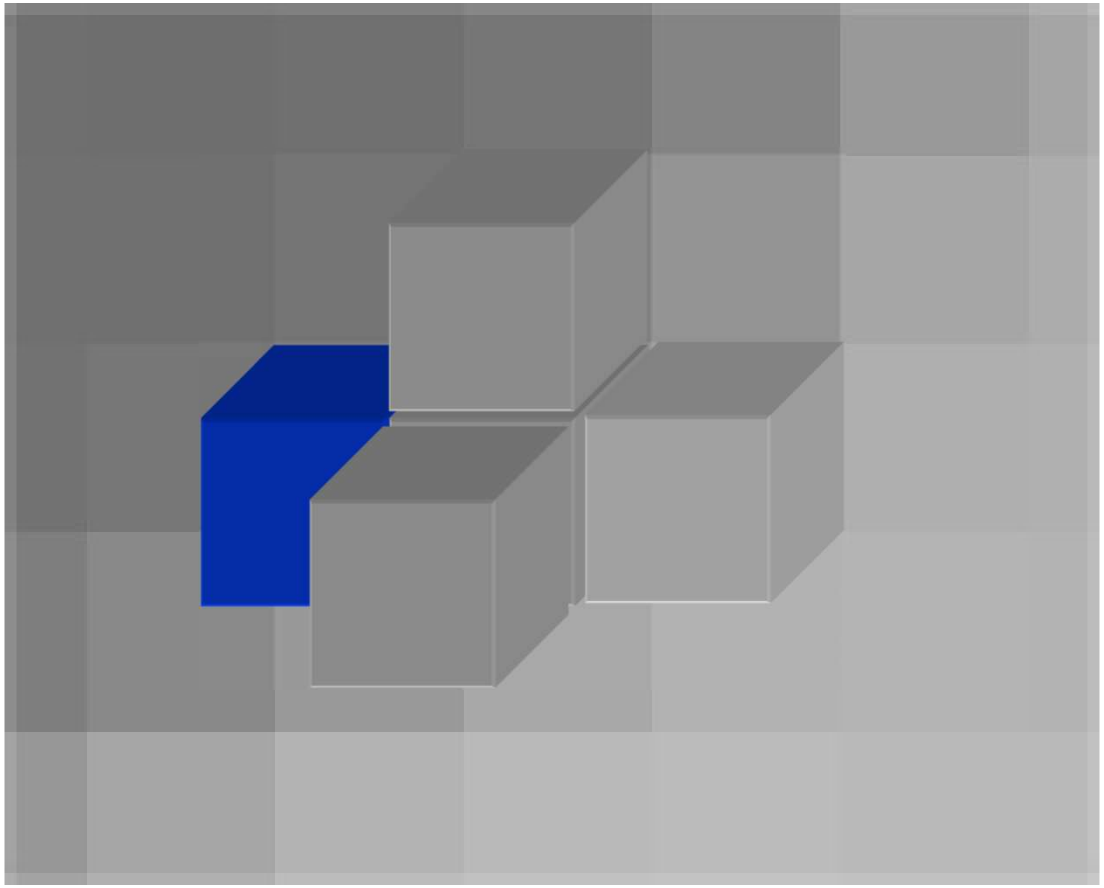
Animation courtesy of
Demetrios J. Halazonetis

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



Animation courtesy of
Demetrios J. Halazonetis

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



density:
0 - 4095

512 x 512 x 400 slices ≈ 100 million voxels (200 Mb)

Animation courtesy of Demetrios J. Halazonetis

YouTube Videos

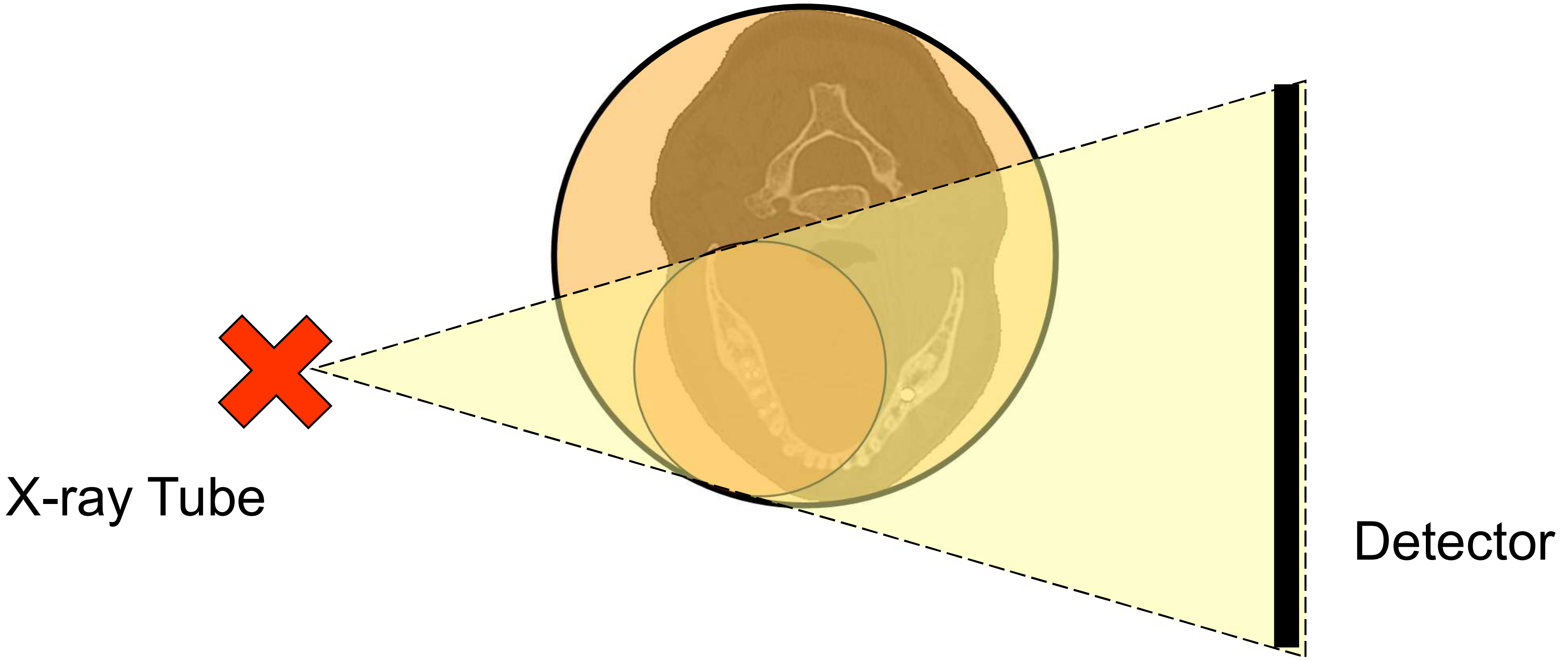
[Filtered back-projection reconstruction of head slice - Samuli Siltanen]

[NewTom VGi evo]

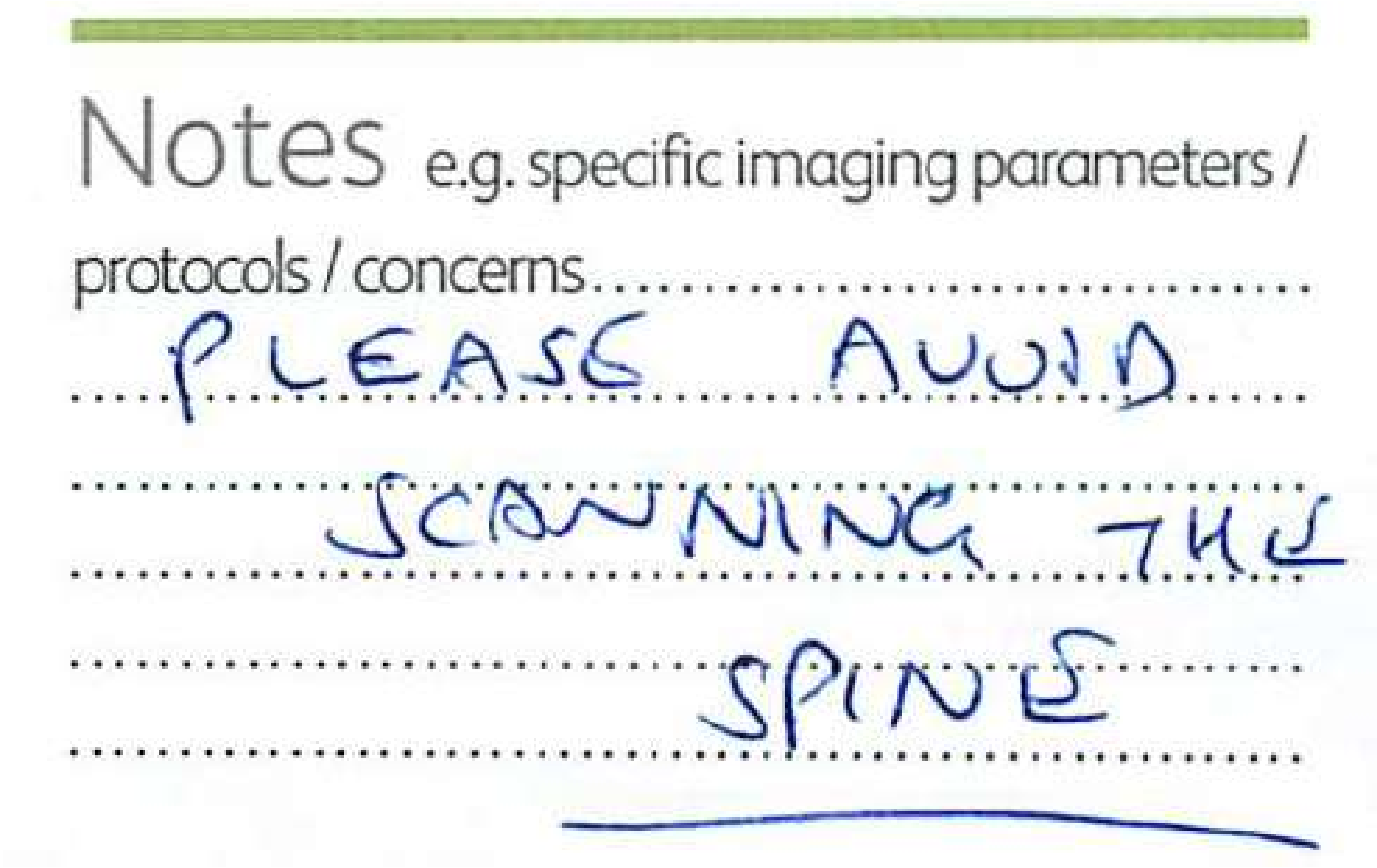
[CBCT scans explained - Atlanta Endodontics]

[CBCT animation video - Maxwell Dziku]

Small Field Of View CBCT (sectional scans)



The parts you can't see receive a low dose (but it is not zero)



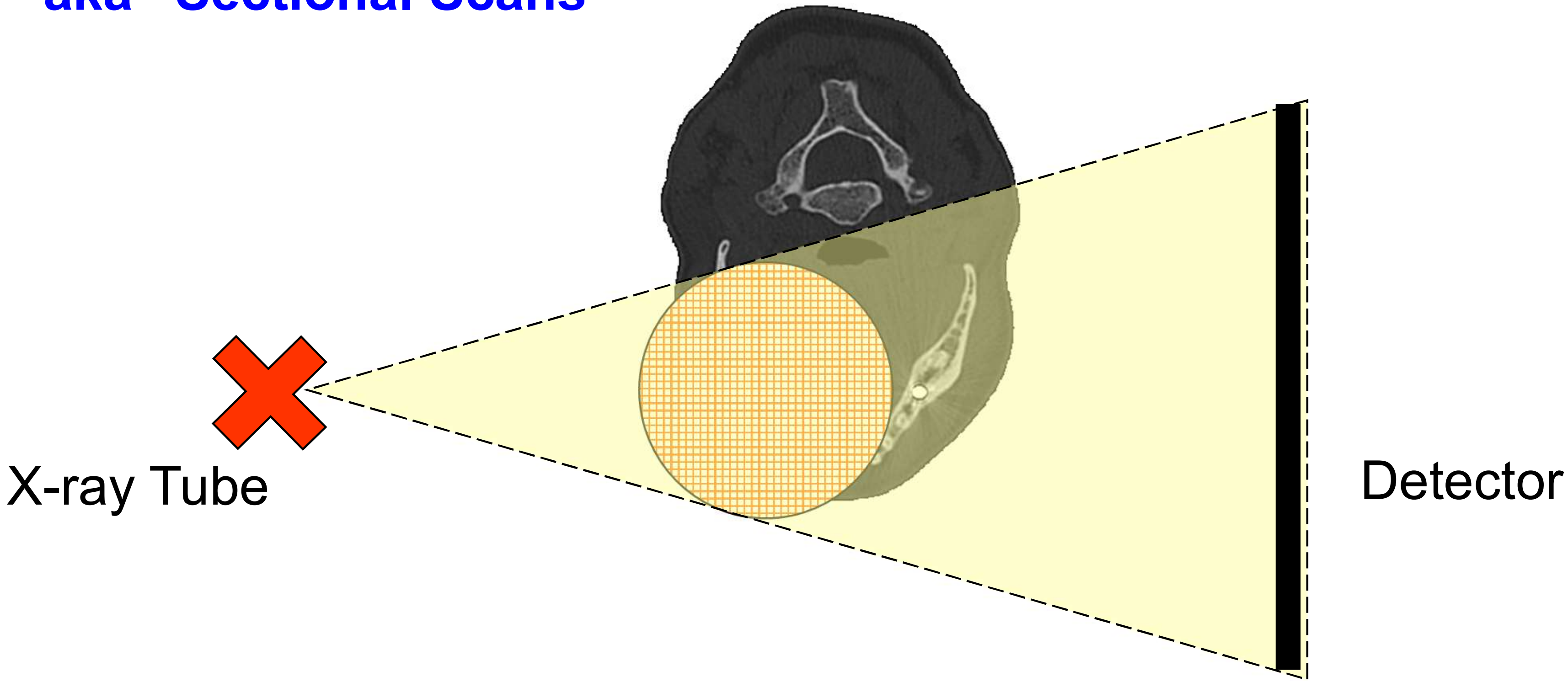
Notes e.g. specific imaging parameters / protocols / concerns

PLEASE AVOID SCANNING THE SPINE

“Sorry mate – no can do!”

Advantages of Small Field Of View CBCT

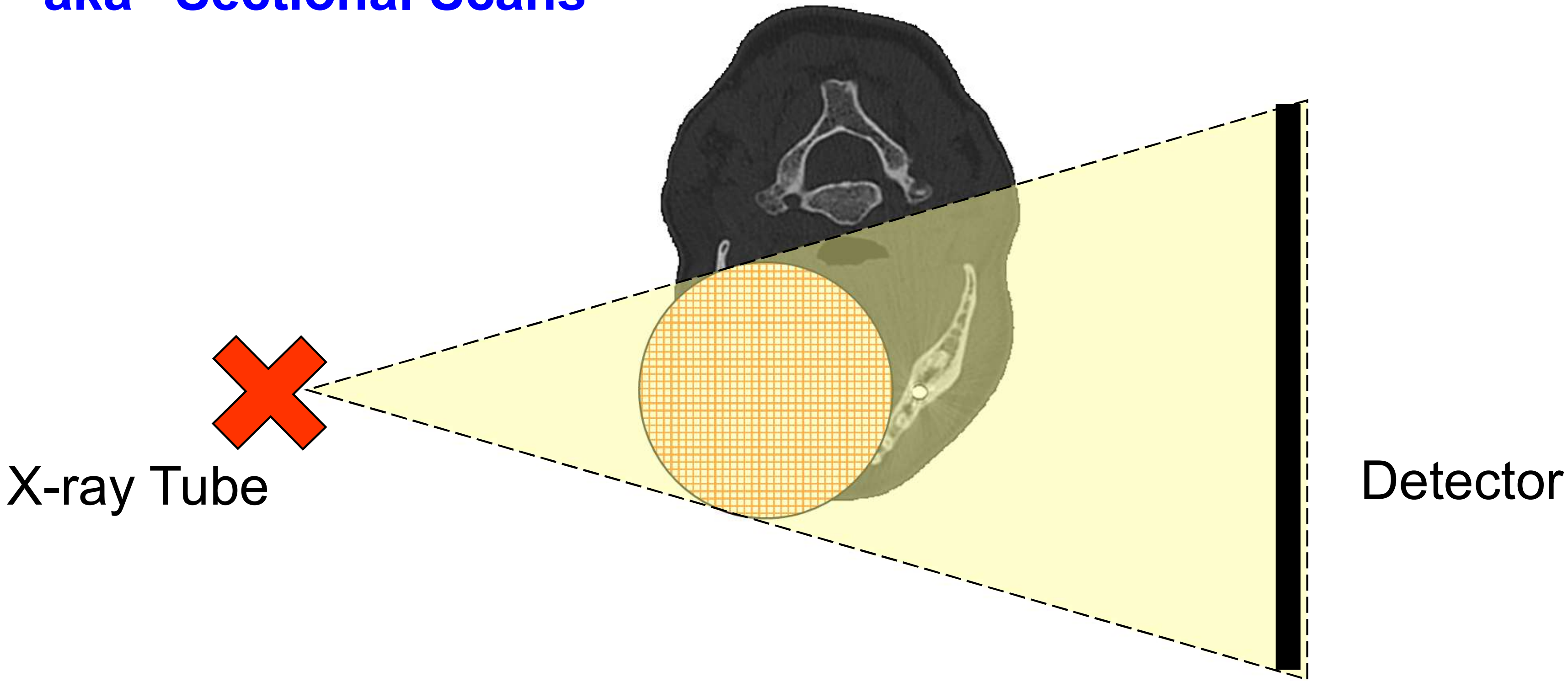
aka "Sectional Scans"



- **Lower dose**
- **Less data to Report on**
- **Smaller detectors means lower cost**
- **Smaller voxels for the same amount of data storage**

Disadvantages of Small Field Of View CBCT

aka "Sectional Scans"



- CBCT measures the density within the Field Of View only
- Material outside the Field Of View has an unpredictable effect
- Pixel values do not accurately represent the tissue densities
- Pixel values may change with size of Field Of View
- Pixel values may also change with software updates

4cm x 4cm

6cm x 4cm

8cm x 5cm

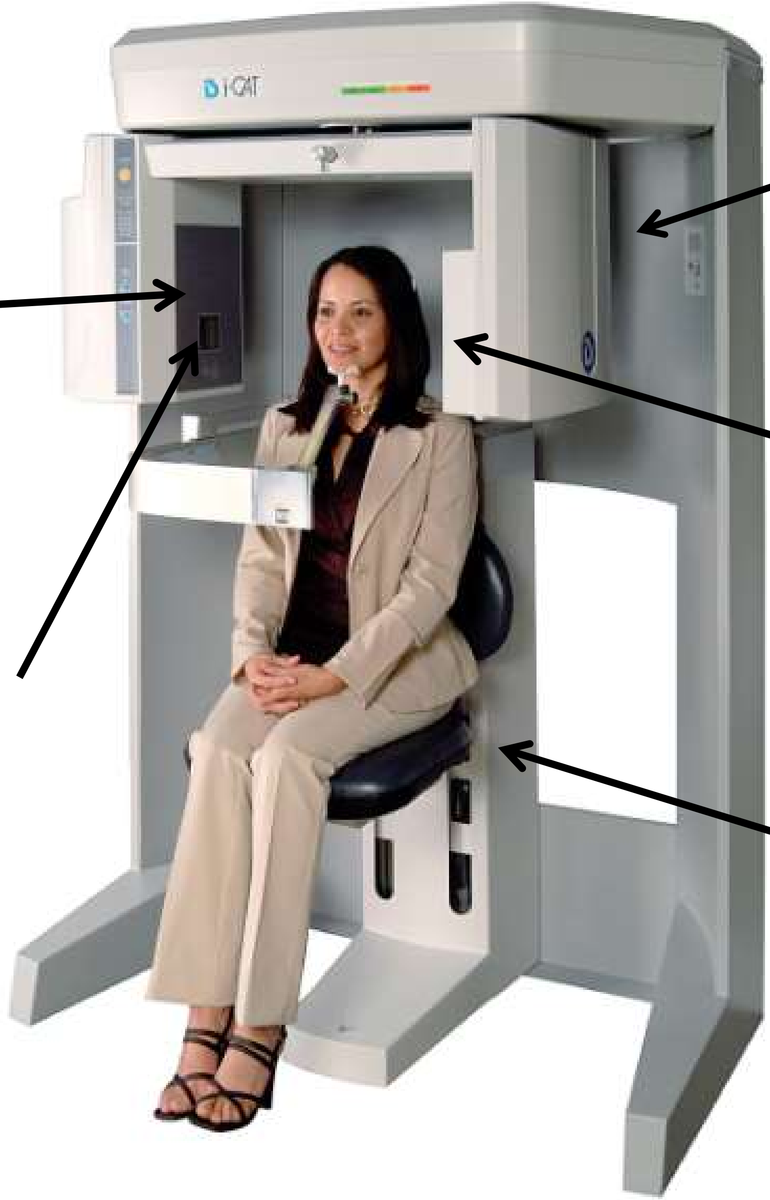
10cm x 6cm

Top of the Line Cone Beam CT Scanner

pulsed
x-ray tube
120kVp

adjustable
collimator
4 to 10cm height

Around £150K



fast scan time
low dose

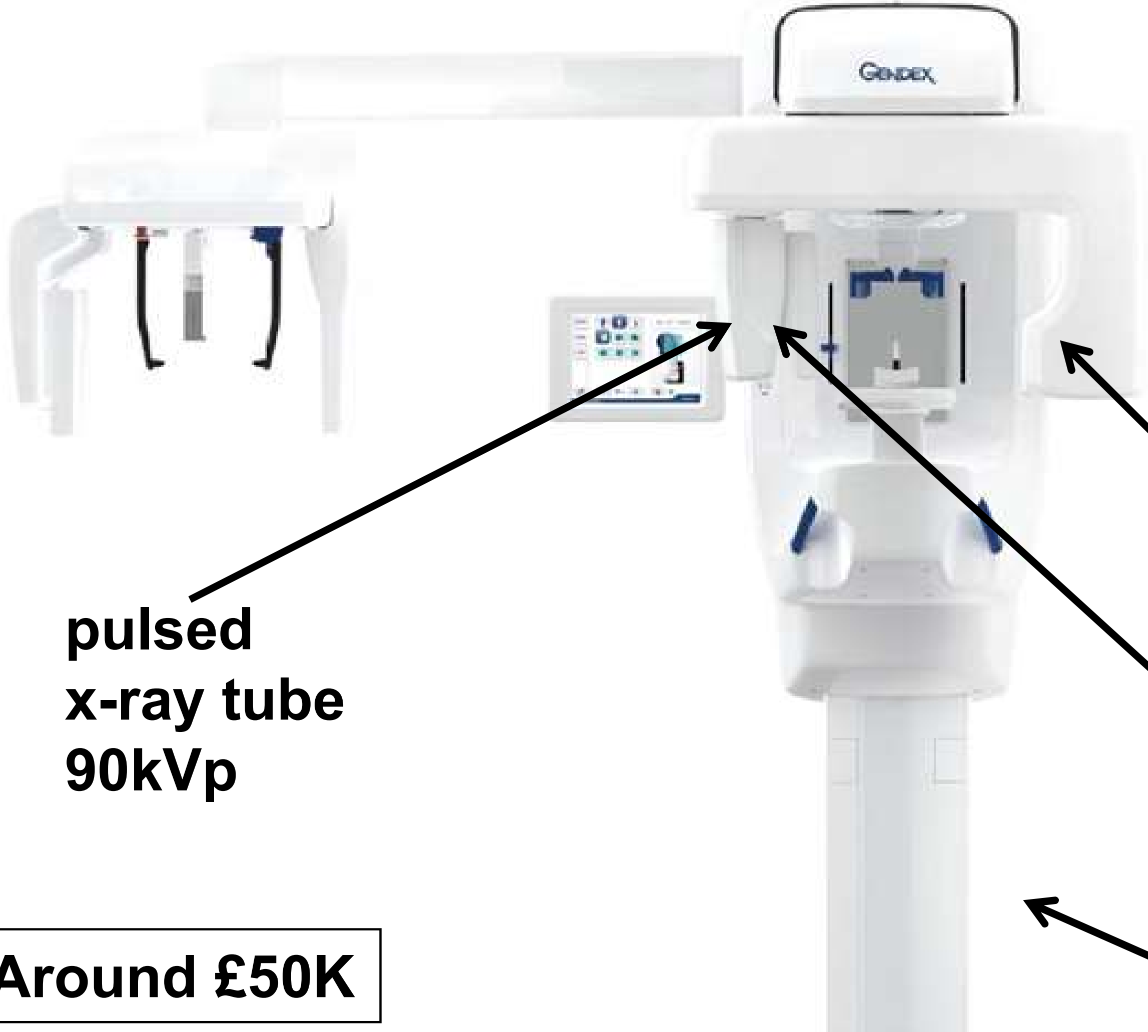
Typical Mn 35μSv

large
detector

adjustable
chair

i-CAT™ is a trademark of Imaging Sciences International LLC of Hatfield, USA

Entry Level Cone Beam CT Scanner



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

Typical Mn 50µSv

small detector

pulsed
x-ray tube
90kVp

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

Around £50K

no chair

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

You get what you pay for !

Image Quality in CBCT scans

- Noise

- *electronic noise (dark current)*
- *photon noise (not enough dose)*

- Artefact

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

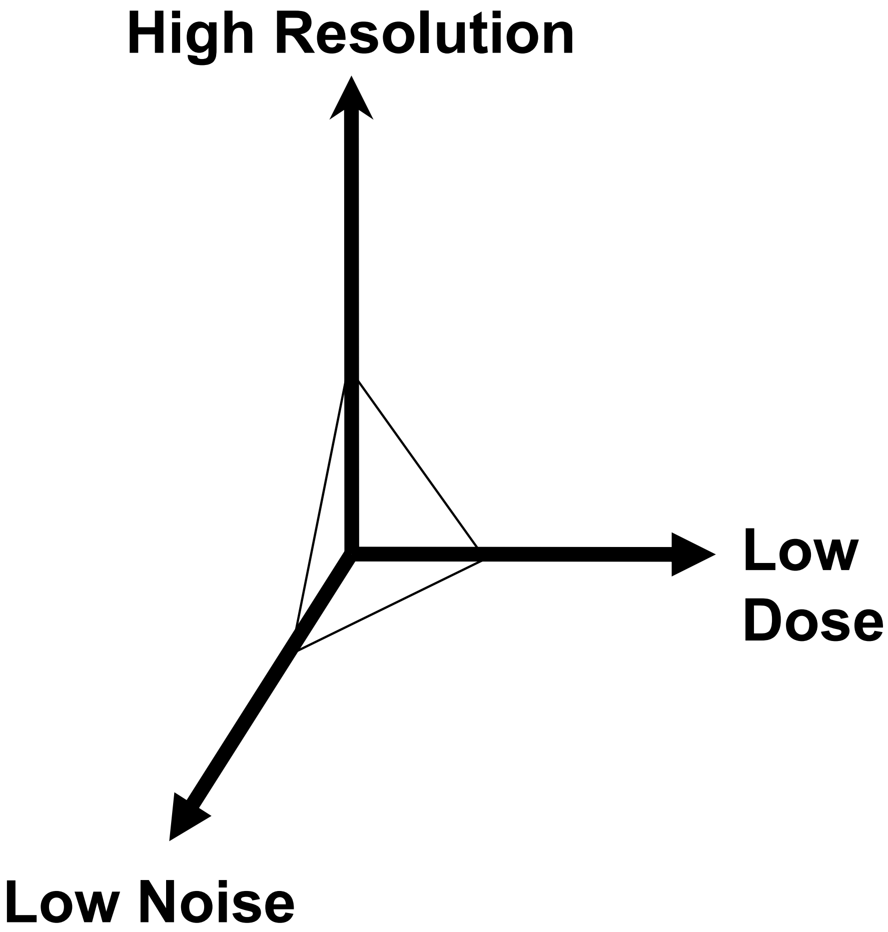
- Spatial Resolution (resolution at high contrast)

- *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)*

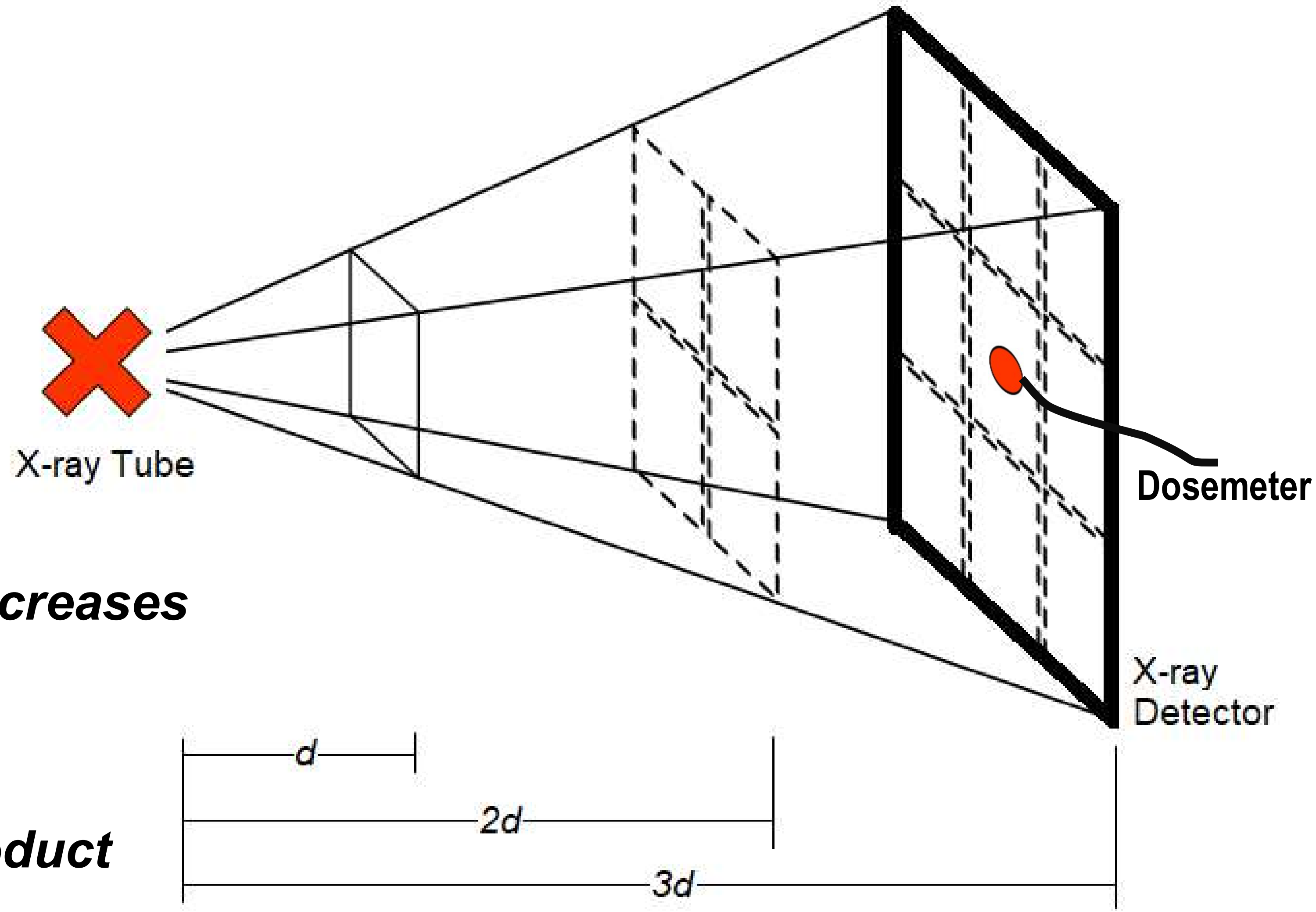
The impossible dream



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

Dose Area Product (DAP)

measured in $mGy.cm^2$



- ***Absorbed Dose decreases as $1/d^2$***
- ***Area increases as $1/d^2$***
- ***The Dose Area Product remains constant***

Dose Area Product (DAP)

measured in mGy.cm^2

Dose Area Product (DAP) =

Absorbed Dose at the centre of the field

x Area of the field

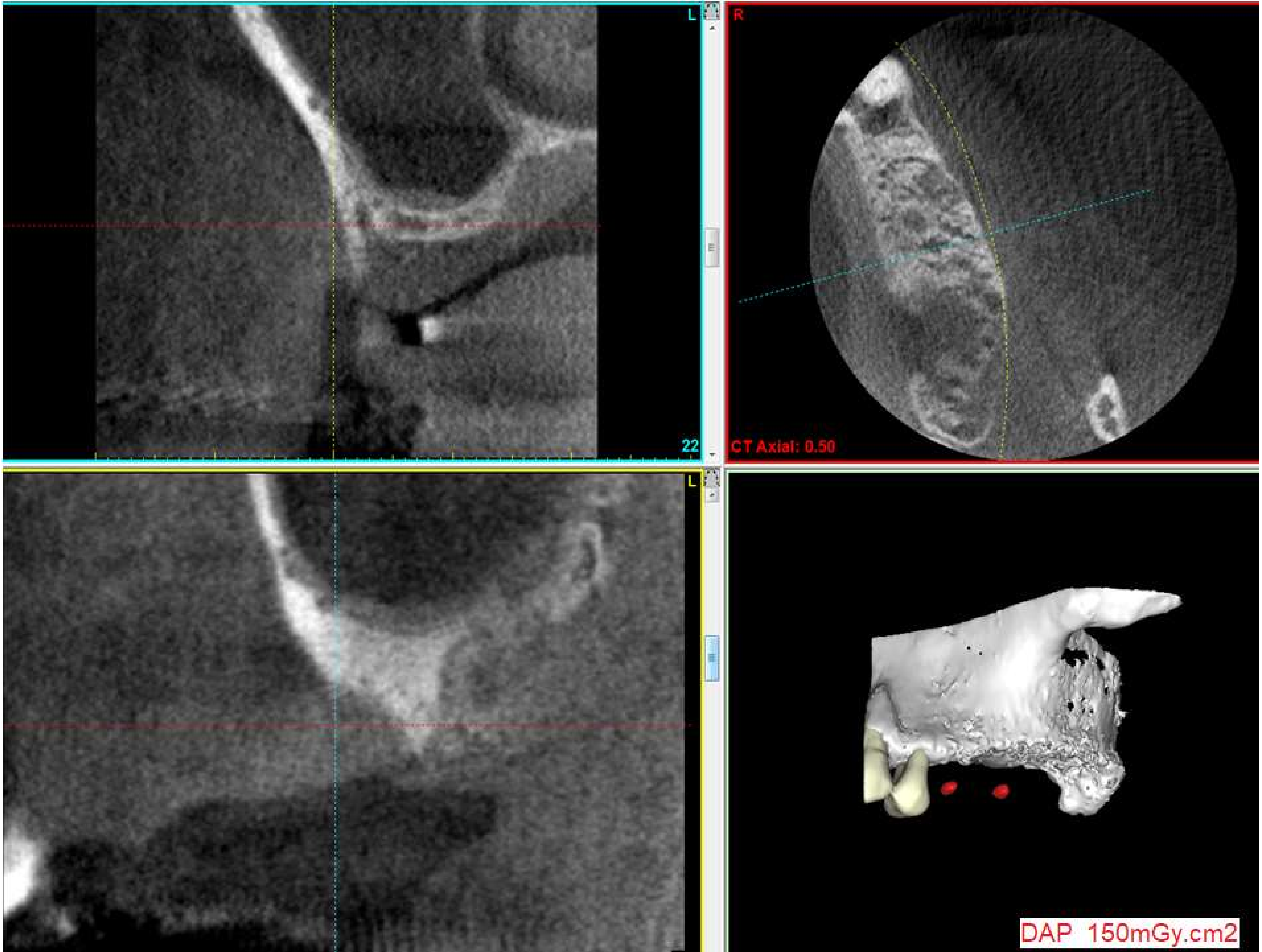
at the same distance from the source.

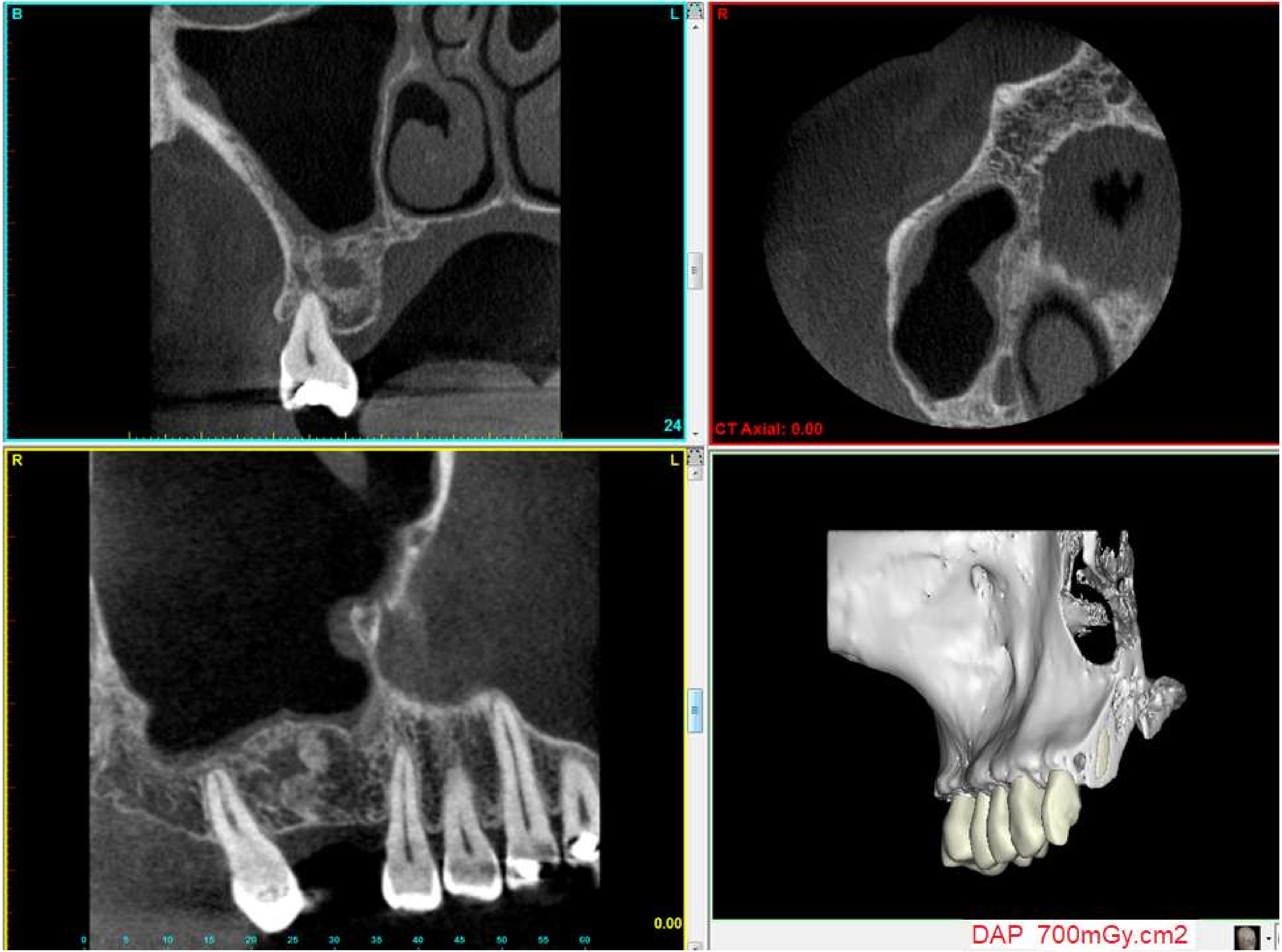
DAP is a “dose index”:

- a standard way of comparing dose from different examinations.

DAP will increase with:

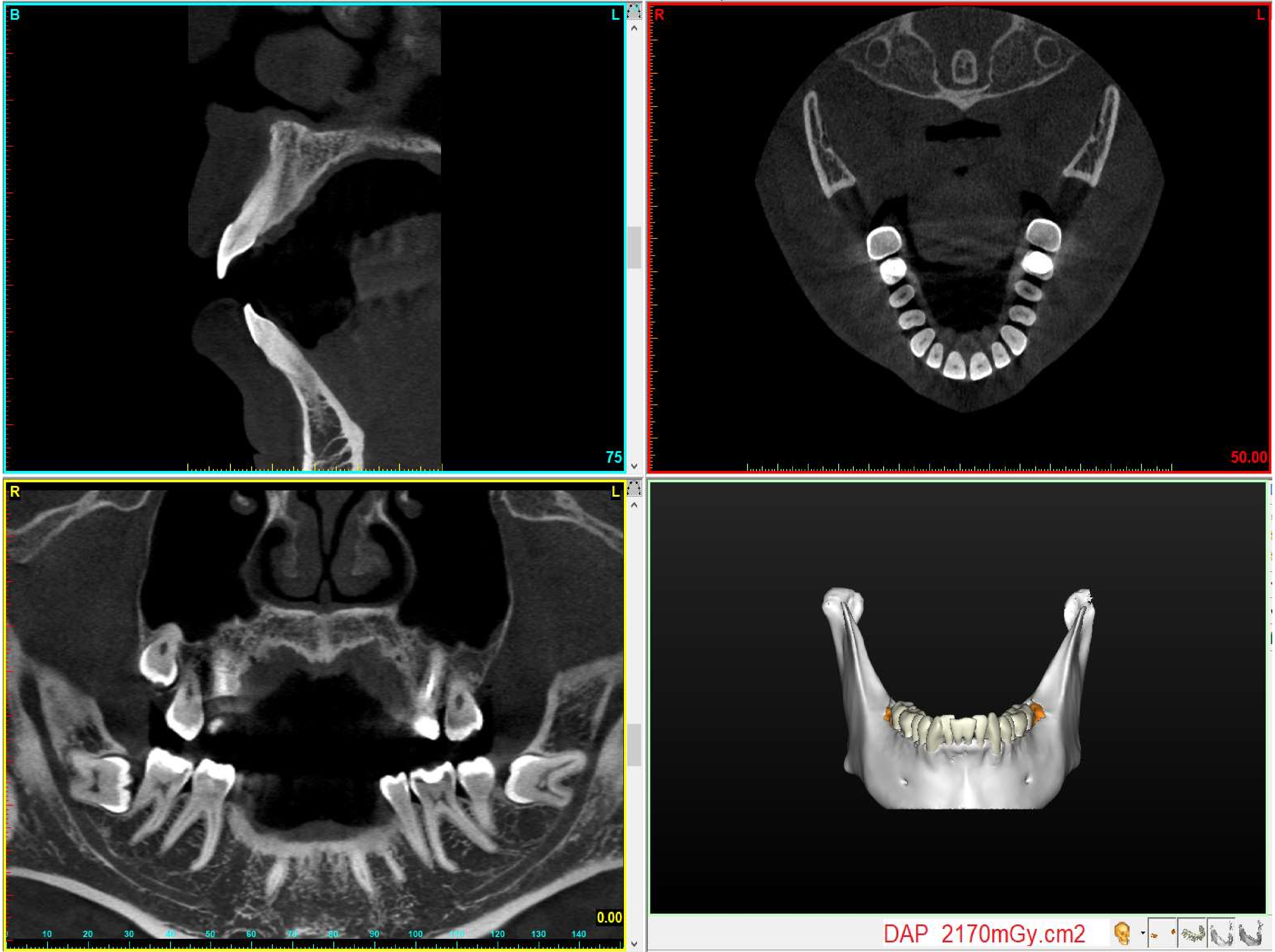
- ***field size***
- ***mAs***


L
22
R
CT Axial: 0.50
L
DAP 150mGy.cm2


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
DAP 700mGy.cm2


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
DAP 150mGy.cm2


B
L
67
R
CT Axial: -27.38
R
L
DAP 350mGy.cm2


B
L
75
R
L
50.00
R
L
0.00
10 20 30 40 50 60 70 80 90 100 110 120 130 140
DAP 2170mGy.cm2

Reasonable DAP Values

ONE QUADRANT – around 150 - 265mGy.cm^2

ONE ARCH – around 300 – 550mGy.cm^2

BOTH ARCHES – around 600 – 1100mGy.cm^2

265mGy.cm2 is the National Diagnostic Reference Level (DRL) for a single quadrant scan.

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.**

UK National DRLs

- For intra-orals the National DRLs are 1.2 mGy for adults and 0.7 mGy for children (entrance doses)

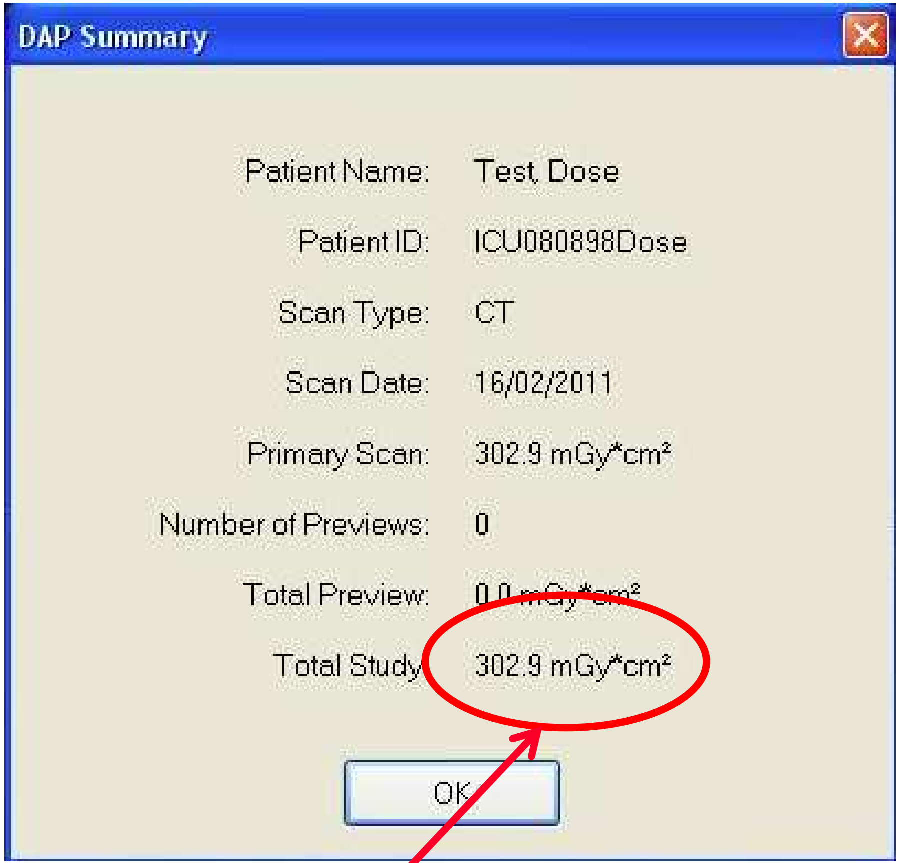
- For DPTs the National DRLs are 81 $mGy.cm^2$ for adults and 60 $mGy.cm^2$ for children (Dose Area Product, DAP)

- For CBCT the National DRLs are 265 mGy.cm2 for adults (maxillary molar implant) and 170 mGy.cm2 for children (impacted maxillary canine) (Dose Area Product, DAP) THIS IS FOR 1 QUADRANT (Small Field Of View scan)

Can we Estimate the Effective Dose from the DAP?

Can we (Guess)timate the Effective Dose from the DAP?

Can we (Guess)timate the Effective Dose from the DAP?



Multiply DAP by 0.1 for Maxilla or 0.15 for Mandible to get the Effective Dose in microSieverts (µSv)

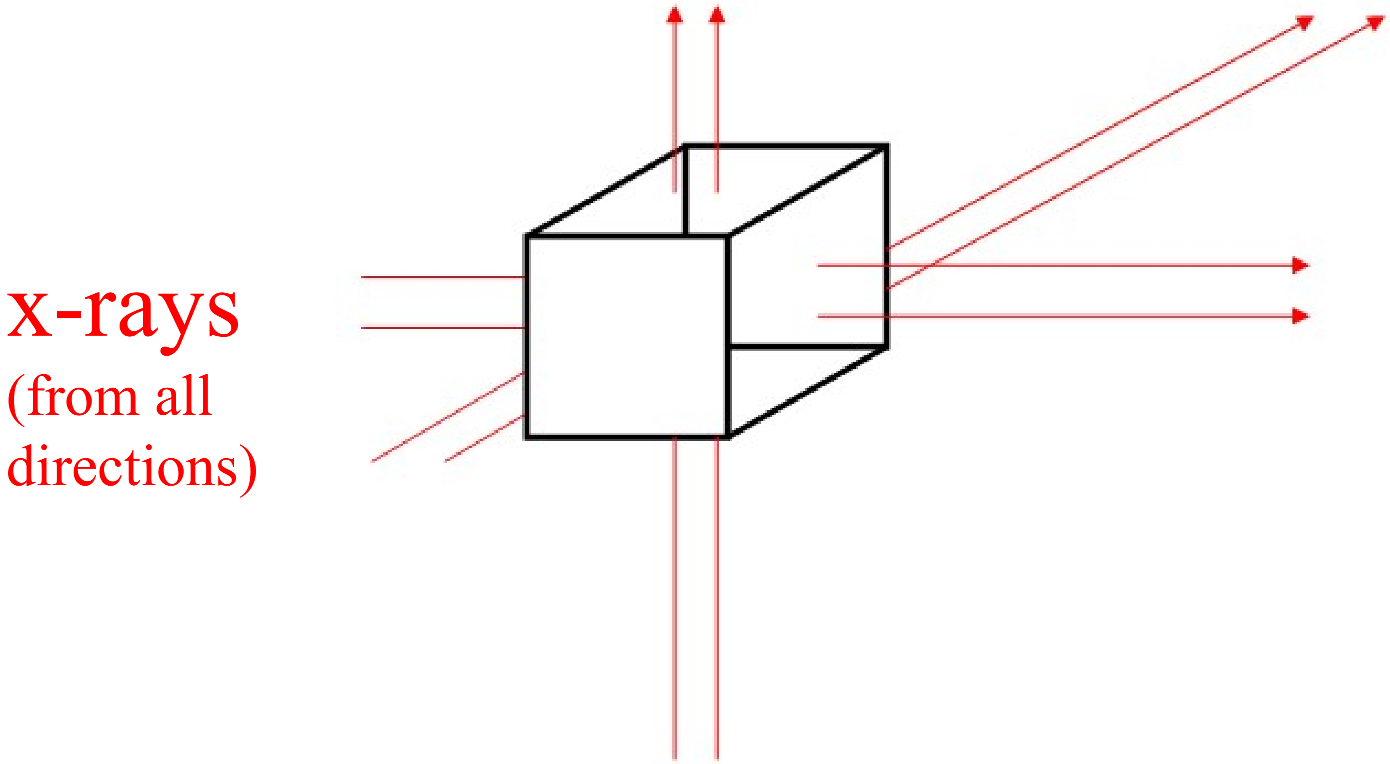
Accuracy: ±50% **Mx 30µSv or Mn 45µSv** ROUGHLY

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**

Proton Noise depends on voxel size



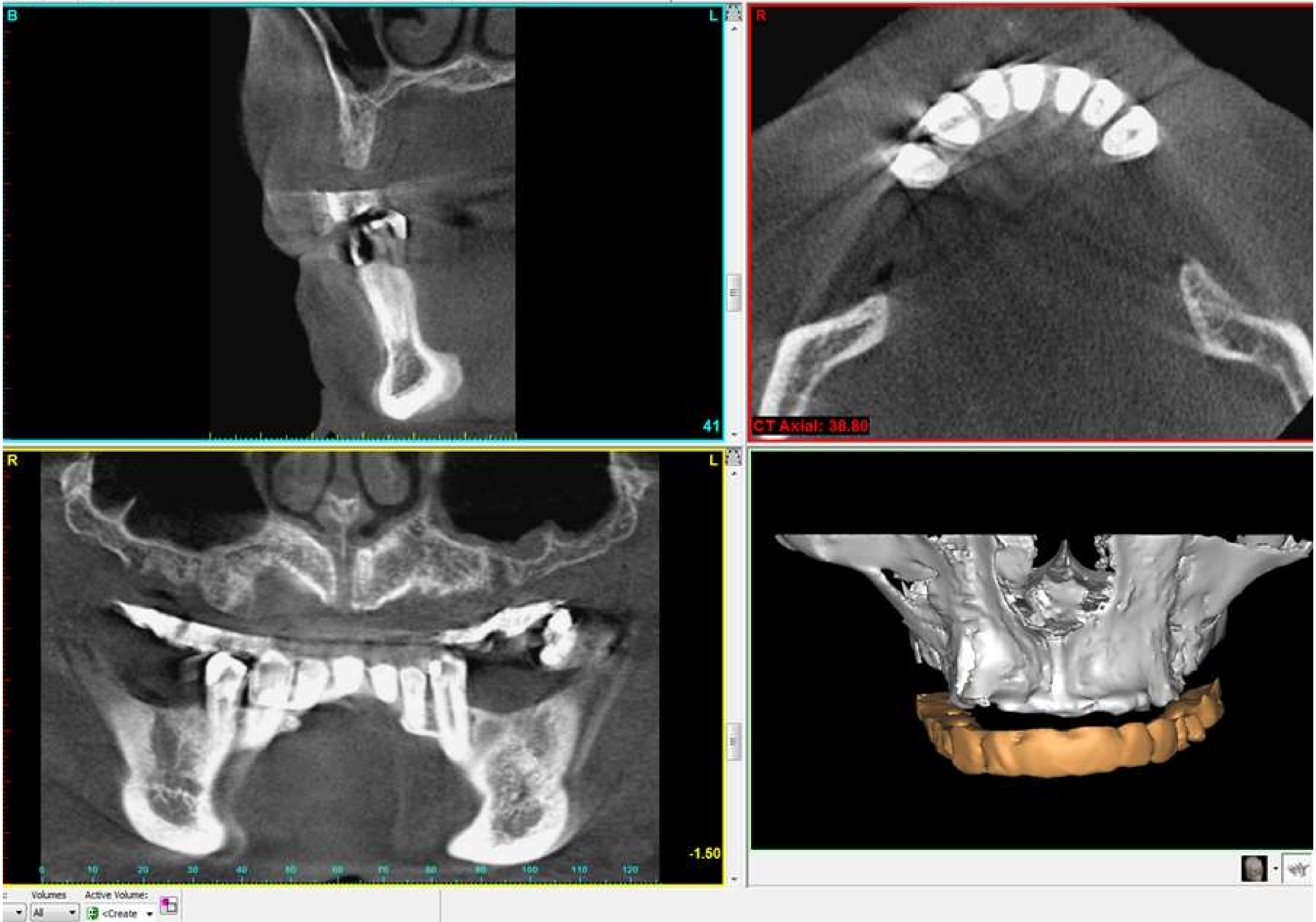
If you halve (1/2) each side of a cube e.g. from 0.4mm to 0.2mm
Number of x-ray photons passing through it goes down by 8 (i.e. 1/8)
Noise goes up by $\sqrt{8}$ = 2.83
mAs (dose) may have to be increased to compensate

Artefacts in CT / CBCT images

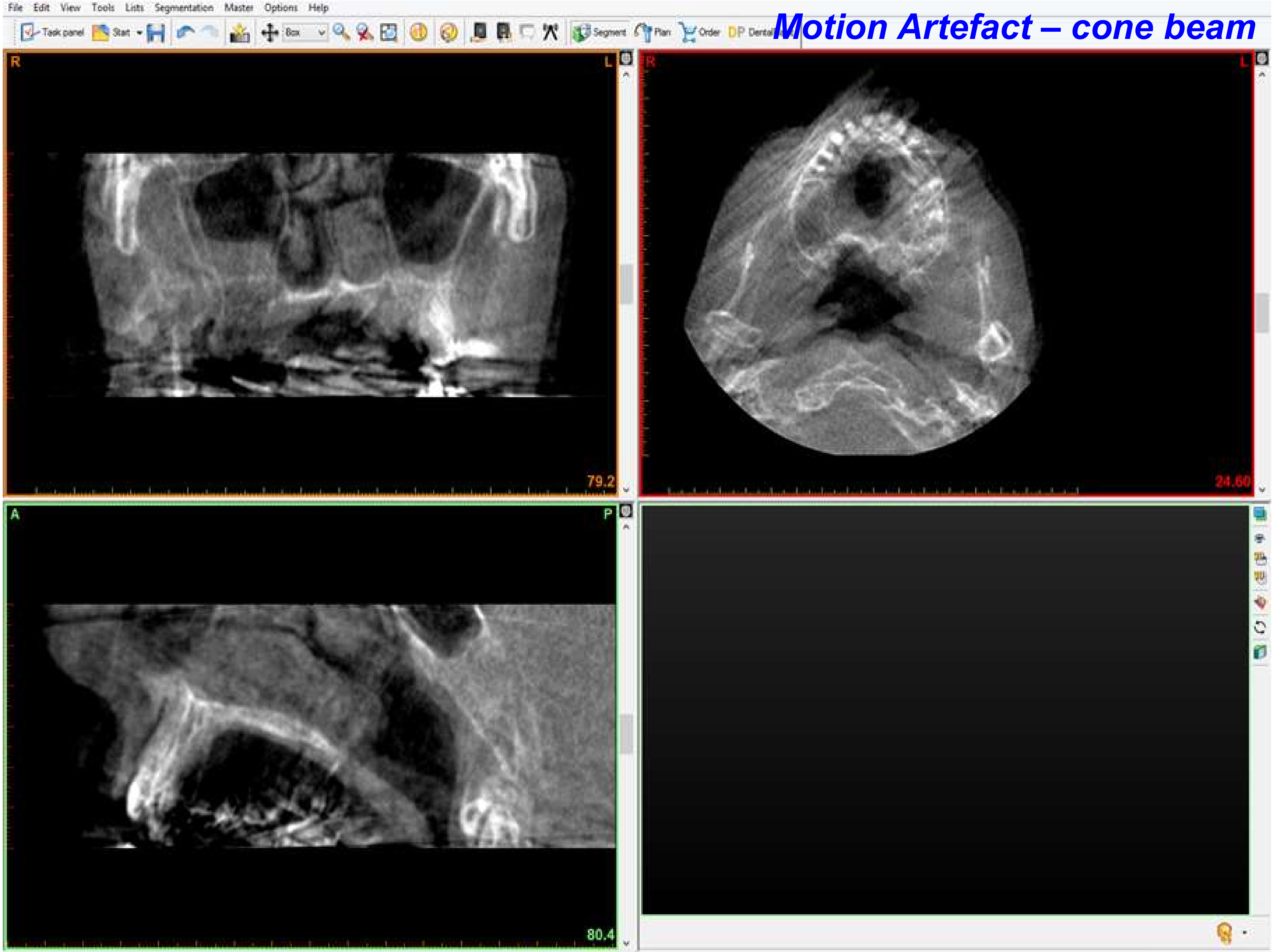
Artefact = structured contribution to the image which has no counterpart in the object.

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

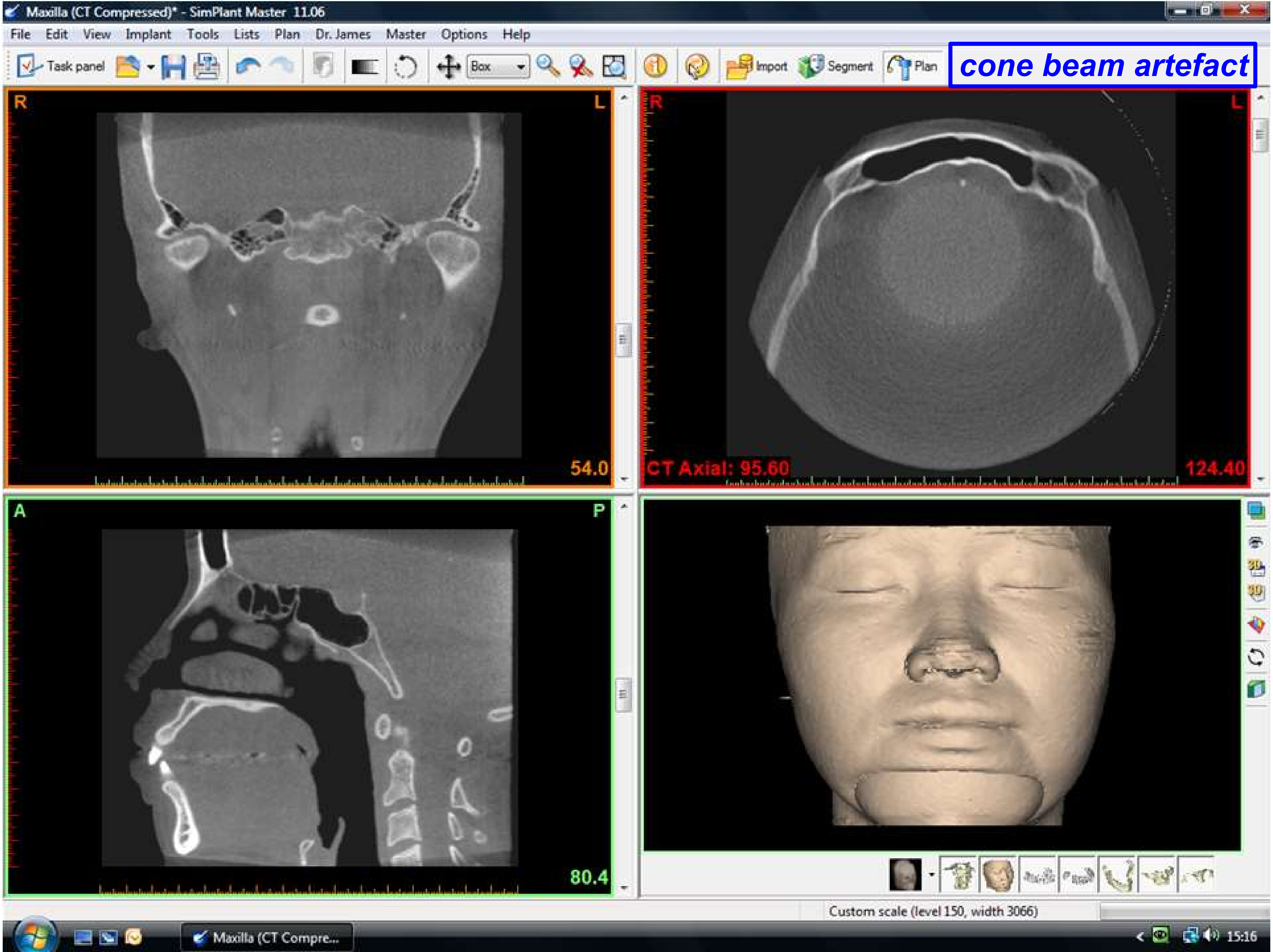
Motion Artefact – cone beam



Motion Artefact – cone beam

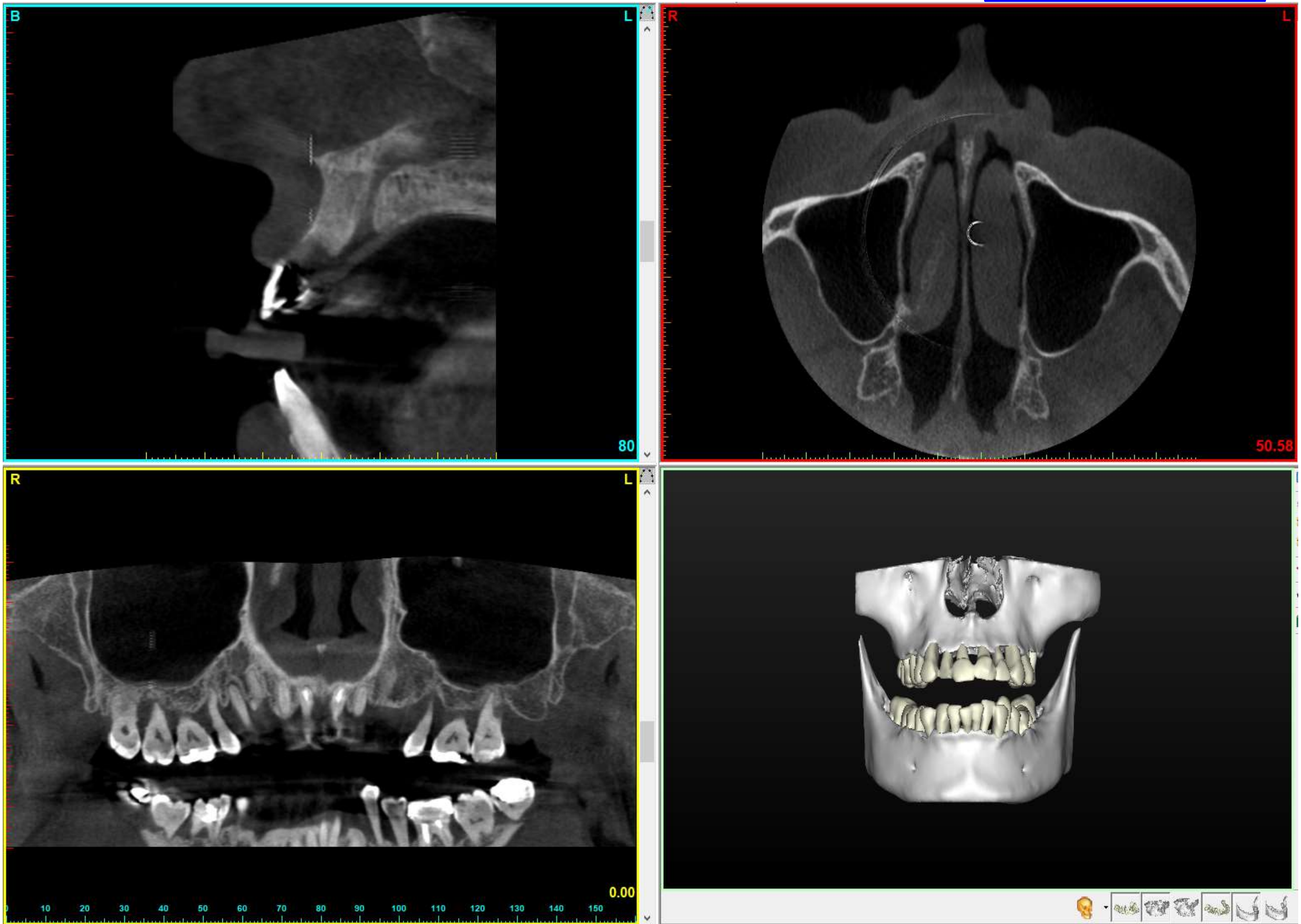


Motion Artefact – cone beam CT



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
R
L
CT Axial: 95.60
124.40
A
P
80.4
Custom scale (level 150, width 3066)
Maxilla (CT Compre...
15:16

ring artefact



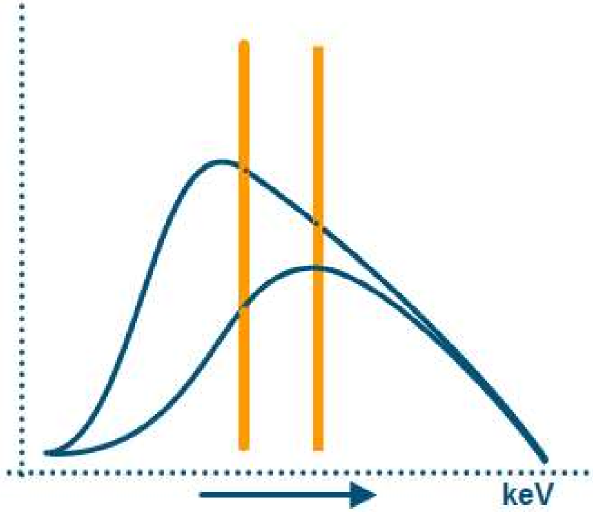
STARBURST ARTEFACT

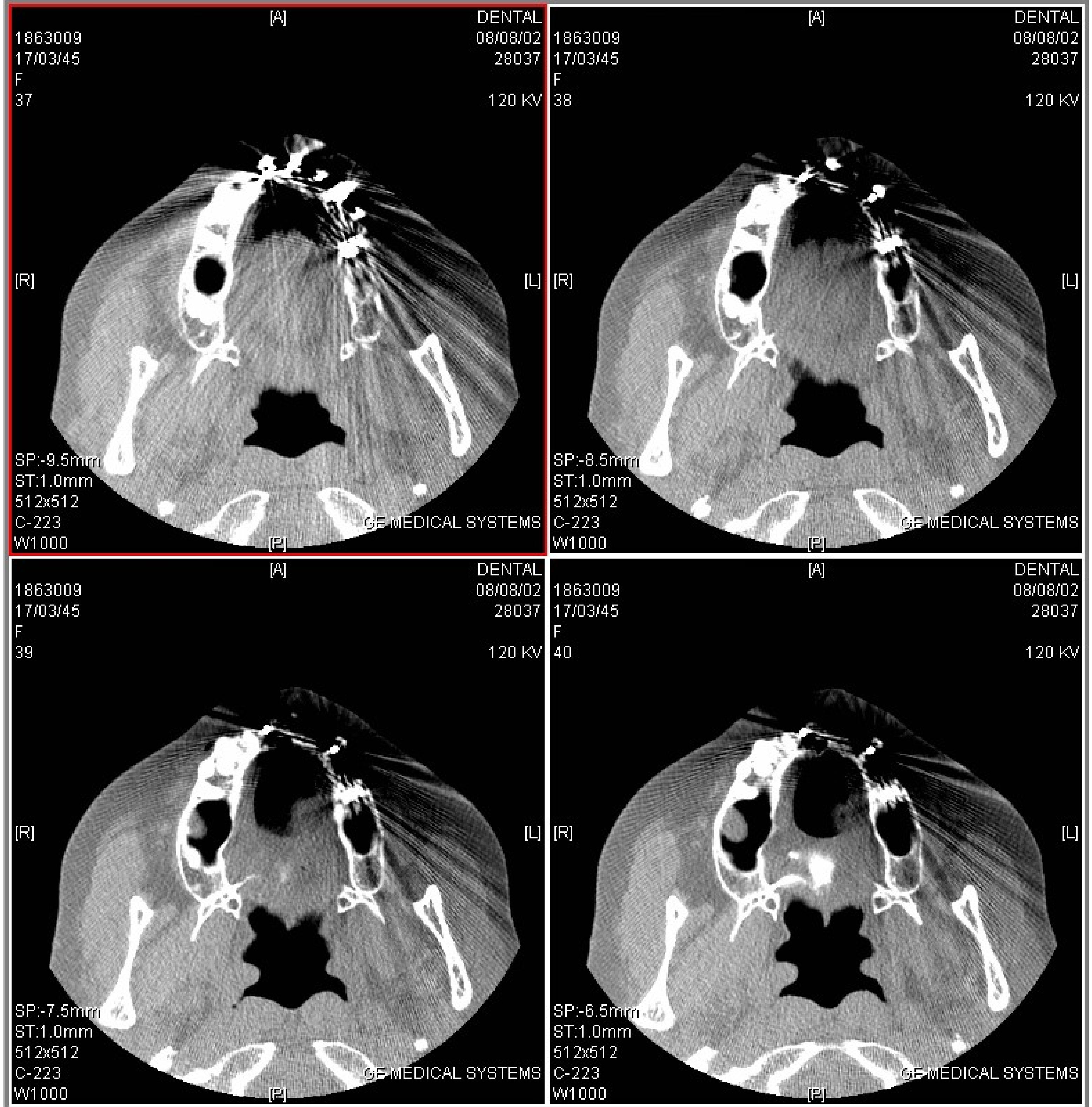
- **Starburst (streak) artefacts arise in CT scans when sharp changes in density are present, e.g. between air and bone or between bone and dense metals**
- **Starburst artefacts are caused by limitations in high frequency sampling**
  - **- partial volume effect**
  - **- beam hardening**
- **Starburst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

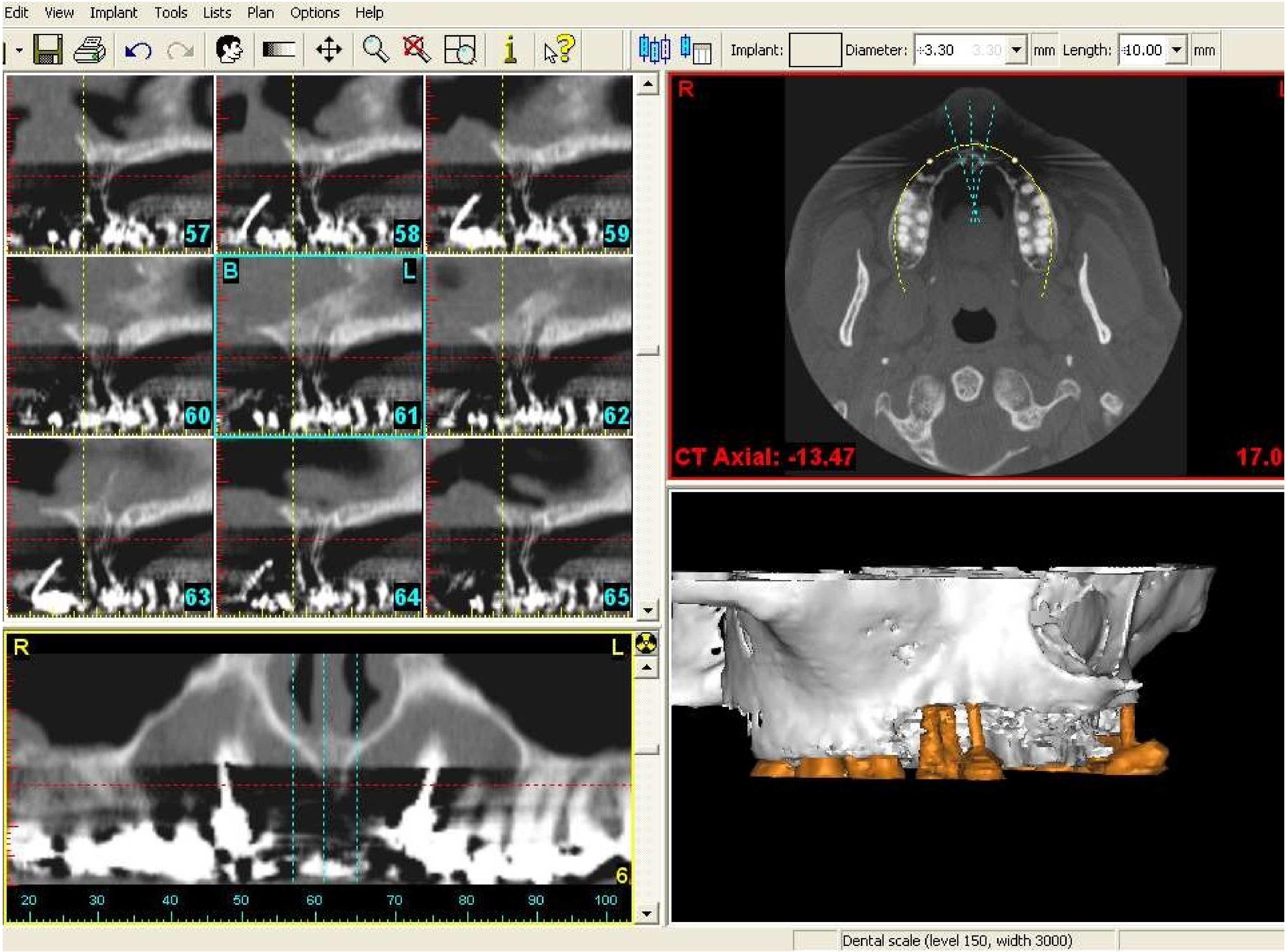

1.00X
R
L
11:36:29 5
1.00X
R
L
11:37:40 12
R
L
11:38:37 19

BEAM HARDENING ARTEFACT

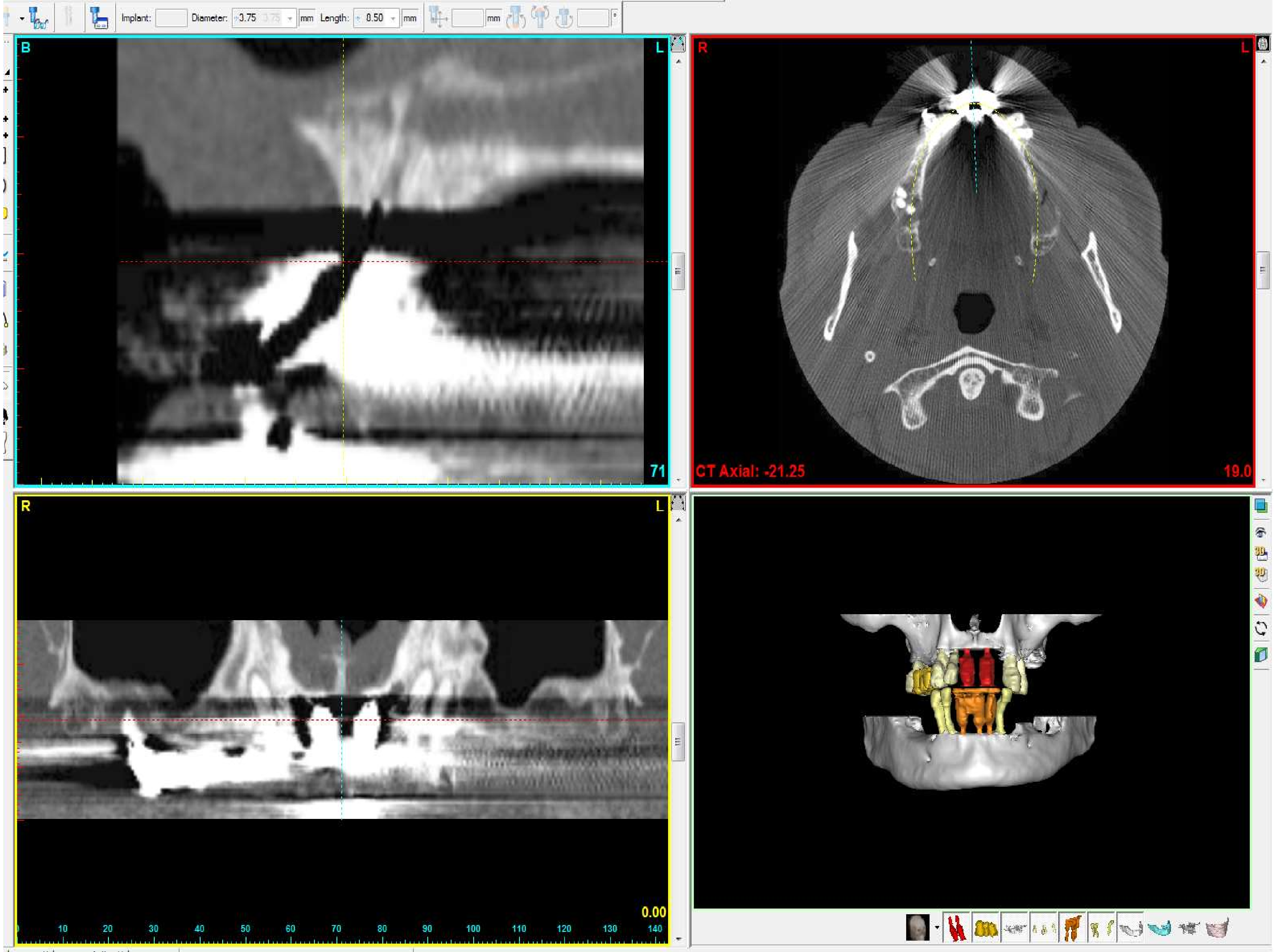
- Beam Hardening artefacts occur in CT scans when metals are present
- Metals cause the low energy x-rays to be filtered out of the x-ray beam
- The average energy becomes higher
- The CT numbers become lower
- Parts of the image appear black



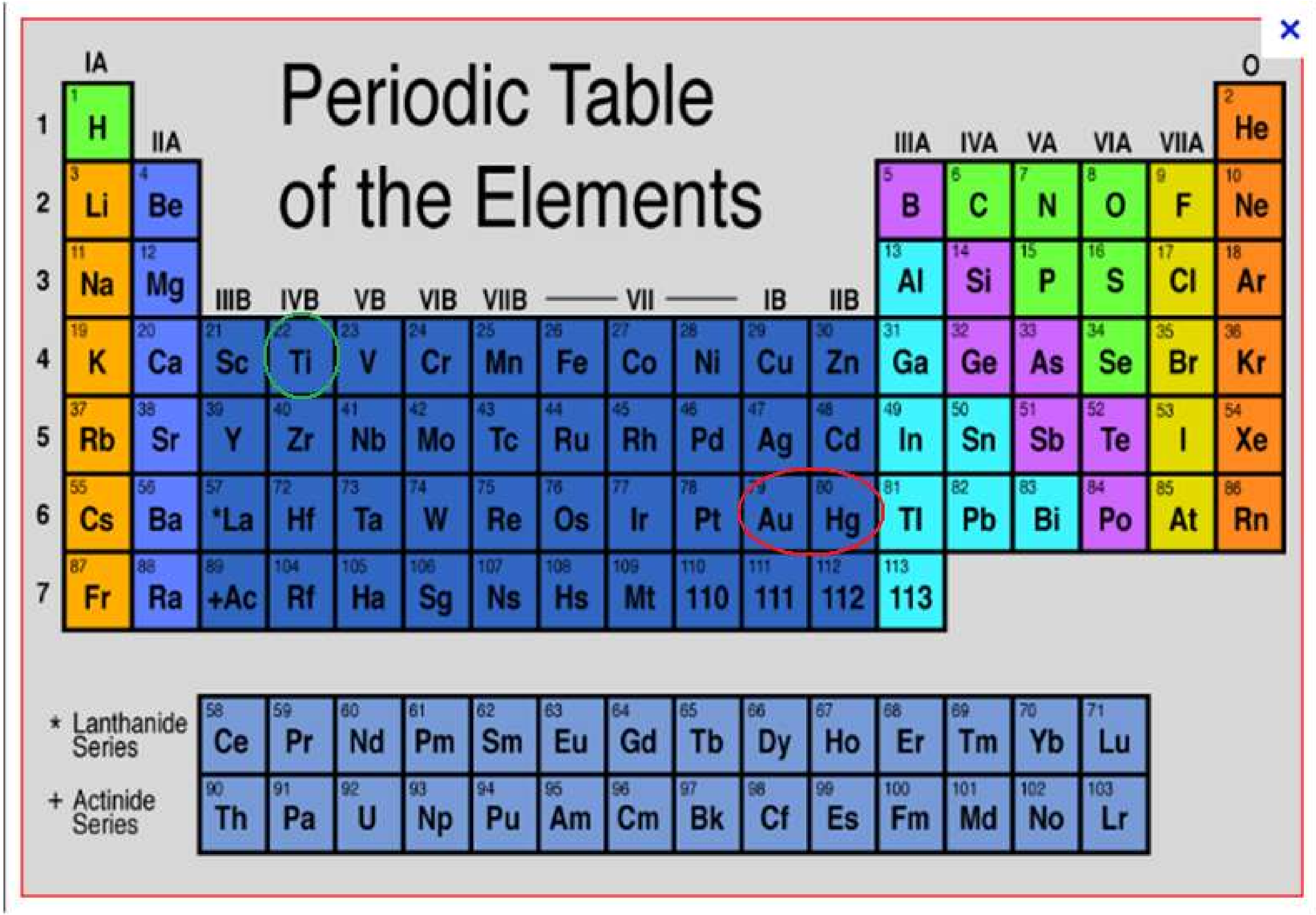

[A]
DENTAL
1863009
08/08/02
17/03/45
28037
F
37
120 KV
[R]
[L]
SP:-9.5mm
ST:1.0mm
512x512
C-223
W1000
GE MEDICAL SYSTEMS
[P]
[A]
DENTAL
1863009
08/08/02
17/03/45
28037
F
38
120 KV
[R]
[L]
SP:-8.5mm
ST:1.0mm
512x512
C-223
W1000
GE MEDICAL SYSTEMS
[P]
[A]
DENTAL
1863009
08/08/02
17/03/45
28037
F
39
120 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
CT Axial: -13.47
17.0
R
L
6
20 30 40 50 60 70 80 90 100
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

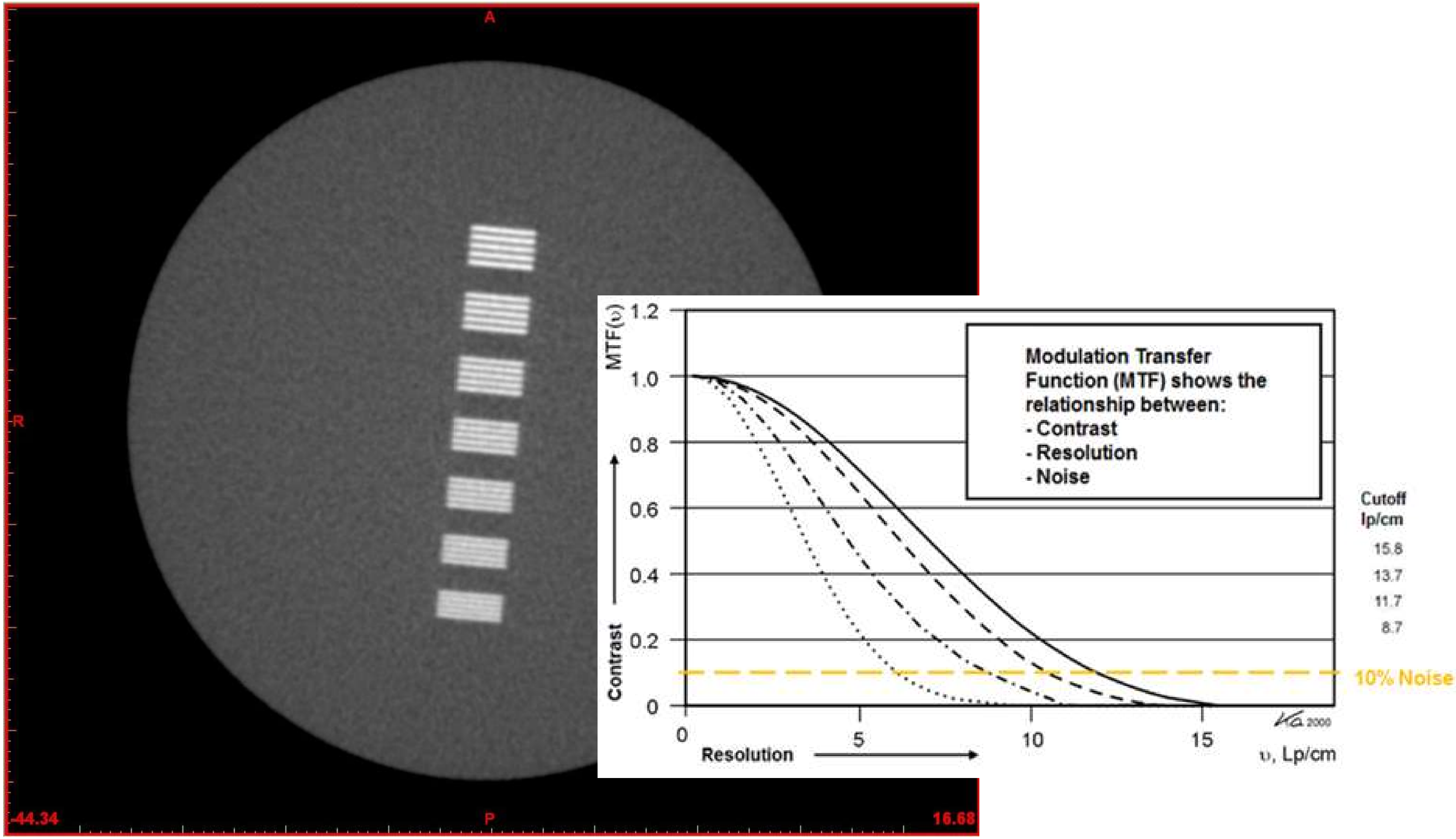


HOW TO AVOID ARTEFACTS

- **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.**

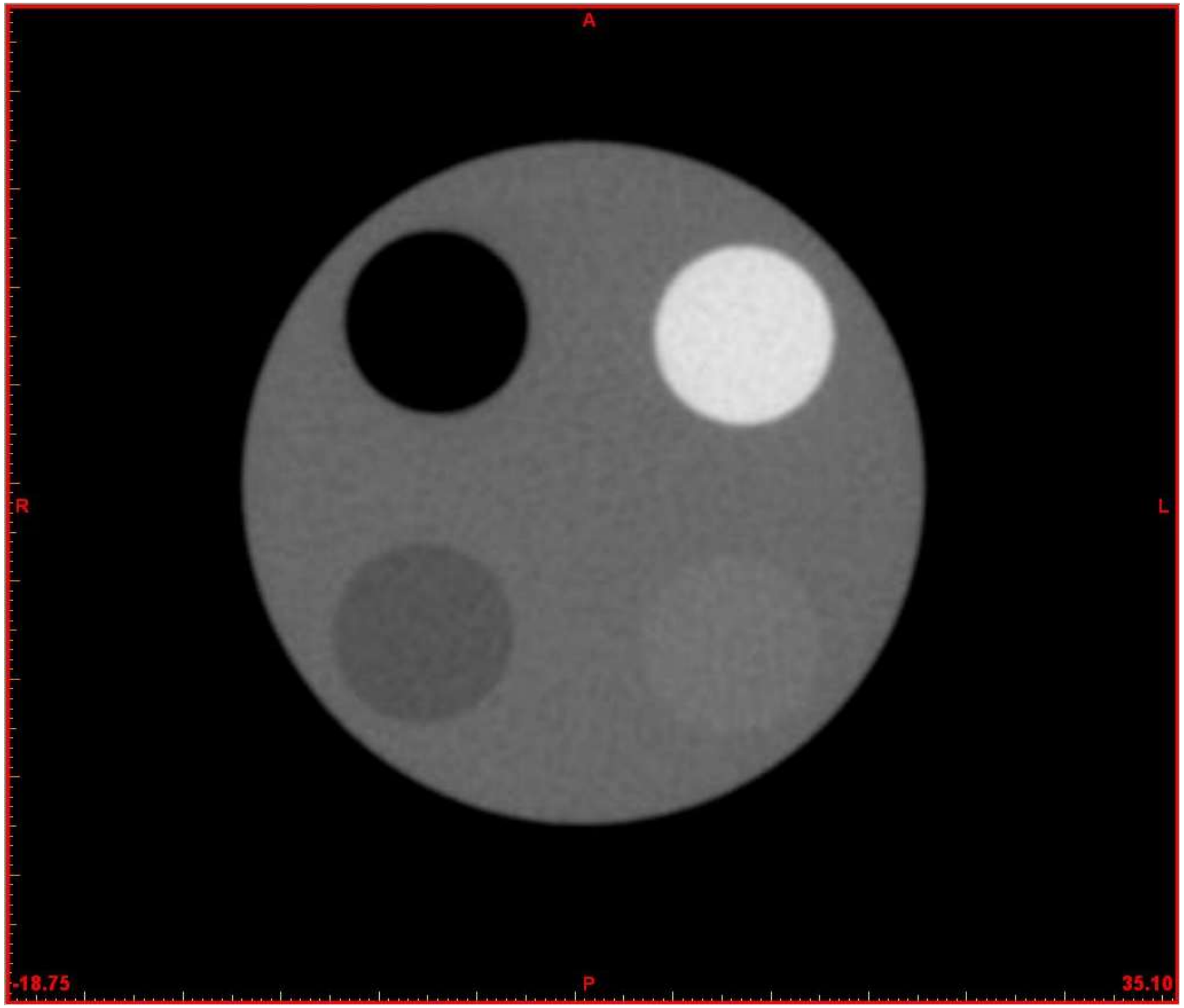
Spatial Resolution

Detail at high contrast



Contrast Resolution

Detail at low contrast



Spatial and Contrast Resolution

Outline of Presentation

- ✔ Introduction
- ✔ Principles of CBCT Imaging
- ✔ CBCT Image Acquisition and Processing
- ✔ Radiation Physics in relation to CBCT
- Dose and Risk

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 **takes the size of the region and the body parts irradiated into account.**

To obtain the Effective Dose:

1. **Measure Absorbed Dose to each organ of interest**

2. **Apply Radiation Weighting factor to obtain Equivalent Dose for each organ of interest**

3. **Take the weighted sum of all the Equivalent Doses.**

Effective Dose (E)

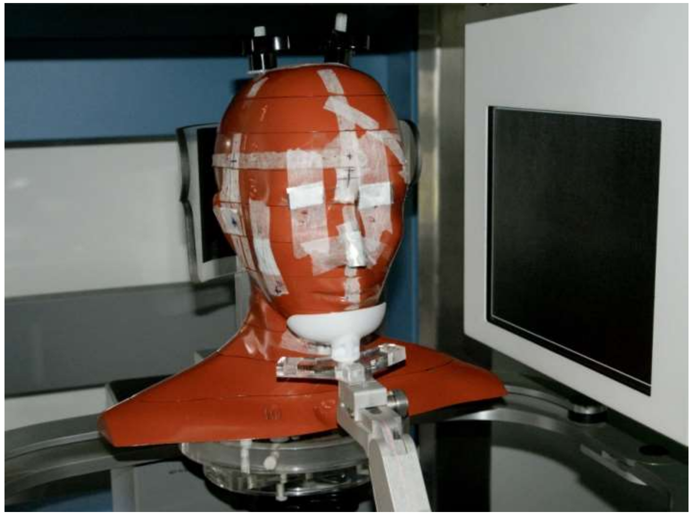
$$E = \sum_T H_T w_T$$

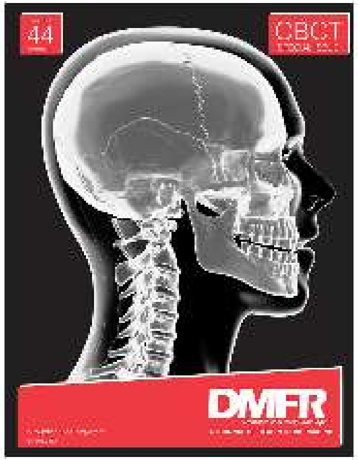
H_T = Organ Equivalent Dose
w_T = Tissue weighting factor

Unit = (Sv) Sievert

Effective Dose is proportional to risk of fatal cancer

	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





DentoMaxilloFacial Radiology

CBCT Special Issue

VOLUME 44, ISSUE 1, 2015

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birpublications.org/dmfr

CBCT SPECIAL ISSUE: REVIEW ARTICLE

Effective dose of dental CBCT—a meta analysis of published data and additional data for nine CBCT units

[1]J B Ludlow, [2]R Timothy, [3]C Walker, [4]R Hunter, [5]E Benavides, [6]D B Samuelson and [6]M J Scheske

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journal homepage: www.elsevier.com/locate/ejrad

Effective dose range for dental cone beam computed tomography scanners

Ruben Pauwels[a,*], Jilke Beinsberger[a,1], Bruno Collaert[b,2], Chrysoula Theodorakou[c,d,3], Jessica Rogers[e,3], Anne Walker[c,3], Lesley Cockmartin[f,4], Hilde Bosmans[f,5], Reinhilde Jacobs[a,6], Ria Bogaerts[g,7], Keith Horner[d,8], The SEDENTEXCT Project Consortium[9]

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Eur J Radiol 81,2,267-271 (February 2012)

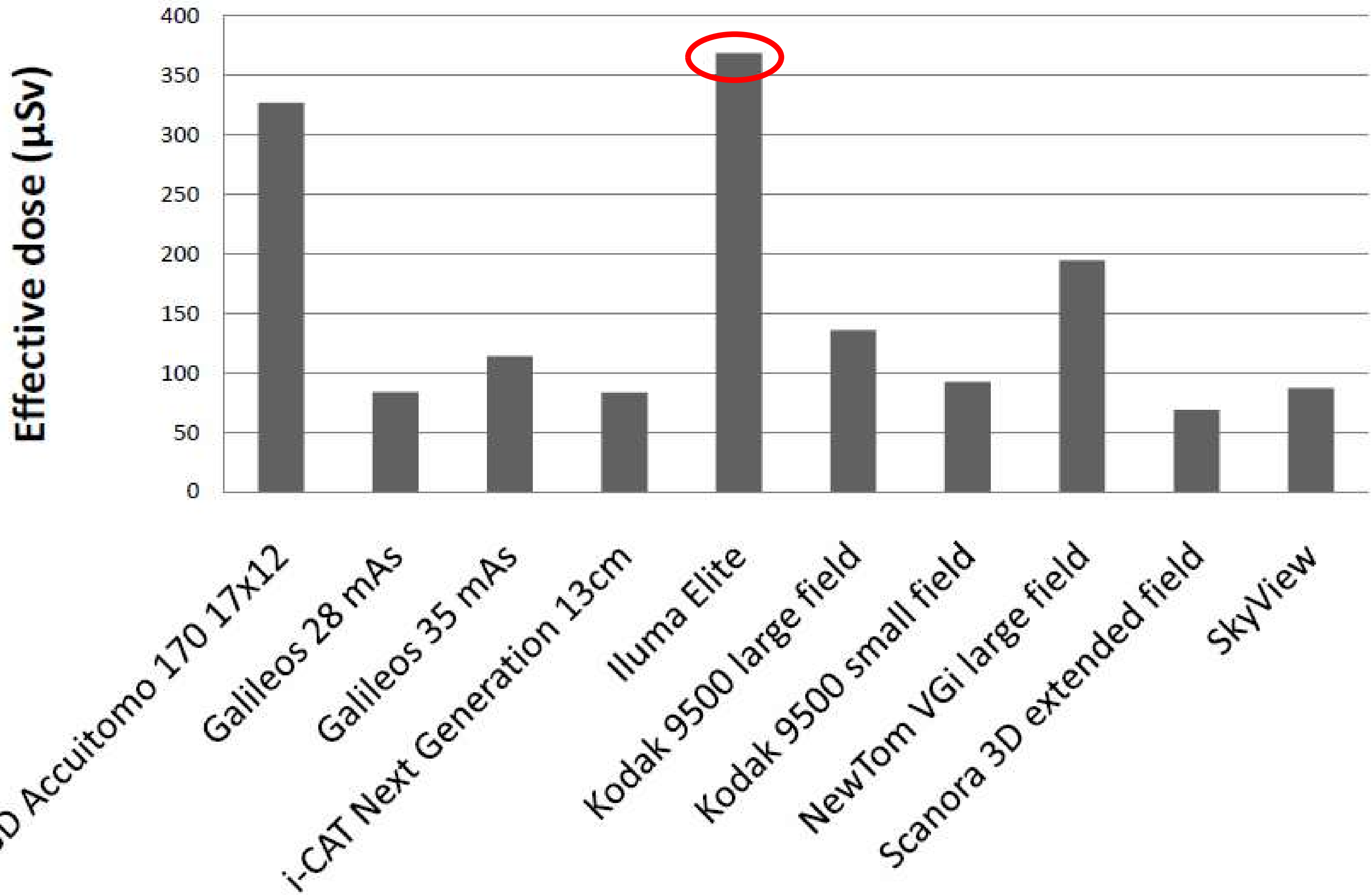
SEDENTEXCT measured Effective Doses for common CBCT scanners and found they were in the range

20 microSieverts to 370 microSieverts

Most dental CBCT scans will in the range

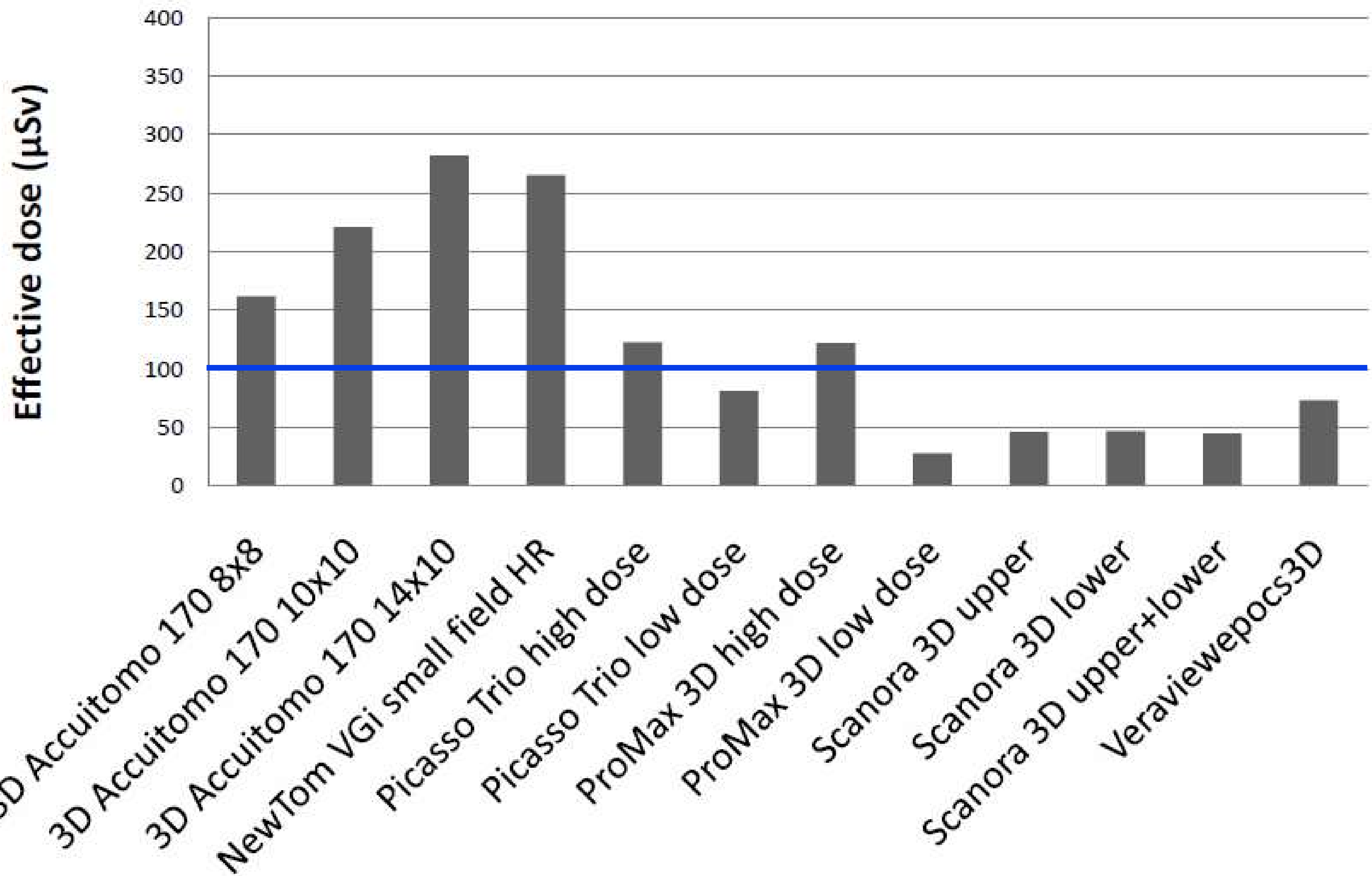
20 microSieverts to 200 microSieverts

Effective dose for large field CBCTs



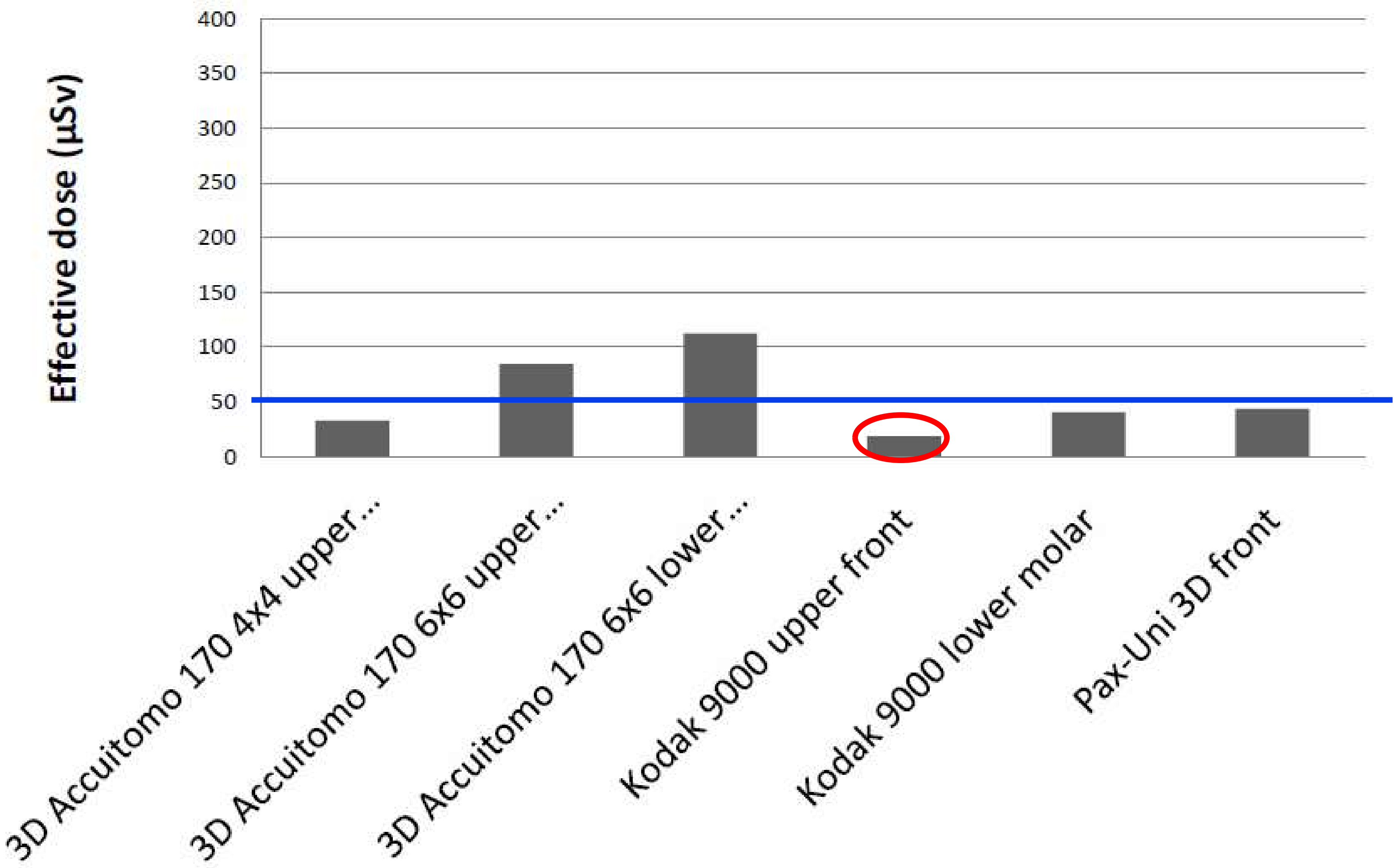
Prof. Ria Bogaerts, Katholieke Universiteit Leuven, March 2011

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

What is the Risk from a CBCT scan?

- **Assume adult patient, dento-alveolar scan, both jaws**
- **Effective Dose might be 100 microSieverts**
- **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**

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

Risk Bands

Negligible	< 1 in a million risk
Minimal	1 in 100,000 to 1 in a million risk
Very Low	1 in 10,000 to 1 in 100,000 risk
Low	1 in 1,000 to 1 in 10,000 risk

Department of Health (1995)

Dental x-rays are in the range "Negligible" to "Very Low"

Cancer: science and society and the communication of risk

Kenneth C Calman

BMJ VOLUME 313 28 SEPTEMBER 1996

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

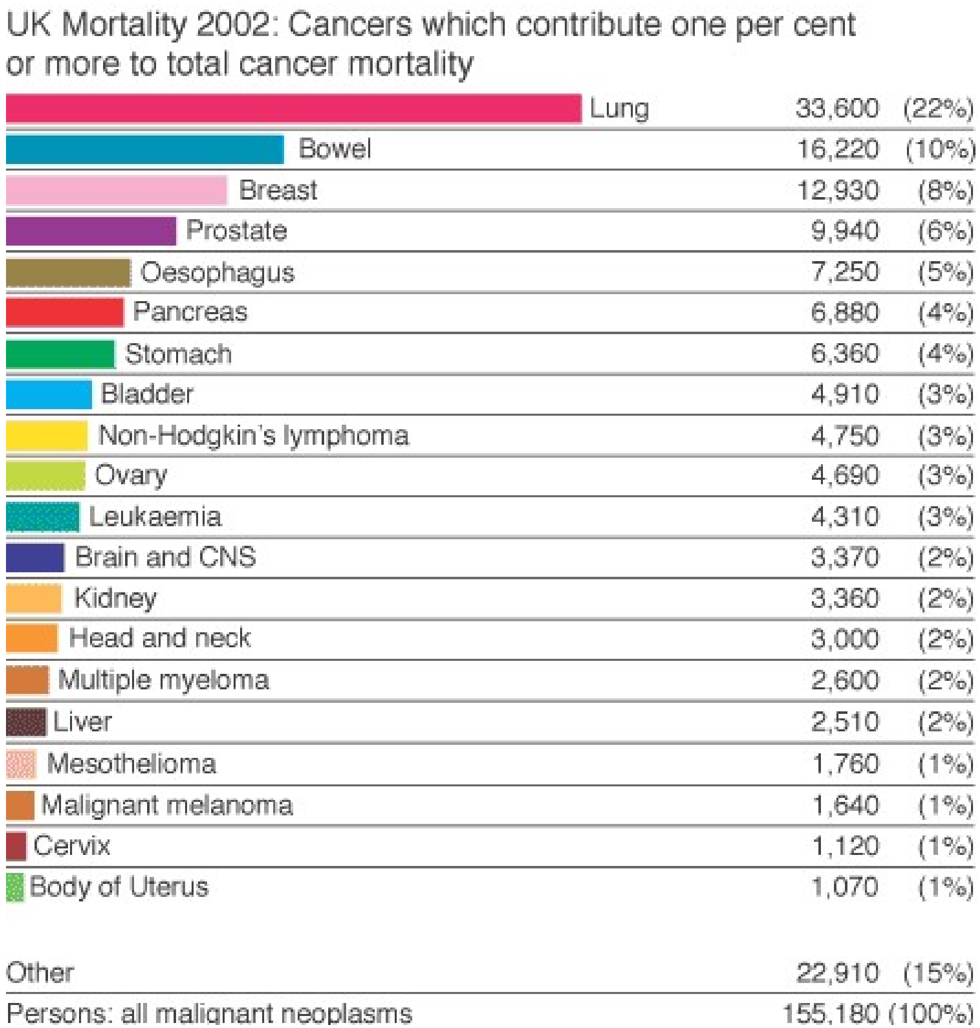
Table 2—*Descriptions of risk in relation to the risk of an individual dying (D) in any one year or developing an adverse response (A)*

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

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

- ***There might be 160 extra cancer deaths per year***
  (if assumptions are correct)

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



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

The End

Thank you for listening.