Alberto Torresin

Struttura Complessa di Fisica Sanitaria
ASST Grande Ospedale Metropolitano Niguarda, Milano

Università degli Studi di Milano – Dip. di Fisica

UNIVERSITÀ DEGLI STUDI DI MILANO

EFOMP: Education and Training Comm (Past Chair)

email: alberto.torresin@unimi.it

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ConeBeamCT (CBCT) from diagnostics to radiotherapy

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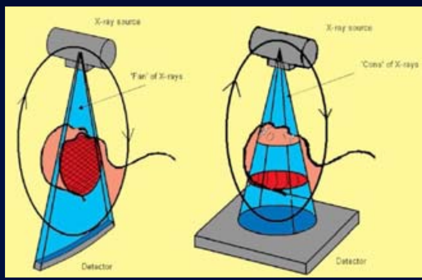
Fan beam and cone beam CT



Fan beam   Cone beam

- Scatter radiation

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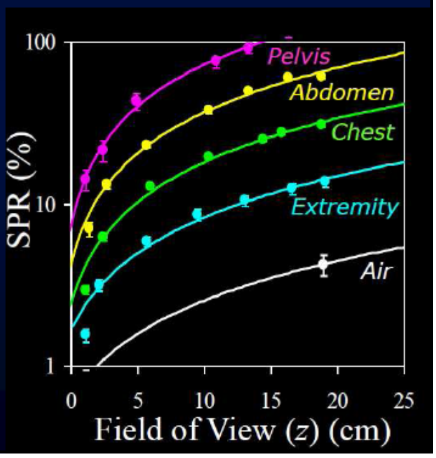
CBCT and Scatter fanction

- As the cone angle(ϕ) is increased, the SPR (scatter to-primary ratio) % becomes significantlY larger
- ϕ ~ 0.5° → SPR ~ 14%
- ϕ > 7° →SPR ~ 120%



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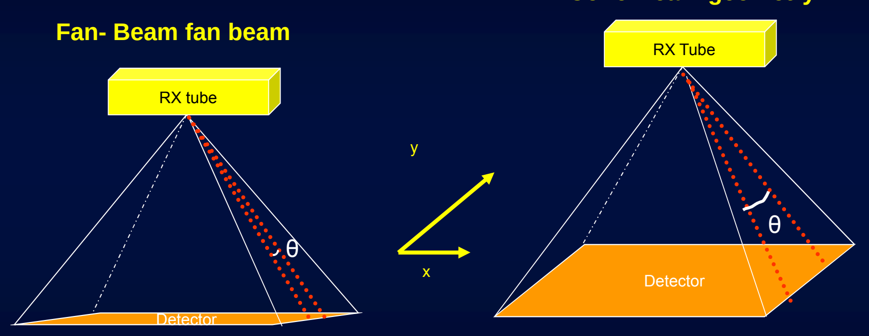
What is Cone Beam ?

We use rectangolar digital detector.
When the detector lateral y dimension are not smal we have cone-beam geometry (CBCT).



One projection corrisponds one slice

3D geometry: a lot of "projections" and multislice

This is the same problem when the number of CT detectors are more than 8

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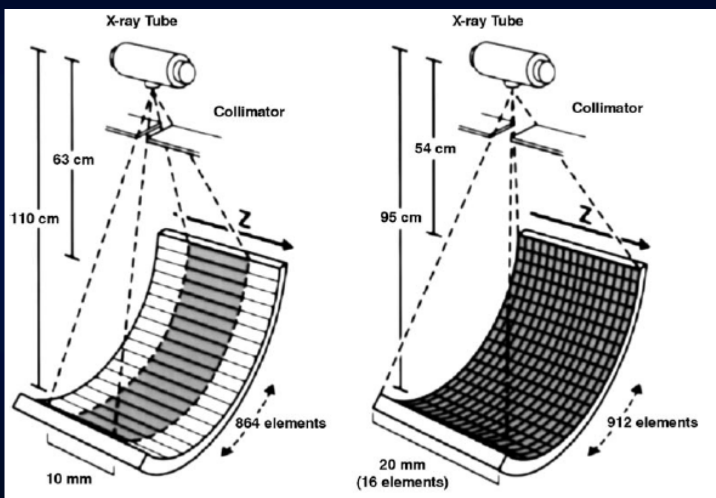
CT geometry



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X- Ray source

The same of diagnostic imaging (more colimationm less filtration low kV, less power and thermal dissipation

Energy : 50 - 120 kV Filtration: 3-15 mm Al

Detector

Se-a flat panel detector
High dynamic rate (until 60 fr/s)

Acquisition Geometry

200˚ - 360˚ rotation angle

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Detector

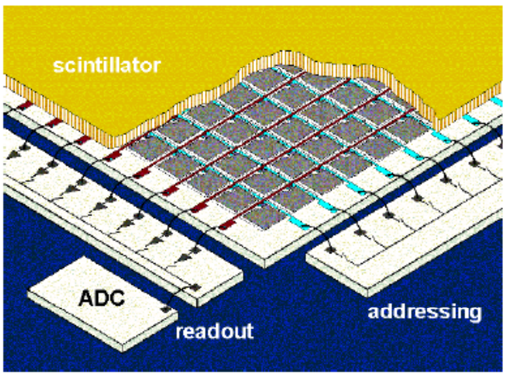

Figure 1. Schematic of a flat-panel detector. An array of amorphous-silicon diodes positioned on a glass plate is covered by a scintillator screen of columnar grown CsI:Tl. Addressing lines and read-out lines are respectively coming from and going to chips at the edge of the plate (courtesy Philips Research Laboratories, Aachen).

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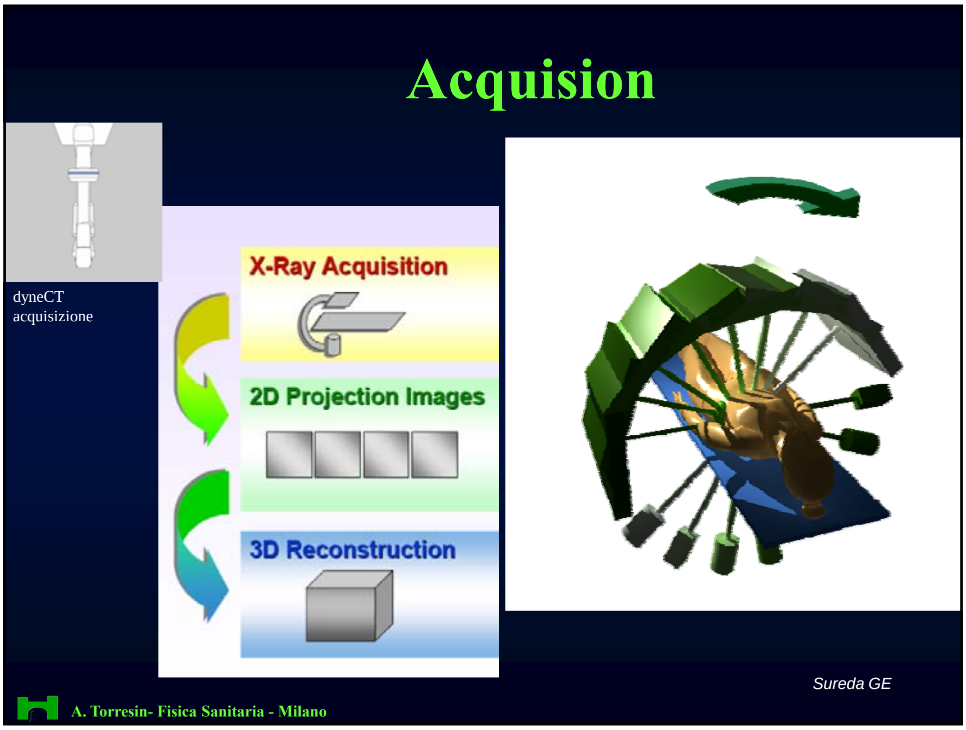
Acquision
dyneCT
acquisizione
X-Ray Acquisition
2D Projection Images
3D Reconstruction
Sureda GE
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Acquisition
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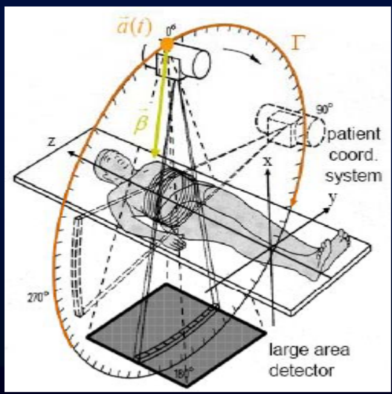
Image reconstruction

During the rotation (360° - 180° +fan angle) planar images are acquired.

These images can be used for reconstruction (theorethical) Radon 3D tecnique is used.
Finally we have a 3D data and 2D images.



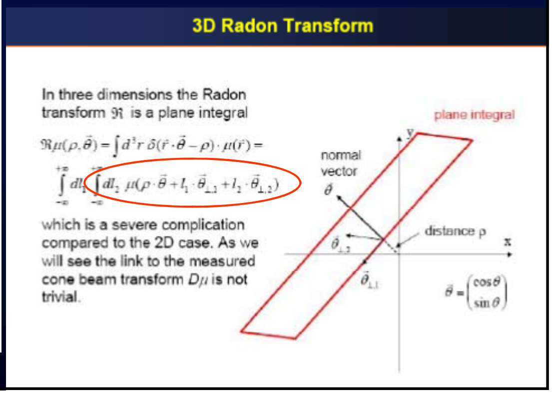
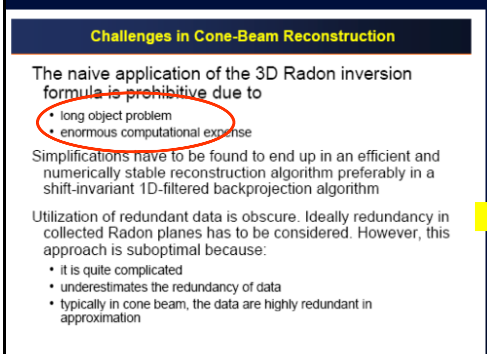


Image reconstruction

Practically we use Feldkamp algorithm or his approximation (es. Feldkamp-Davis-Kress)

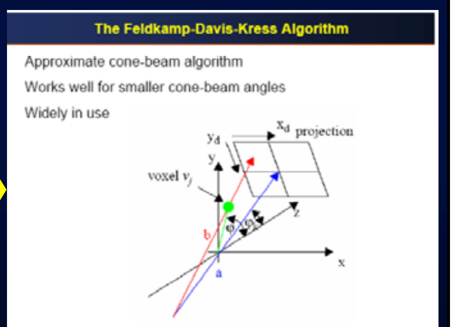


Challenges in Cone-Beam Reconstruction

The naive application of the 3D Radon inversion formula is prohibitive due to
- long object problem
- enormous computational expense

Simplifications have to be found to end up in an efficient and numerically stable reconstruction algorithm preferably in a shift-invariant 1D-filtered backprojection algorithm

Utilization of redundant data is obscure. Ideally redundancy in collected Radon planes has to be considered. However, this approach is suboptimal because:
- it is quite complicated
- underestimates the redundancy of data
- typically in cone beam, the data are highly redundant in approximation



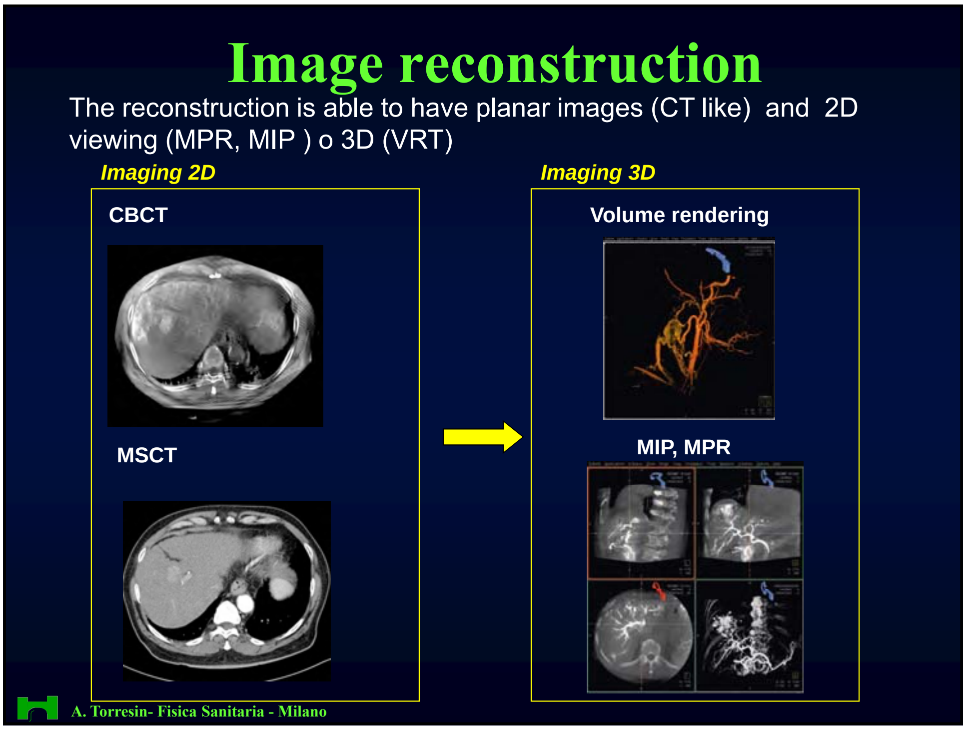


Image reconstruction
The reconstruction is able to have planar images (CT like) and 2D viewing (MPR, MIP) o 3D (VRT)
Imaging 2D
Imaging 3D
CBCT
MSCT
Volume rendering
MIP, MPR
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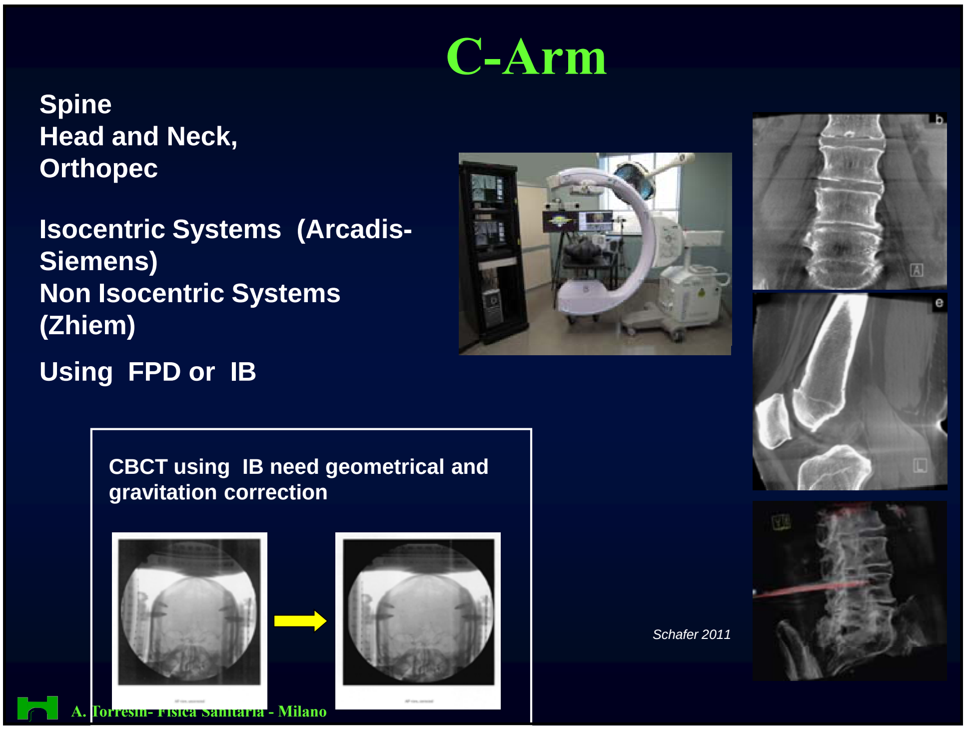
C-Arm
Spine
Head and Neck,
Orthopec
Isocentric Systems (Arcadis-Siemens)
Non Isocentric Systems (Zhiem)
Using FPD or IB
CBCT using IB need geometrical and gravitation correction
Schafer 2011
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O-Arm

In the begining for ***Orthopedic*** *applications*

Now also for ***neurosurgery*** *and* ***angiography***

Detector : a-Si/CsI (Varian - *Paxscan*); 40x30 cm^2;

pixel = 0.194 mm; 2.0kjx1.5k

Filtration: >3.7 mm di Al

Detector source distance : 116.8 cm

Acquisition: 80 -100 -120 kV; 400 mAs (100 mA, 391 projection, 10 ms/projection , 360° , 13s);

Matrix: 256 x 256 x 192, FOV = 21,2 x 21,2 x 16 cm^3

Schouten 2012

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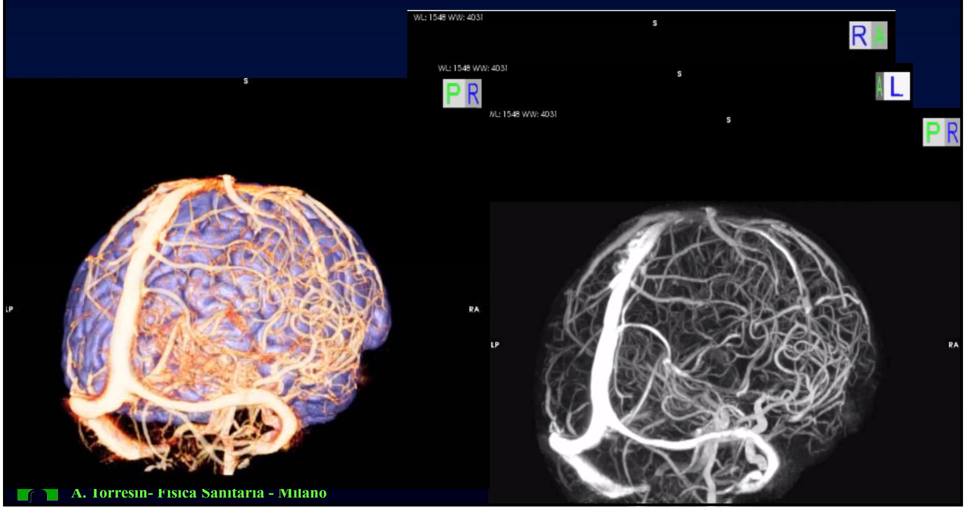
CBCT…some examples



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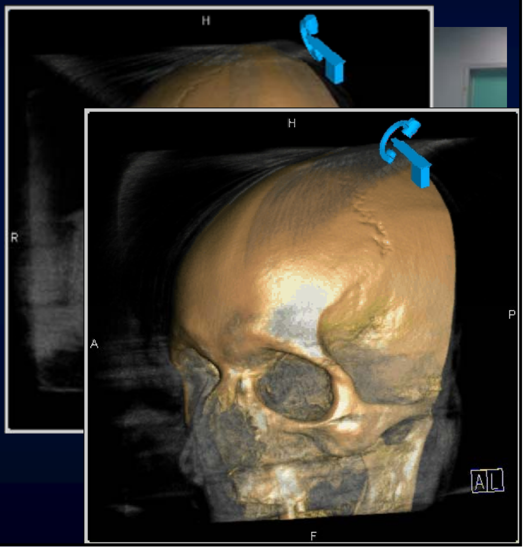
CBCT…some examples

- AXIOM Artis FDi systems (Siemens)
  - FPD 40x30 cm^2
  - a-i/CsI Trixel
  - 0.154 mm pixel size 360°



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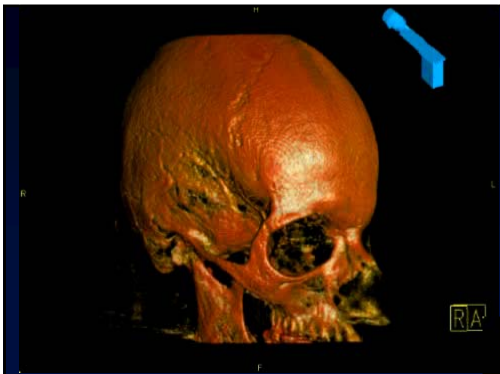

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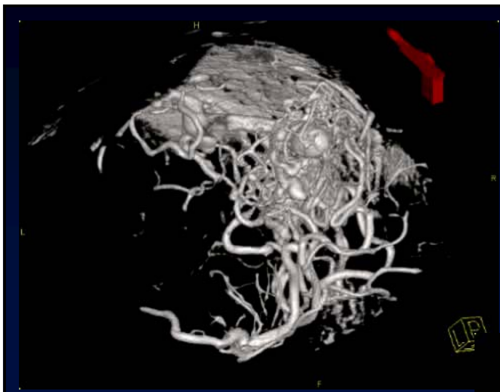

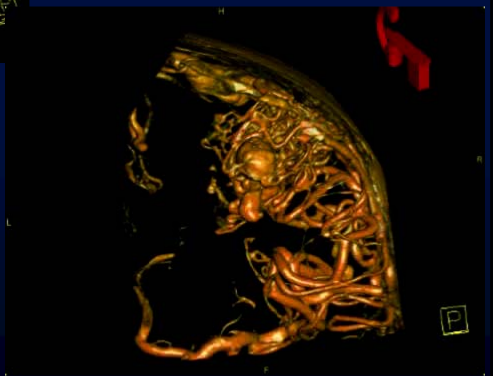

CBCT in Radiotherapy

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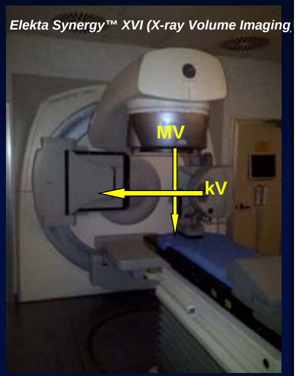
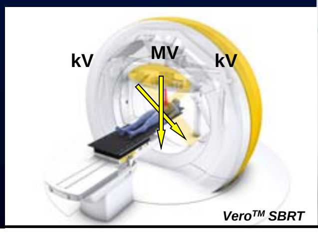
Radiotherapy : kV e MV CBCT

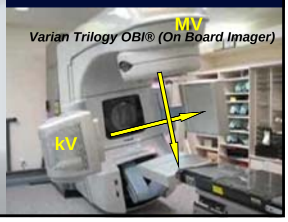
Portal imaging:
MeV 2D acquisition (EPID).
Gemetrical verification
This is the first "imaging gantry-mounted"

Cone Beam CT in RT

Varian Trilogy OBI® (On Board Imager)
Elekta Synergy™ XVI (X-ray Volume Imaging)
Siemens Artiste™ kVision e Mvision* (old)
Vero™ SBRT

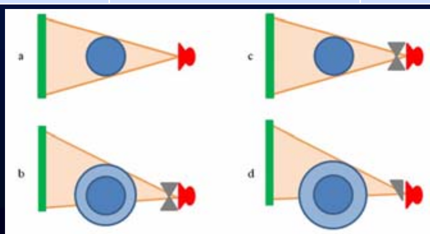






Radiotherapy : kV e MV CBCT

	X ray tube	Detector	Rotation	Reconstructed volume
XVI	90° respect to the head treatment	41x41cm² flat panel a-Si/CsI PerkinElmer Optoelectronics – RID 1640. Pixel 0.4mm Matrice 1kx1k.	~120 s x 360° ~70 s x 180° (360° chest –pelvi) (180° Head & Neck)	Axial FOV: 27 o 41cm (**); Longit FOV: 26 o 12.5 cm
OBI	90° respect to the head treatment	40x30 cm² a-Si:H flat panel 2048x1536 con pixel da 0.194mm	~60 s x 360° ~30 s x 200° (360° chest-pelvi) (200° Head & Neck)	Axial FOV: 25 o 45 cm; Longit FOV:18 o 16
Artiste kVision	180° 90° respect to the head treatment	a-Si flat panel OPTIVUE ™ 1000 ART Imager pixel 0.4 mm ;1024x1024 Active area 409.6x409.6 mm²	Protocol depend . From 2 to 4 min	Axial FOV: 27 o 48 Longit FOV: 27 cm



Different FOV need lateral detector shift

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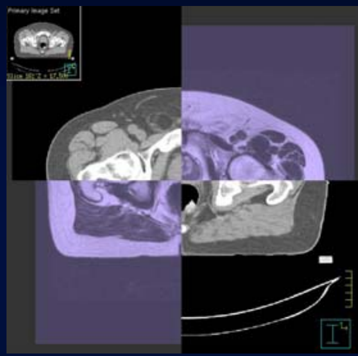
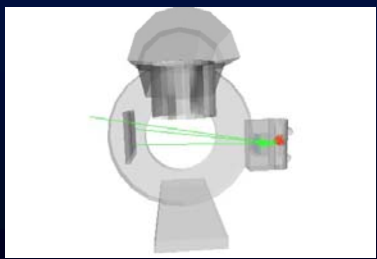
Hyer et al. 2010, JACMP

Elekta XVI





- Synergy XVI (Elekta)
  - FPD 41x41 cm^2
  - a-Si/CsI (PerkinElmer Optoelectronics - RID 1640)
  - pixel = 0.40 mm

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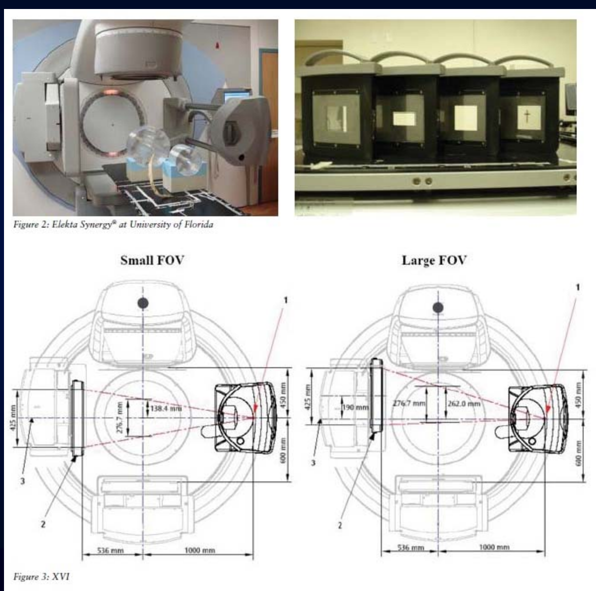
Elekta XVI



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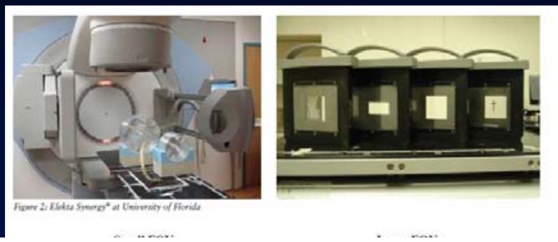
Song WY et al, Med Phys, 2008 and Elekta data Sheet

Elekta XVI



Protocol	Head-and-neck*	Prostate	Pelvis	Chest
Phantom size (cm)	18	30	30	30
kV collimator	S20	M10	M20	L20
kVp	100	120	120	120
mA	10	40	25	25
ms/frame	10	40	40	40
#frames	361	643	643	643
Total mAs	36.1	1028.8	643	643
Acquisition angle**	350° to 190°cw	273 to 269°cw	273° to 269°cw	273° to 269°cw

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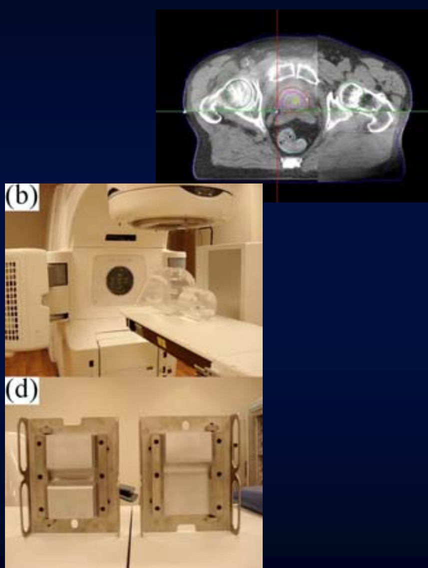
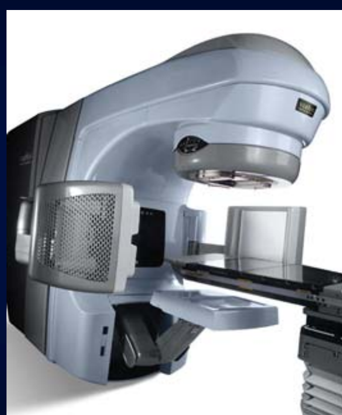
Song WY et al, Med Phys, 2008 and Elekta data Sheet

Varian





Song WY et al, Med Phys, 2008 and Elekta data Sheet

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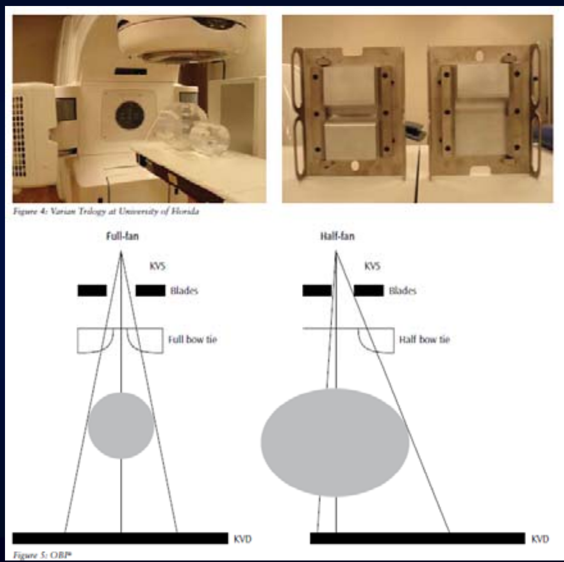
Varian OBI



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Song WY et al, Med Phys, 2008 and Elekta data Sheet

Image Quality

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Acceptance Test (AT) and Quality Control (CQ)

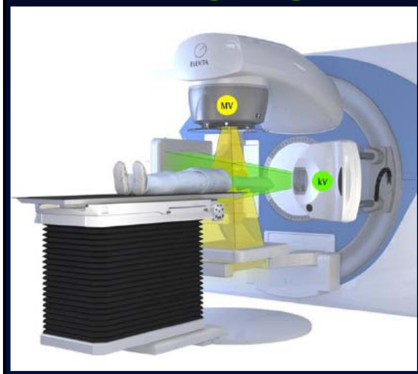
- Quality control begins when the equipment is installed, and continues throughout its lifetime.
- The acceptance test, commissioning, and status testing of equipment should ensure that the system is operational according to the manufacturer's specifications
- At the time of acceptance, baseline measurements of image quality and dosimetry should be taken along with parameters that affect these factors.
- These measurements will be used as a reference for comparison with later measurements, and can indicate if the system performance has degraded and needs corrective action.

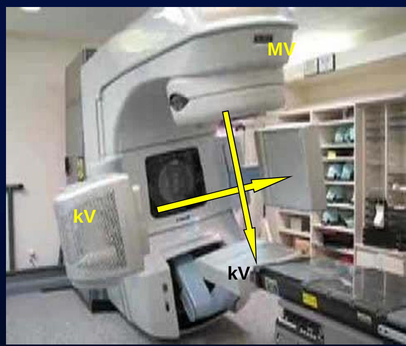
Acceptance Test (AT) and Quality Control (CQ)

- CBCT AT and CQ involve Image Quality&dose
- Large experience in Image Quality&dose in
  - Angiography
  - Dental

BUT in radiotherapy Image quality&dose needs different approaches

CBCT in radiotherapy





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Acceptance Test (AT) and Quality Control (CQ)

- CBCT in radiotherapy:
  - – Patient Geometrical setting
  - – Replanning

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The EFOMP-ESTRO-IAEA protocol for quality control of CBCT

EFOMP European Federation of Organisations for Medical Physics

ESTRO European Society for RADIOTHERAPY & ONCOLOGY

IAEA International Atomic Energy Agency

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EFOMP CBCT working group

Authors (alphabetically)	Affiliation
Jonas Andersson	Norrlands University Hospital, Umea, Sweden
Alexandru Dasu	Linkoping University, Linkoping, Sweden
Sue Edyvean	Public Health England (PHE), Chilton, Didcot, Oxfordshire, UK
Julia Garayoa Roca	Fundacion Jimenez Diaz, Madrid, Spain
Vesna Gershan	Faculty of Natural Sciences and Mathematics, Skopje, Macedonia
Hugo de las Heras Gala *	QUART GmbH, Zorneding, Germany
Irene Hernandez Giron	Leiden University Medical Center, Leiden, The Netherlands
John Holroyd	Dental X-ray Protection Services, PHE, UK
Mats Nilsson Skane	University Hospital, Malmo, Sweden
Primož Peterlin	Institute of Oncology Ljubljana, Slovenia
Osvaldo Rampado	University hospital, Turin, Italy
Christie Theodorakou	The Christie NHS Foundation Trust, Manchester, UK
Alberto Torresin**	Medical Physics Dep. Ospedale Niguarda Ca' Granda, Milano, Italy

* Group leader
** EFOMP supervisor - Education and Training Chairperson of EFOMP

Officially approved from IAEA and ESTRO

This report is dedicated to our deceased colleague and friend Wil van der Putten, who co-founded the WG.

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A fruitful consensus of 20 authors from 12 countries

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An approach to be applied all around the globe

Unified

- **Unite experts** from different fields (radiology and radiotherapy)
- Find a procedure **applicable to all CBCT devices** (dental and interventional radiology & radiotherapy)

Justified

- Use **as plain a language** as possible
- Explain **why it is necessary** to perform the tests
- Describe the **connections with other guidelines** (keep compliance)

Accessible to everyone

- Try to use **inexpensive or free** tools
- Recommend only **objective** and **feasible** tests
- **Publish it for free** (all authors have worked on top of their duties!)

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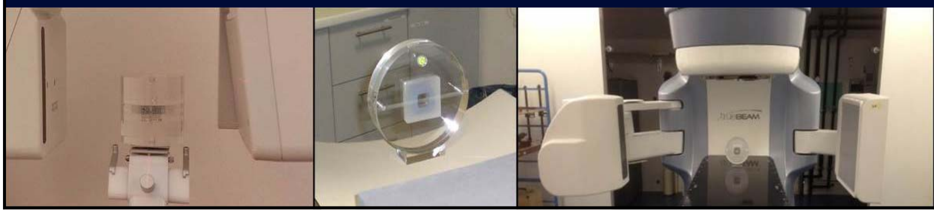
Important:

- The purpose of this guideline is to demonstrate that the same tools (phantoms with specific geometrical setting and software QA evaluation) can be used for all applications of CBCT: dental, interventional radiology and radiotherapy as shown below in the image



The giants' shoulders (previous work)

ICRP publication 129 (2015) — Dose considerations

European guidelines (Pub. Nrs. 162 and 172) (2012)
German standard DIN 6868-161 (2013)
British guidelines HPA-CRCE-010 (2010)
— Dental applications

French guideline SFPM N° 29 (2014) — Radiotherapy applications

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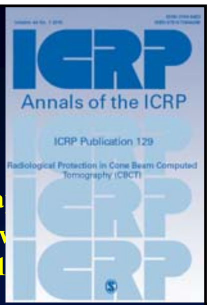
Issue:



- **The ICRP publication 129:**

  "Radiological Protection in Cone Beam Computed Tomogra (CBCT)" Rehani MM, Gupta R, Bartling S, Sharp GC, Pauv R, Berris T, et al. ICRP publication 129. Ann. ICRP 2015;44(1 127

  is the most recent international effort to provide unified recommendations for quality control of CBCT devices.

- **However, the recommendations are focused on the measurement of dose and they only briefly mention measurements of image quality.**

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Objective

The purpose of these guidelines (under discussion since January 2014 within the EFOMP working group) is to present an objective, practical and unifying procedure for quality control of all imaging CBCT applications.

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Quality control in cone-beam computed tomography (CBCT)

EFOMP-ESTRO-IAEA protocol

- **Simplicity in terminology and methodology** has been favoured where different but equivalent terms or methods were available.
- **The presented tools and procedures aim to simplify the work** of professionals involved in the quality control of CBCT.
- The document may also satisfy the **research interest of many Medical Physicists** in objective comparisons among different technologies.
- **Consensus among the group** and with **existing national and international guidelines** has been pursued to define action levels for the different technologies.

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Image quality and dose

To guarantee safety and efficiency of the devices, we recommend frequent tests of

Image quality & dose

...because they take little time (using appropriate software) and represent an overall assessment for quality control

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Phantoms

Phantom	Diameter (mm)	Height (mm)	Materials	Noise/ Uniformity	CNR	Spatial resolution	Contrast resolution	Voxel density values	Artefacts	Geometric accuracy	Applications
Quart DVT_AP	160	150	PMMA PVC Air Enhancement set[2]	Y	Y	Y	*	Y	Y	Y	Universal CBCT[1]
Quart DVT_KP CBCT 161	160	40	PMMA PVC Air	Y	Y	Y	*	Y	Y	Y	Universal CBCT[3]
Quart DVT_150	120 x 120 x 60 mm^3			N	N	Y	N	N	N	N	Dental 3D
SedentexCT IQ	160	162	PMMA Aluminium PTFE Delrin LDPE Air	Y	Y	Y	Y	Y	Y	Y	Dental CBCT
QRM ConeBeam CT	160	143	Water eq Bone eq Air -200HU to -3HU	Y	Y	Y	Y	Y	N	N	Universal CBCT[4]
Steiding *et al*	100	100	-1000HU -30HU 0 30HU HA100-bone eq	Y	Y	Y	N	Y	Y	N	Universal CBCT[5]
Torgersen *et al*	160	70	Polyethene Nylon Acetal Teflon	Y	Y	Y	Y	Y	N	Y	Dental CBCT

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Phantoms

Phantom	Diameter (mm)	Height (mm)	Materials	Noise/ Uniformity	CNR	Spatial resolution	Contrast resolution	Voxel density values	Artefacts	Geometric accuracy	Applications
Catphan	150	250	Teflon, Delrin Acrylic, Polystyrene, H20, LDPE, PMP, Air	Y	Y	Y	Y	Y	Y	Y	Universal CBCT[5]
CIRS radiotherapy	250	330	Electron Density anatomic insert , uniform slab, bone,	Y	Y	Y	Y	Y	Y	Y	Universal CBCT[5]

* The traditional, subjective evaluation of contrast resolution is substituted in these phantoms by an objective evaluation of contrast-to-noise ratio (CNR)
[1]As stated by the manufacturer: dental volume tomography, C-arm angiography, CT
[2]Enhancement set includes: Water, Soft Tissue, Bone and Bone and Tooth equivalent materials
[3]As stated by the manufacturer: dental volume tomography, CBCT, 3D imaging
[4]As stated by the manufacturer: dental volume tomography, C-arm, angiography, CT scanners with large flat panel detectors
[5]As stated by the manufacturer: CBCT systems

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Image quality assessment

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Image Quality

- Image quality is less or more important connected with CBCT application
- CBCT for patient set up
  - Bone / soft tissues (in connection with image registration)
  - Spatial and contrast resolution
  - Geometrical accuracy
- CBCT for replanning
  - Bone or soft tessue (in connection with image registration)
  - Geometrical accuracy
  - Uniformity
  - Linearity (gray level/HU/electron density)
  - Spatial and contrast resolution
  - Artifacts

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Methodology

- Introduction
- Definition
- Purpose
- Equipment
- Test frequency
- Procedures
  - Freeware tip
- Action levels

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Image quality assessment

The parameters used for image quality assessment are:

- *Uniformity*
- *accuracy of density values (or Hounsfield units where appropriate)*
- *geometrical evaluation*
- *Noise*
- *low-contrast resolution (including contrast-to-noise ratio)*
- *high-contrast resolution.*

Detailed procedures using free software and commercially available test phantoms are described in the guidelines, which are currently under external review.

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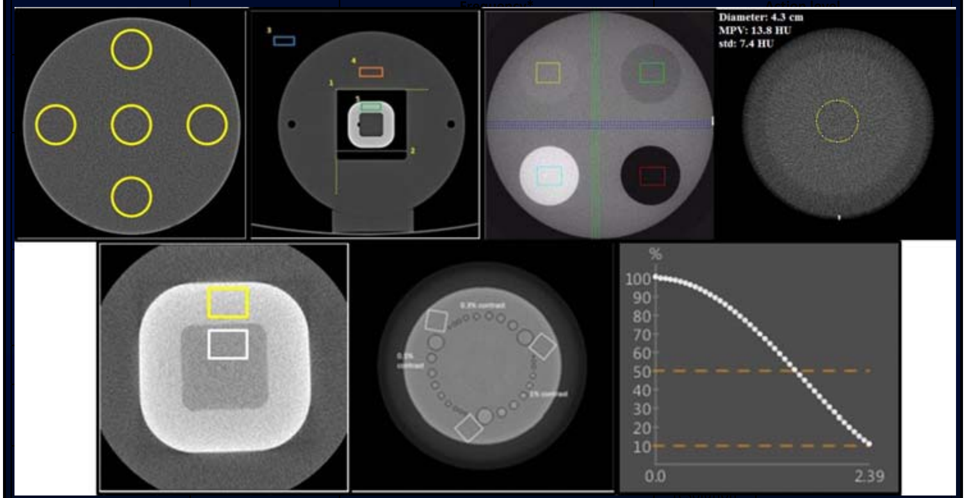
The image quality evaluation is based on objective measurements on phantoms



*Monthly tests are possible with dedicated software

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Summary table of image quality parameters, procedures and action levels. Action levels are highly dependent on the phantom and method used to assess it.

Parameter	Procedures	Frequency*			Action level		
		Dental	Interventional radiology	Radiotherapy	Dental	Interven-tional rad.	Radiotherapy
3.1 Uniformity	XYZ uniformity curves	Annual		Monthly	Manufacturer specifications, or > 10% difference air water		Deviation from baseline > 10 HU
	DIN method				Uniformity parameter U < 5		
3.2 Geometrical precision	Geometrical accuracy	Annual (or none)		Monthly	> 1 mm	> 2 mm	> 2 mm for conventional treatments, >1 mm for SRS/SBRT
	Linearity	Annual (or none)		Monthly			
	Spatial Stability	n.r.		Monthly (coincidence of isocentres daily)	n.r.	n.r.	
3.3 Voxel density values	Voxel values for different materials	Annual		Monthly	Manufacturer specifications, or > 25% difference air water	Deviations > 50 HU from the baseline value (still under research)	
3.4 Noise	ROI standard deviation	Annual		Monthly	Differences from baseline > 20%		
3.5 Low contrast resolution	Contrast-to-noise ratio	Annual			Differences from baseline > 40% Acceptance indicator < 100§		
3.6 Spatial resolution	Frequency at 10 % of the modulation transfer function	Annual			< 10 lp/cm (high resolution mode)	< 5 lp/cm	

Dose measurements

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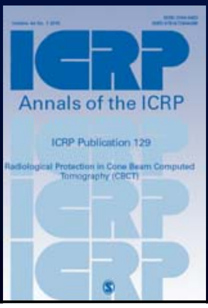
Procedure	Reported value	Method	Reference
MV CBCT			
Head and neck	50–150 mGy	Absorbed dose at isocentre	Pouliot et al., 2005
MV CBCT			
Head and neck	60–73 mGy	TLDs, film and ion chamber measurements in cylindrical and anthropomorphic phantoms	Gayou et al., 2007
Pelvis	99–121 mGy		
kV CBCT			
Head and neck	1–17 mGy	$CTDI_w$	Song et al., 2008
Chest	11–18 mGy		
Pelvis	24–54 mGy		
kV CBCT			
Head and neck	36.6 mGy	$CTDI_w$	Cheng et al., 2011
Pelvis	29.4 mGy	Effective dose, TLDs in female phantom,	
Head and neck	1.7 mSv		
Pelvis	8.2 mSv	absorbed dose to the lens of the eye	
Head and neck	3.8 mGy (new protocol) 59.4 mGy (old protocol)		
kV CBCT			
Head and neck	2.1–10.3 mSv	Effective dose, TLDs in female phantom	Kan et al., 2008
Chest	5.2–23.6 mSv		
Pelvis	4.9–22.7 mSv	Mean skin dose at irradiated site, TLDs in female phantom	
Head and neck	13–67 mGy		
Chest	14–64 mGy		
Pelvis	12–54 mGy		
kV CBCT			
Head and neck	7 ± 0.5 mGy (at simulator)	Average absorbed dose, TLD measurements in anthropomorphic phantom	Stock et al., 2012
Pelvis	1 ± 0.05 mGy (at linac) 12 ± 3 mGy (at linac) 36 ± 12 mGy (at linac)		
kV CBCT			
Chest	Spinal cord: 8–22 mGy Left lung: 12–29 mGy Right lung: 16–40 mGy Heart: 17–30 mGy Body: 12–31 mGy	Absorbed doses from Monte Carlo simulation	Spezi et al., 2012
kV CBCT			
Head and neck	Spinal cord: 1.3–1.7 mGy Mandible: 4.5–8.3 mGy Right parotid: 0.3–2.7 mGy Left parotid: 0.5–2.7 mGy Left eye: 0.1–1.8 mGy Right eye: 0.1–1.8 mGy Oral cavity: 1.7–3.8 mGy	Absorbed doses from Monte Carlo simulation	Spezi et al., 2012

Doses in (CBCT) procedures in radiotherapy.



What is the right Dosimetric indicator?

- Air measurements?

- CTDI and DLP approach?

- Dose Area Product KAP/DAP

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Due to the lack of standardization of radiation dosimetry for CBCT, there are 3 different formalisms:

lack of standardization of radiation dosimetry for CBCT

✓ CTDI [mGy]
✓ KAP [mGy cm^2]
✓ Ka(FDD): Kerma in air at the focal spot-to-detector distance [mGy]

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The dose is evaluated by measuring the KAP or the incident air kerma ($K_{a,i}$) at the detector

Parameter	Frequency			Action level		
	Dental	Interventional radiology	Radiotherapy	Dental	Interventional radiology	Radiotherapy
KAP (Kerma area product)	Annual			KAP larger than 250 mGy cm^2	Not available	Not available
K_a(FDD) (air kerma at the detector)				D_{FOV} larger than 50 mGy (following equation 5.1)		

Open Questions (1/2)

Scattering within the patient:

- can contribute to additional dose to the patient
- reaching the detector can contribute to image degradation
  - Add additional noise
  - Reduce contrast
  - Induce localized artifacts

Open Questions (2/2)

Frequent use of CBCT adds a significant amount of dose to the patients beside the already large doses from regular megavoltage photon beams

1) CBCT patient organ dose must be evaluated

2) CBCT patient organ dose should be calculated by TPS (Total $_{dose}$: kV_{dose} + MV_{dose})

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What to measure ?

Patient's Organ Dose calculated from:

- Scanner Output
  1. From CTDI or CBDI (mGy)
  2. From Kerma Area Product (KAP (mGy cm^2)

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Kerma in air

K_{air}

	Pelvis on line Chest on line	Head and Neck on line S20	Prostate on line
voltage	120 kV	100 kV	120 kV
current	25 mA/frame	10 mA/frame	40 mA/frame
Time per frame	40 ms/frame	10 ms/frame	10 ms/frame
collimator	M20	S20	M10
start --> stop	-179,3° → 179,0°	-100° → 100°	-179,3° → 179,0°
No. Frame	648	362	648
→ mAs	648 mAs	36,2 mAs	1038,8 mAs
K_{air}/frame @virtual iso	**66,2 μGy / frame**	**3,77 μGy / frame**	**27,3 μGy / frame**
nK_{air} @virtual iso	**6,6 mGy / 100mAs**	**3,8 mGy / 100mAs**	**6,6 mGy / 100mAs**

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From KAP (mGy cm^2)

MC - PCXMC2.0 Rotation

- **PCXMC 2.0 Rotation (Stuk, Helsinki, Finland)**
- **Monte Carlo *data sets based***
- **Reference Phantom: Cristy/Eckerman**

- **Input Parameters**
  - **Anatomical and geometrical patient info (age, weight, gender…)**
  - **RX tube info: filtration, field…**
  - **KAP**

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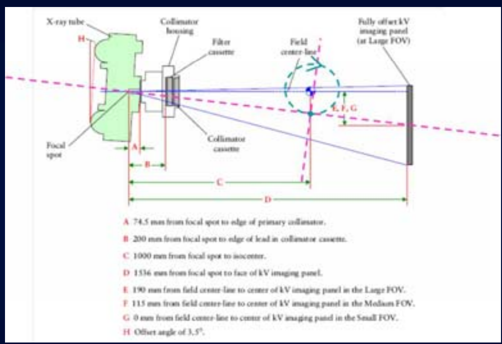
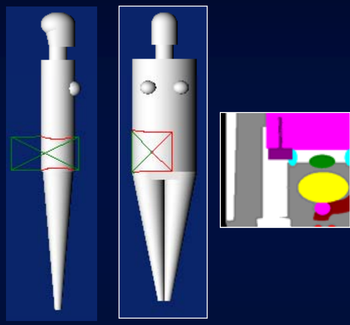
PCXMC modelling

- PCXMC needs isocentric symmetrical fields





LL view AP view

K_{air} @ iso = (6,6 mGy/100 mAs * 648 mAs) ~ 43 mGy

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Patient's Organ Dose pCT vs CBCT

Typical prostate IGRT/IMRT

	Dose (mGy)		
	pCT/exam	CBCT/exam	In vivo CBCT/ exam
Prostate	17	18	
Testis	8	11	
Bladder	21	24	
Rectum	16	17	17.2 (1)
Kidney	2	2	

(1): C.Walter et al, Radiotherapy and Oncology 85 (2007) 418–423

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Patient's Organ Dose
IMRT vs CBCT

- **For a typical prostate IGRT/IMRT course (~80 Gy)**

Where?	IMRT dose/fraction (Gy)	kV CBCT dose/fraction (Gy)
PTV	2	
Rectum	0.9	0.017
Bladder	0.7	0.024

- **The usage of kV CBCT in the clinical practice should be kept as minimum as possible (OAR)**

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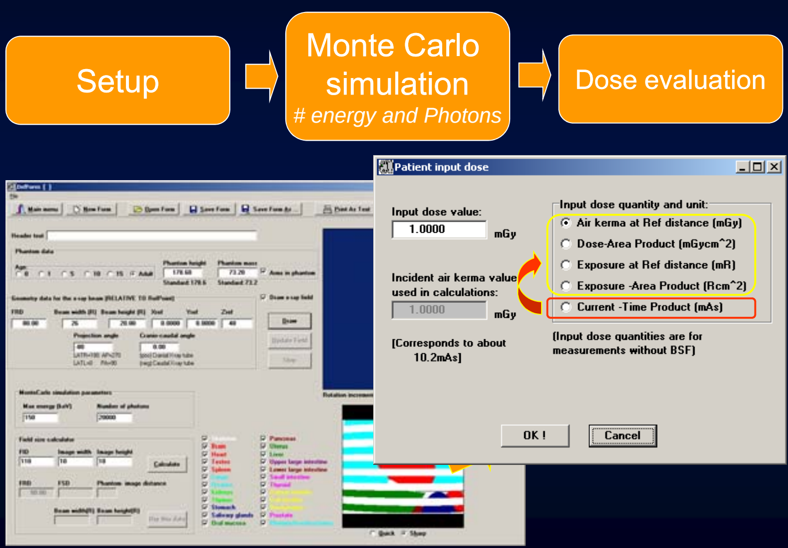

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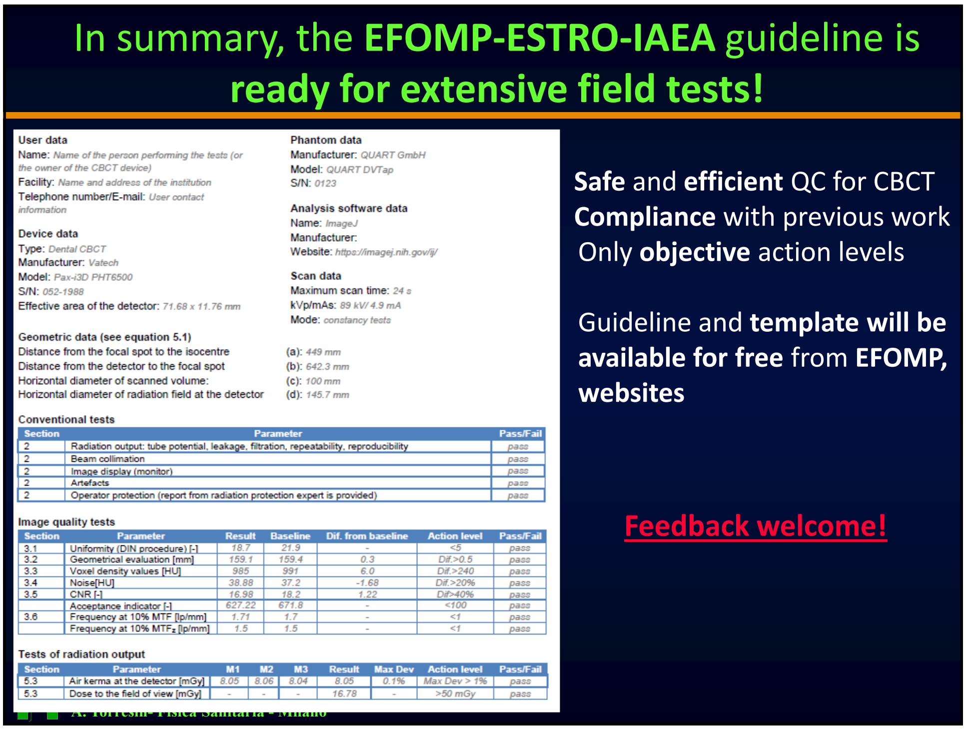


User data
Name: *Name of the person performing the tests (or the owner of the CBCT device)*
Facility: *Name and address of the institution*
Telephone number/E-mail: *User contact information*

Device data
Type: *Dental CBCT*
Manufacturer: *Vatech*
Model: *Pax-i3D PHT6500*
S/N: *052-1988*
Effective area of the detector: *71.68 x 11.76 mm*

Phantom data
Manufacturer: *QUART GmbH*
Model: *QUART DVTap*
S/N: *0123*

Analysis software data
Name: *ImageJ*
Manufacturer:
Website: *https://imagej.nih.gov/ij/*

Scan data
Maximum scan time: *24 s*
kVp/mAs: *89 kV/ 4.9 mA*
Mode: *constancy tests*

Geometric data (see equation 5.1)
Distance from the focal spot to the isocentre (a): *449 mm*
Distance from the detector to the focal spot (b): *642.3 mm*
Horizontal diameter of scanned volume: (c): *100 mm*
Horizontal diameter of radiation field at the detector (d): *145.7 mm*

Conventional tests

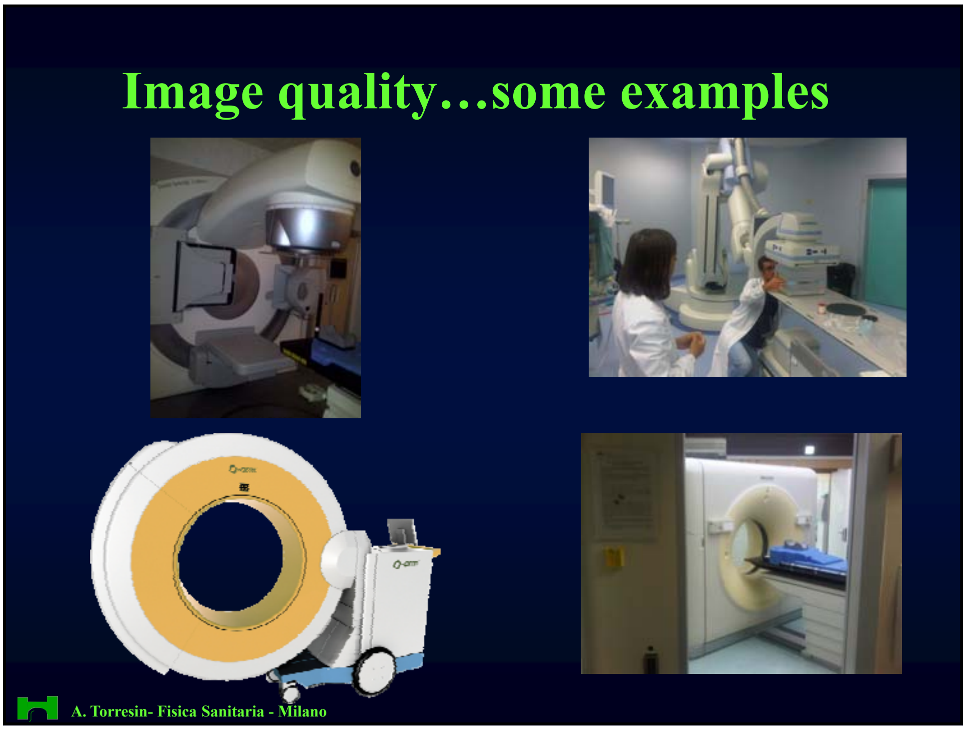
Section	Parameter	Pass/Fail
2	Radiation output: tube potential, leakage, filtration, repeatability, reproducibility	pass
2	Beam collimation	pass
2	Image display (monitor)	pass
2	Artefacts	pass
2	Operator protection (report from radiation protection expert is provided)	pass

Image quality tests

Section	Parameter	Result	Baseline	Dif. from baseline	Action level	Pass/Fail
3.1	Uniformity (DIN procedure) [-]	18.7	21.9	-	<5	pass
3.2	Geometrical evaluation [mm]	159.1	159.4	0.3	Dif.>0.5	pass
3.3	Voxel density values [HU]	985	991	6.0	Dif.>240	pass
3.4	Noise[HU]	38.88	37.2	-1.68	Dif.>20%	pass
3.5	CNR [-]	16.98	18.2	1.22	Dif>40%	pass
	Acceptance indicator [-]	627.22	671.8	-	<100	pass
3.6	Frequency at 10% MTF [lp/mm]	1.71	1.7	-	<1	pass
	Frequency at 10% MTF_z [lp/mm]	1.5	1.5	-	<1	pass

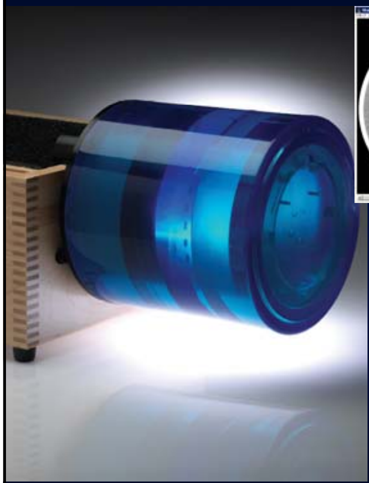
Tests of radiation output

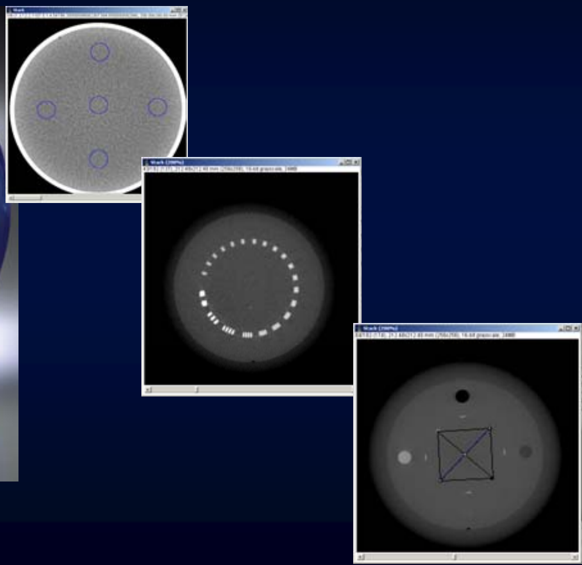
Section	Parameter	M1	M2	M3	Result	Max Dev	Action level	Pass/Fail
5.3	Air kerma at the detector [mGy]	8.05	8.06	8.04	8.05	0.1%	Max Dev > 1%	pass
5.3	Dose to the field of view [mGy]	-	-	-	16.78	-	>50 mGy	pass



Phantom for image quality

CatPhan 600





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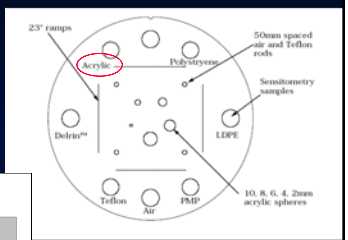
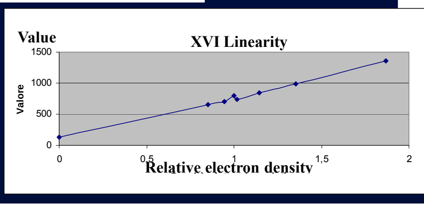
Linearity – Contrast Scale

$$CS = \frac{\mu_{acrylic} - \mu_{water}}{mean_{acrylic} - mean_{water}}$$





Linearity - Contrast scale

	CBCT Elekta XVI	CT Philips Brilliance 16	AngioCT Axiom Siemes	O-Arm Medtronic
Contrast Scale (CS)	5,60E-04	1,84E-04	2,93E-04	6,10E-05

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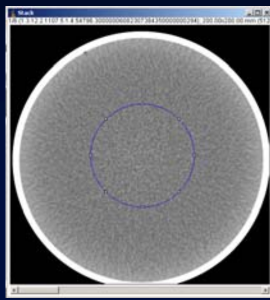
Uniformity and Noise



Uniformity and Noise

	CBCT Elekta XVI	CT Philips Brilliance 16	AngioCT Axiom Siemens	O-Arm Medtronic
Voltage (kV)	120	120	70	120
Uniformity %	1,46	0,4	0,9	0,4
Noise %	1,26	0,47	2,97	0,7

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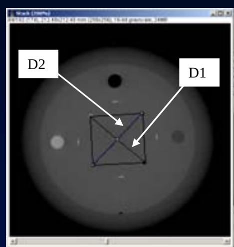
Geometrical Distorsion

$$GD\% = 100 \bullet Max \frac{Dist_{measured} - Dist_{true}}{Dist_{true}}$$



Geometrical Distortion

	CBCT Elekta XVI	CT Philips Brilliance 16	AngioCT Axiom Siemens	O-Arm Medtronic
Voltage (kV)	120	120	70	120
Geometrical Distorsion	0,5%	0,5%	0,3%	1,5%

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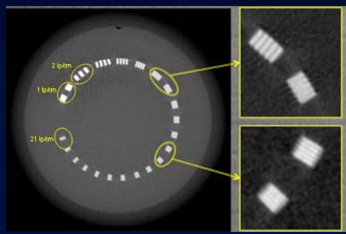
Spatial Resolution



Spatial Resolution

	CBCT Elekta XVI	CT Philips Brilliance 16	AngioCT Axiom Siemes	O-Arm Medtronic
MTF%	7 lp/cm	6 lp/cm	8 lp/cm	9 lp/cm

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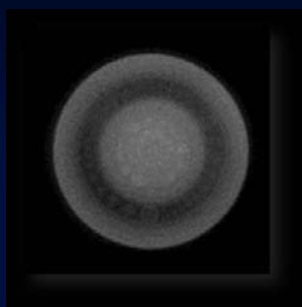
Low Contrast Resolution



Low Contrast Resolution

	Minimum visible dimension (mm)			
Nominal contrast	CBCT Elekta XVI	CT Philips Brilliance 16	AngioCT Axiom Siemens	O-Arm Medtronic
1,0%	3	2	3	3

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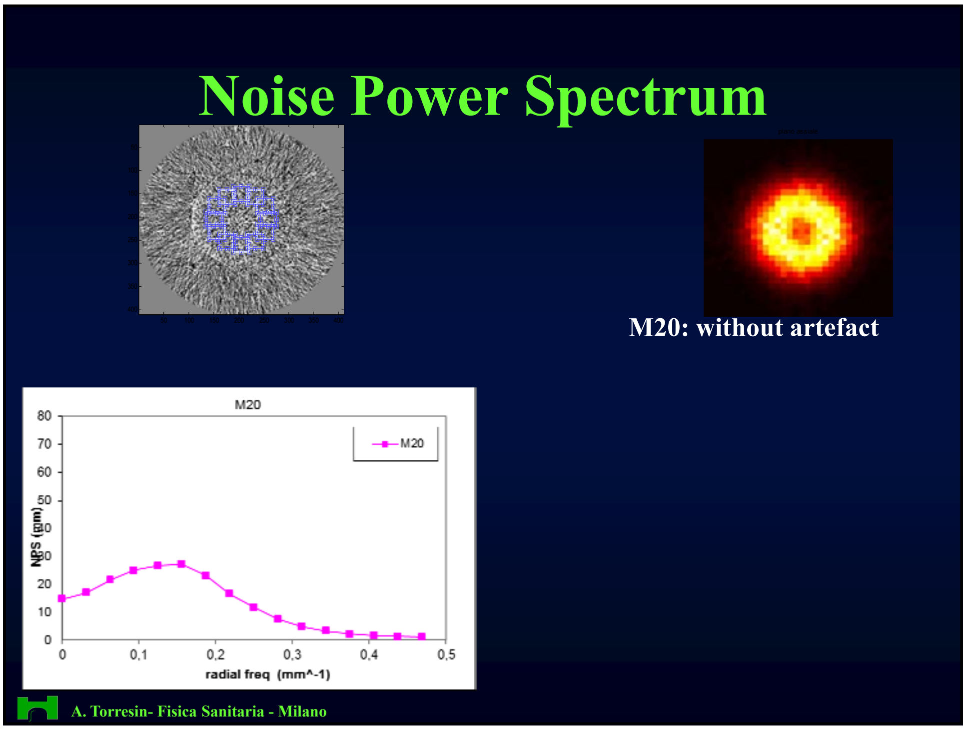
Noise Power Spectrum
M20: without artefact
M20
M20
NPS (gm)
radial freq (mm^-1)
80
70
60
50
20
10
0
0
0,1
0,2
0,3
0,4
0,5
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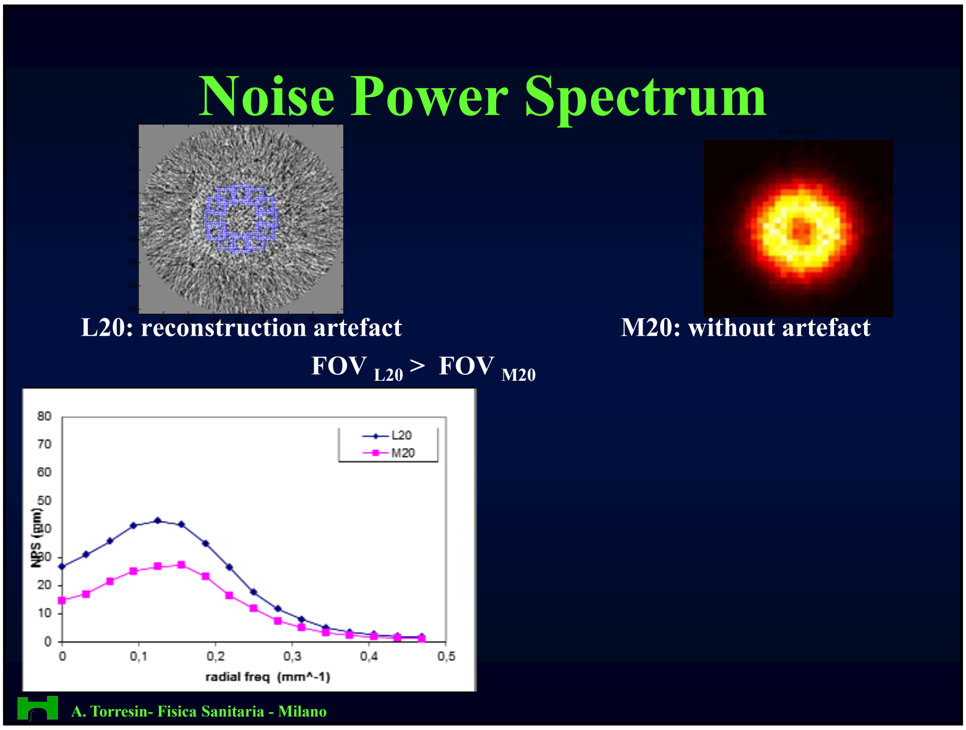
Noise Power Spectrum
L20: reconstruction artefact
M20: without artefact
FOV L20 > FOV M20
L20
M20
NPS (gm)
radial freq (mm^-1)
80
70
60
50
20
10
0
0
0,1
0,2
0,3
0,4
0,5
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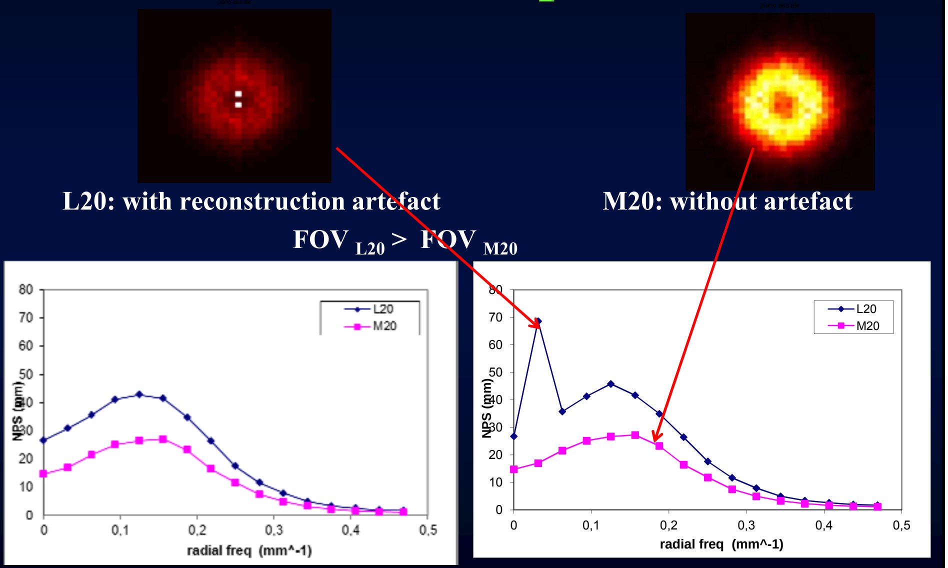
Noise Power Spectrum



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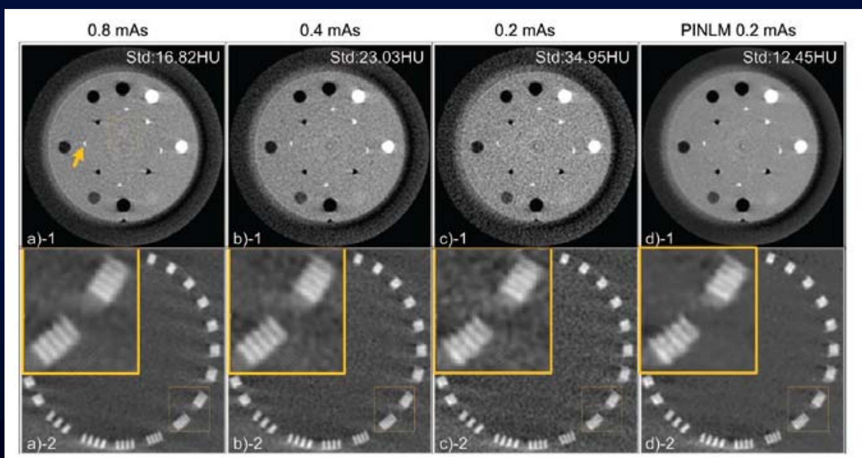
To improve the image quality of CBCT Reconstructed image algorithm

Yan et al. Med Phy 2014

- A progressive dose control scheme: **dose reduction - reconstructed algorithm** and **image quality**.



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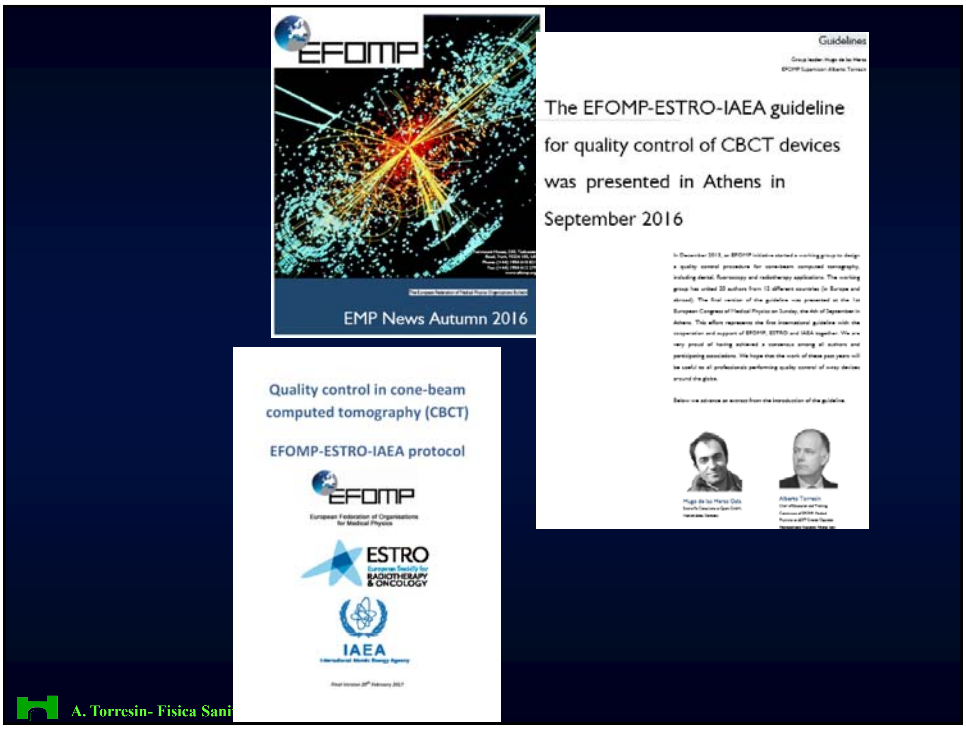

Training

- The level of training in radiological protection should be commensurate with the level of expected radiation exposure (ICRP Publication 113)
- All workers intending to use CBCT for diagnostic purposes should be trained in the same manner as for diagnostic CT, and those intending to perform interventional CBCT should be trained in the same manner as for interventional CT.

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Conclusions

- These guidelines include the minimum tests that should be performed to ensure reliable, safe and consistent performance of CBCT devices.
- This minimum has been sought to guarantee compatibility with all manufacturers, all cone beam modalities and existing national and international documents

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Conclusions

- A spreadsheet will be prepared to support the data analysis
- The protocol will be useful to compare measurements of different centers
- Any comments from you are welcome!

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For exercise

- **Quality control in cone-beam computed tomography (CBCT): EFOMP-ESTRO-IAEA protocol**
- **Two open source sotware: ImageJ and IQ Works for image display and Image Analysis**
- **You can find an image acquisition of Cadphan Phantom acquired by Claudia Carbonini (Medical Physicis of Med Phys- Niguarda, MI, Italy) using Elekta Synergy CBCT.**
- **DEMO of some application of the protocol;**

All the best from Milano

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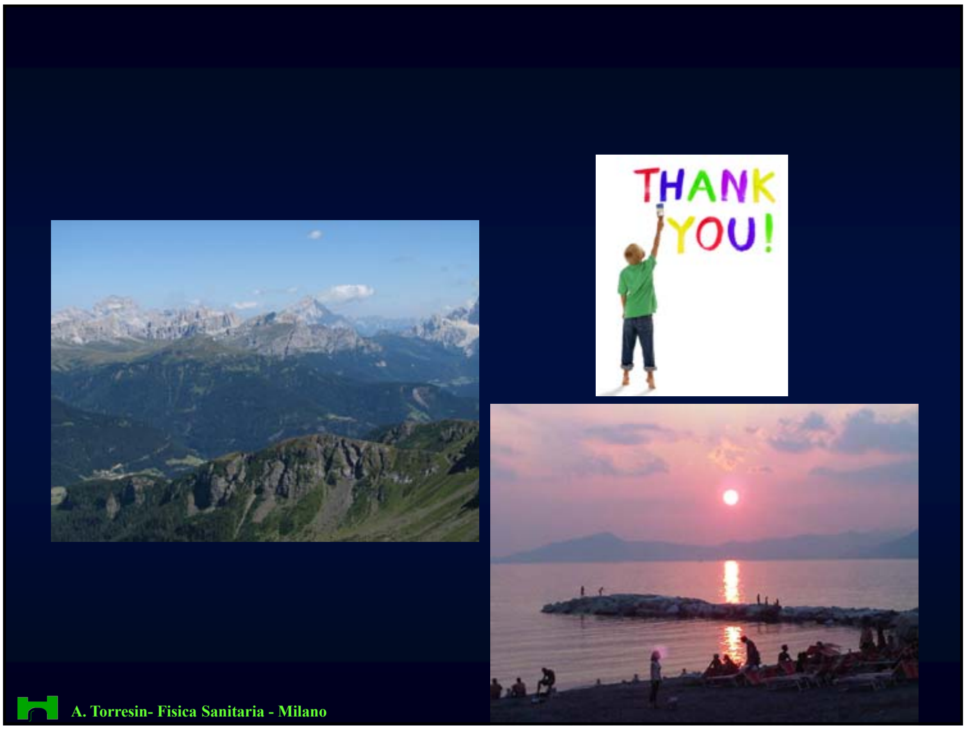
THANK YOU!
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