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SANT' ANDREA
FACOLTÀ DI MEDICINA E
PSICOLOGIA

U.O.C Radioterapia Oncologica

Mattia F. Osti

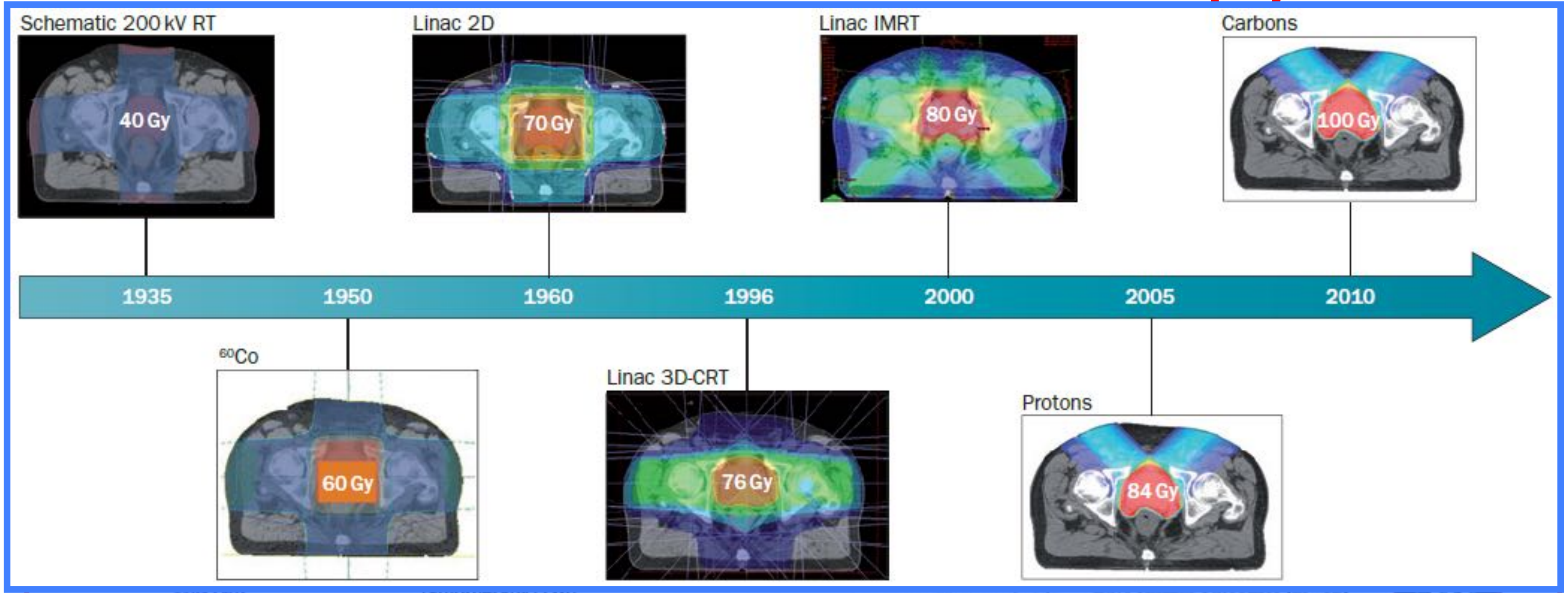
IGRT nella pratica clinica: basse o alte dosi per il paziente?

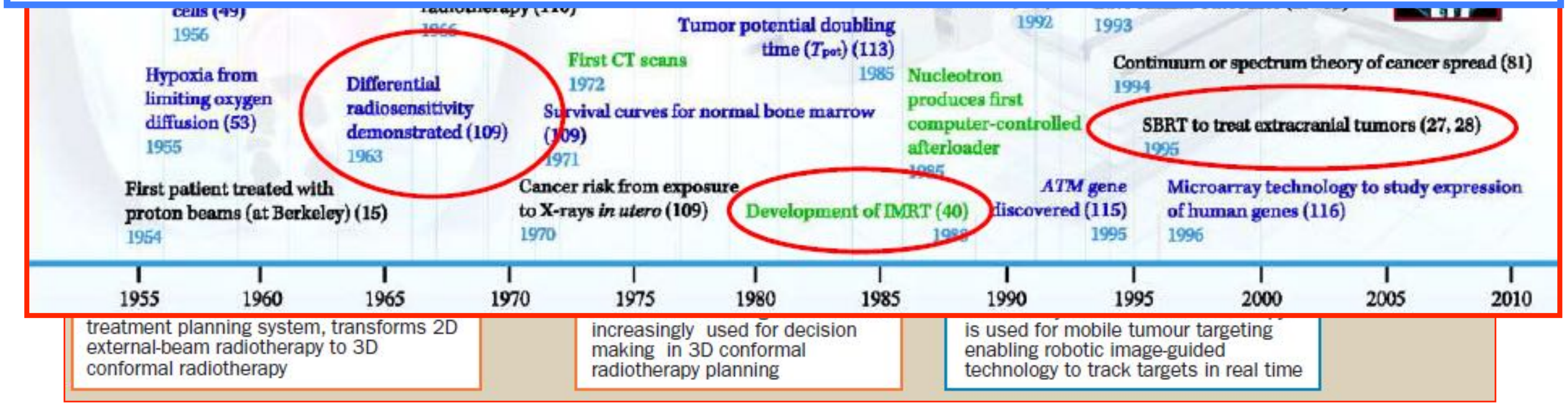
Image-guided Radiation Therapy in clinical practice: low or high doses for the patients?

Rimini, 9.11. 2015

AIRO
Associazione
Italiana
Radioterapia
Oncologica

Evolution of Radiotherapy





treatment planning system, transforms 2D external-beam radiotherapy to 3D conformal radiotherapy

increasingly used for decision making in 3D conformal radiotherapy planning

is used for mobile tumour targeting enabling robotic image-guided technology to track targets in real time

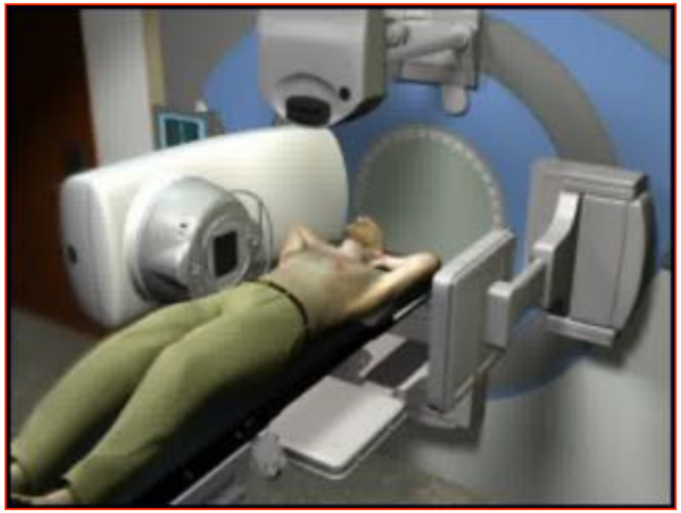
Cancer Res 2009; 69: (2), 2009

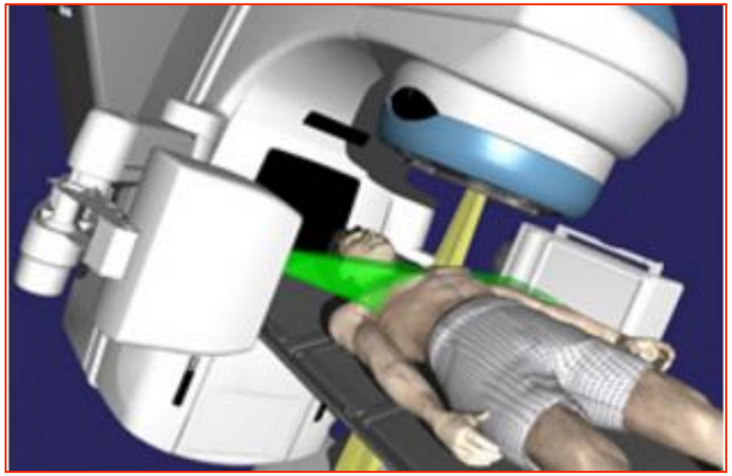
Thariat, J *et al. Nat. Rev. Clin. Oncol.* 10, 2013

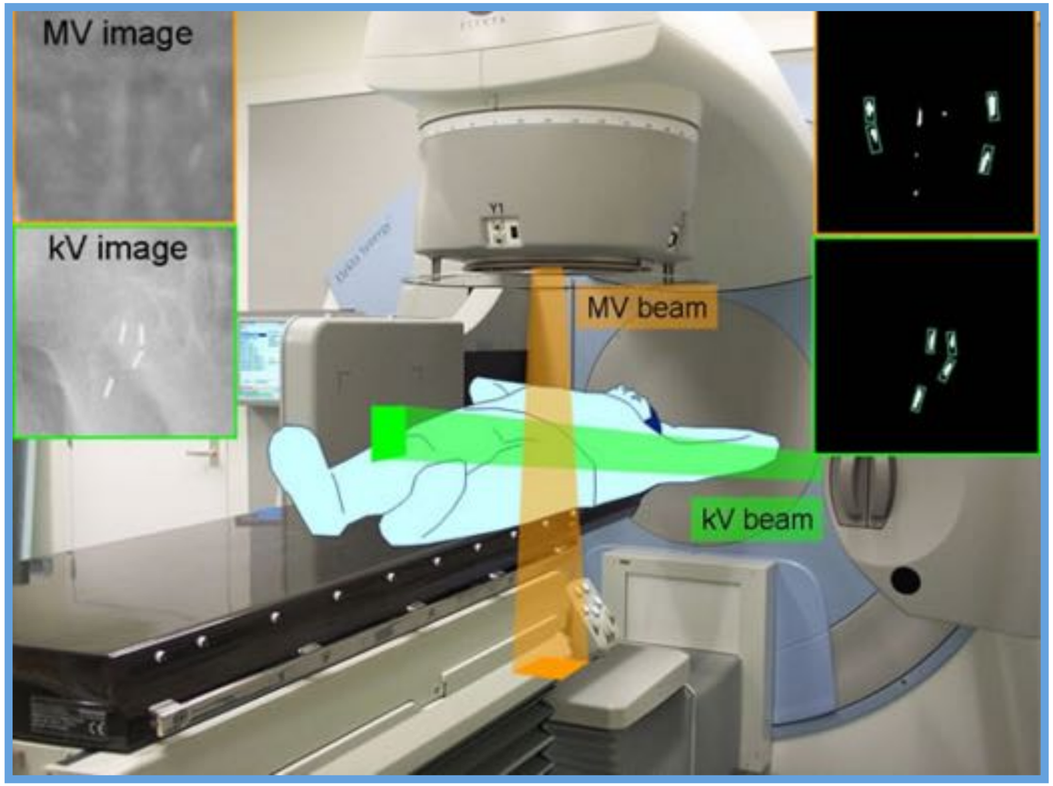
Basic hypotesis of Image-Guided Radiation Therapy

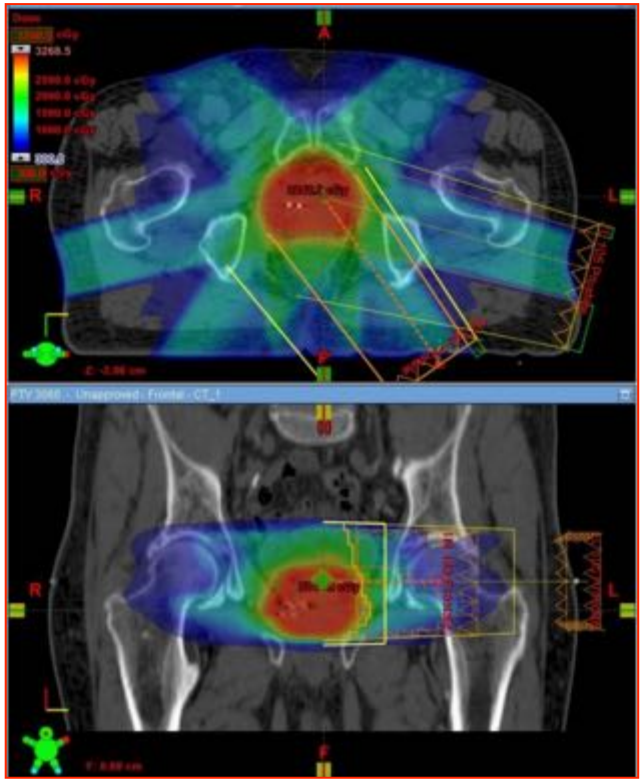
"Increasing the precision and accuracy of radiation delivery will reduce toxicity with potential for dose escalation and improved tumor control"

RTOG, Reasearch Plan 2002-2006 IGRT Committee
Int. J Radiat Oncol Biol Phys 2001;51






MV image
kV image
MV beam
kV beam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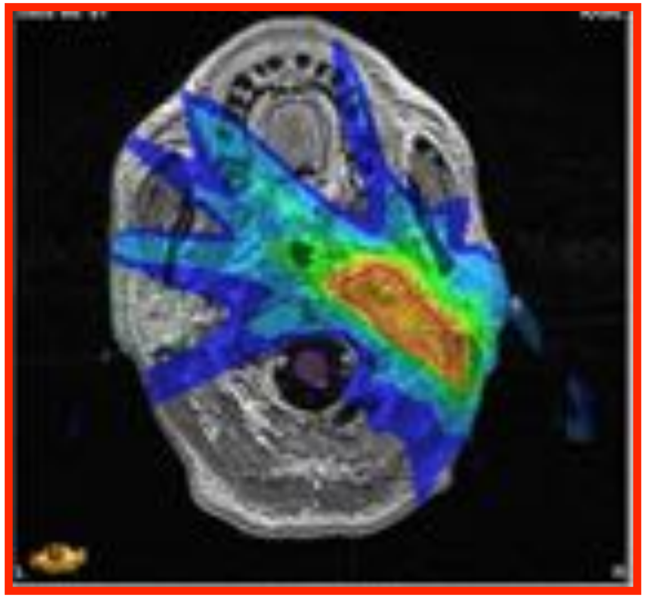
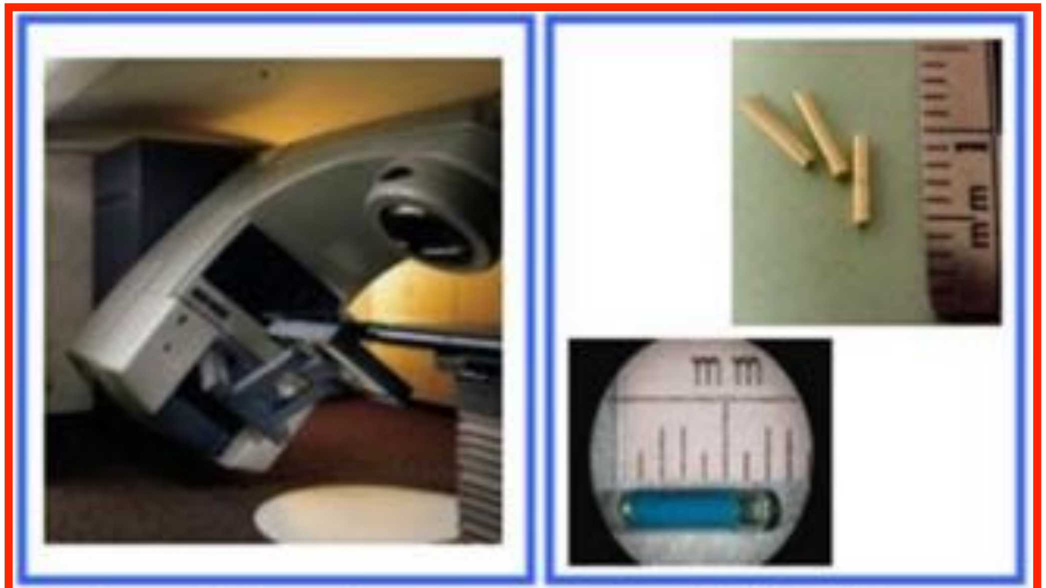


Different IGRT

Ultrasound

kV Radiographic

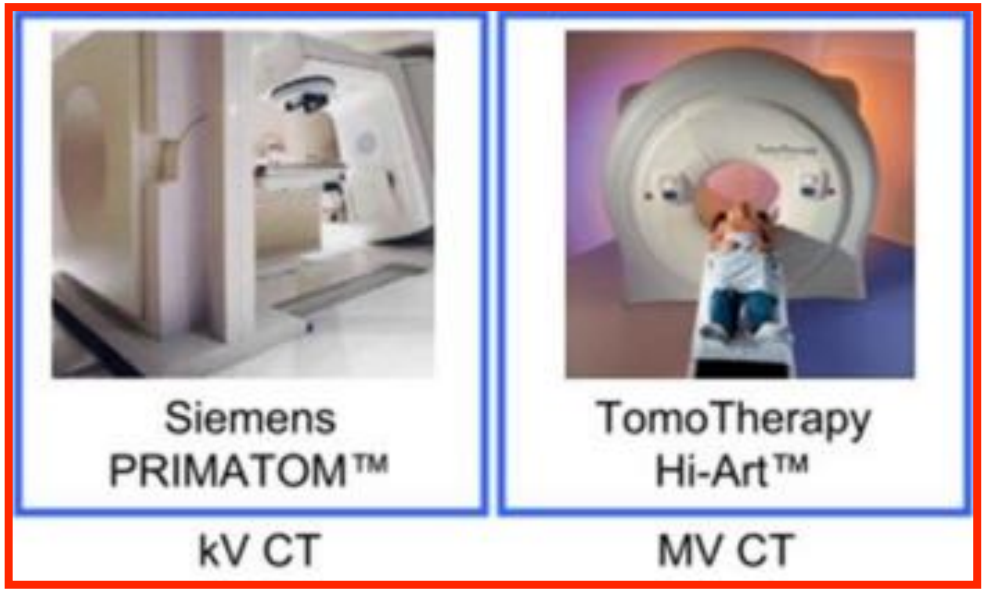


Portal Imaging

Markers

In - Room Imaging Technologies

CT on rails



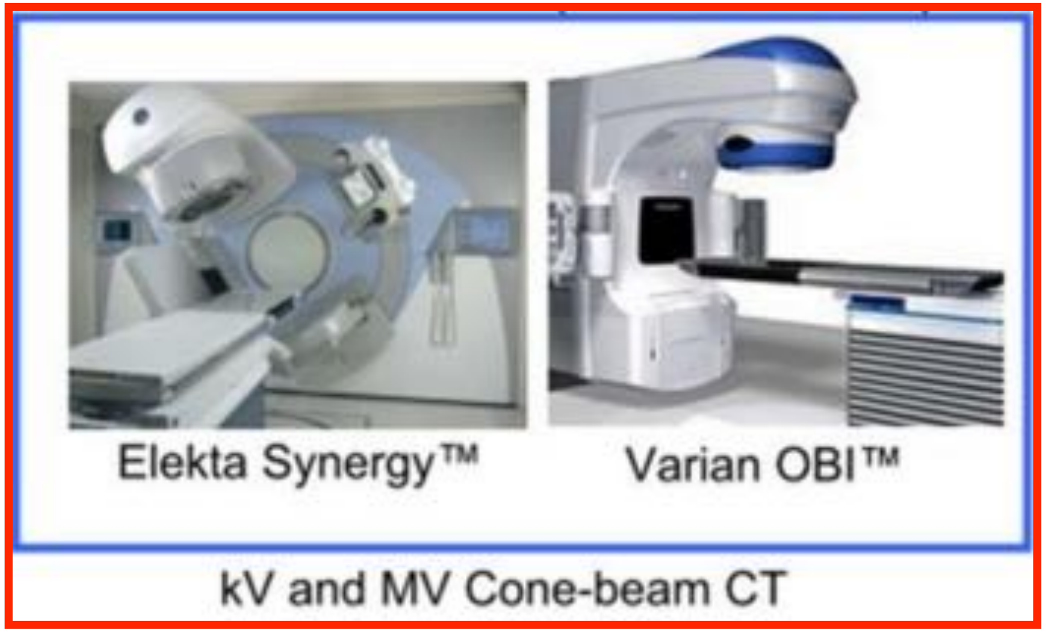
Siemens PRIMATOM™

TomoTherapy Hi-Art™

kV CT

MV CT

kV and MV CB imaging

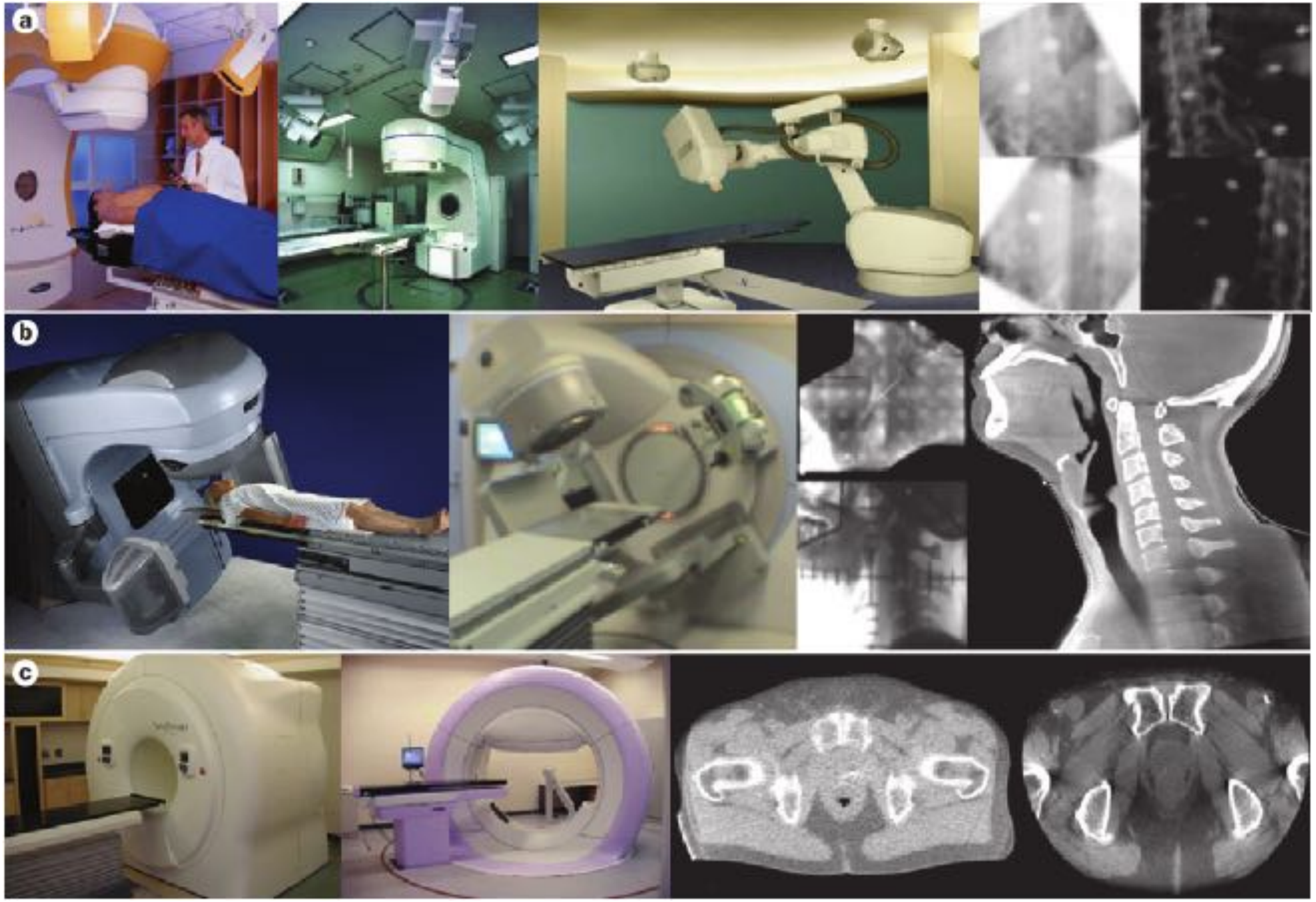


Elekta Synergy™

Varian OBI™

kV and MV Cone-beam CT

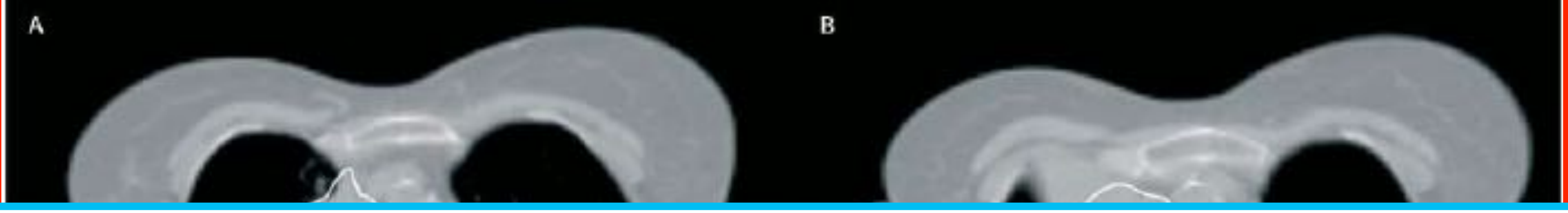
Image-guided radiotherapy: from current concept to future perspectives

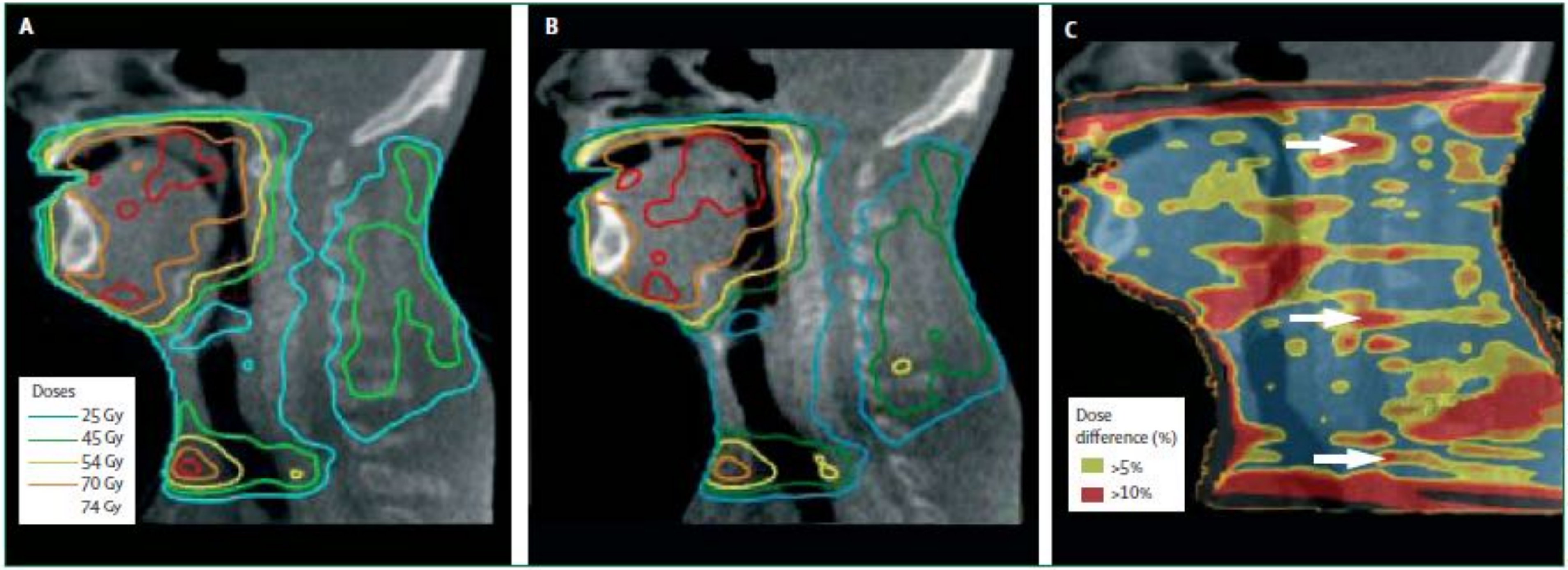


Jaffray, D. A. *Nat. Rev. Clin. Oncol.* **9**, 688–699 (2012)

Image-guided radiotherapy: rationale, benefits, and limitations

Lau

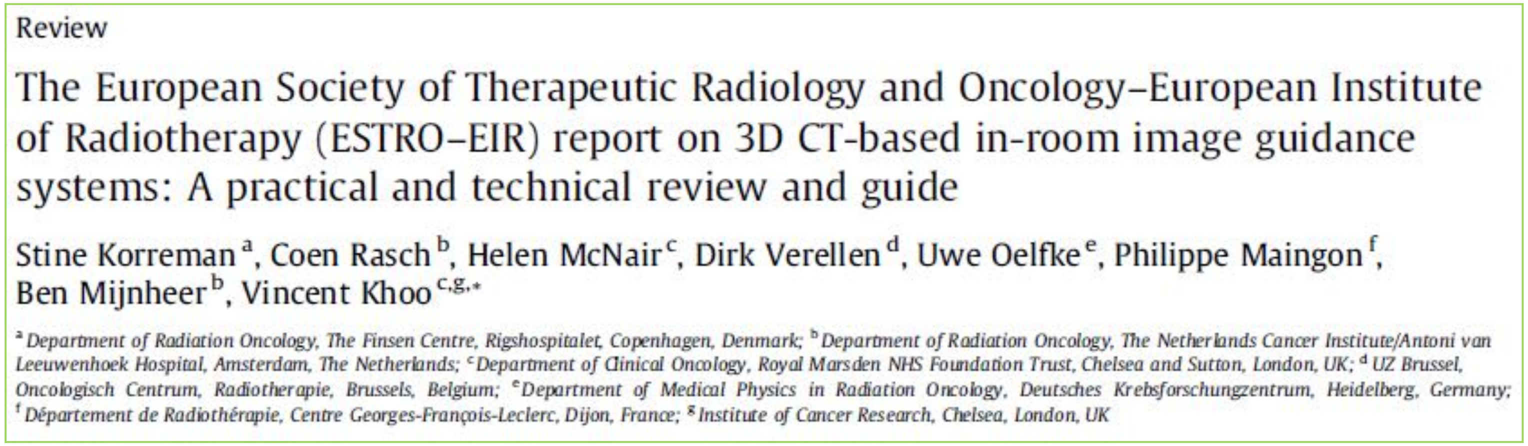




Differing doses because of anatomical changes from weight loss during radiotherapy

Change in volume and position of adenocarcinoma of right lung during radiotherapy

Lancet Oncol 2006; 7



Review

The European Society of Therapeutic Radiology and Oncology–European Institute of Radiotherapy (ESTRO–EIR) report on 3D CT-based in-room image guidance systems: A practical and technical review and guide

Stine Korreman[a], Coen Rasch[b], Helen McNair[c], Dirk Verellen[d], Uwe Oelfke[e], Philippe Maingon[f], Ben Mijnheer[b], Vincent Khoo[c,g,*]

[a] Department of Radiation Oncology, The Finsen Centre, Rigshospitalet, Copenhagen, Denmark; [b] Department of Radiation Oncology, The Netherlands Cancer Institute/Antoni van Leeuwenhoek Hospital, Amsterdam, The Netherlands; [c] Department of Clinical Oncology, Royal Marsden NHS Foundation Trust, Chelsea and Sutton, London, UK; [d] UZ Brussel, Oncologisch Centrum, Radiotherapie, Brussels, Belgium; [e] Department of Medical Physics in Radiation Oncology, Deutsches Krebsforschungzentrum, Heidelberg, Germany; [f] Département de Radiothérapie, Centre Georges-François-Leclerc, Dijon, France; [g] Institute of Cancer Research, Chelsea, London, UK

✓EIR and ESTRO provide consensus statement with evidence-based and pragmatic guidelines on topics of practical relevance for radiation oncology

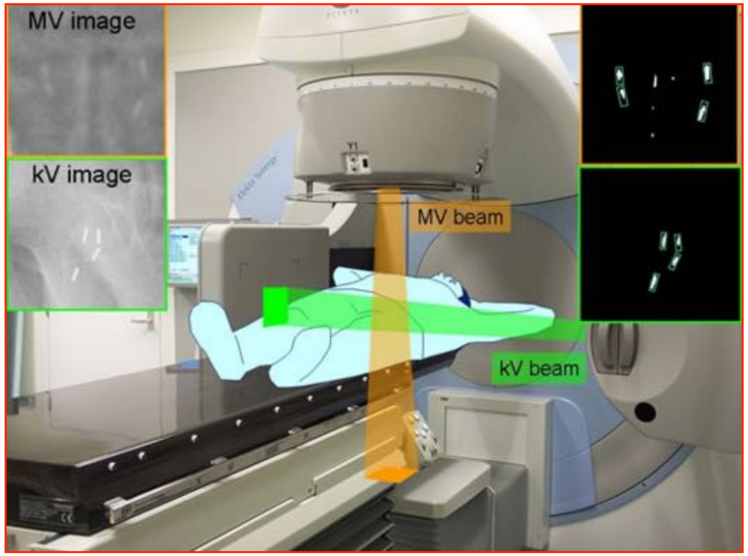
✓This report focuses primarily on 3D CT – based in-room image guidance (3DCT-IGRT)

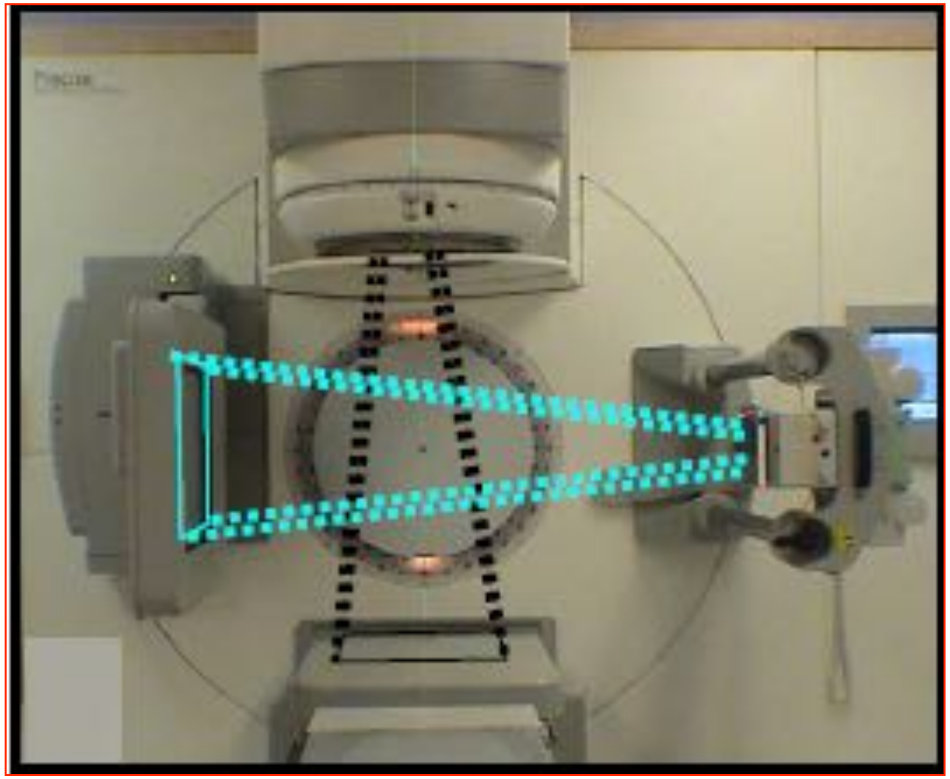
✓Provided an overview and current standing of 3DCT-IGRT addressing the rationale, objective, principles and applications for treatment delivery and quality assurance

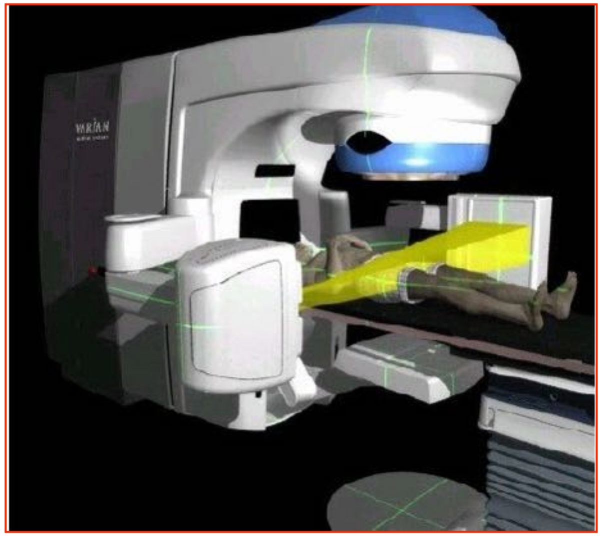
✓kV CT and kV CBCT (cone-beam CT) as well as MV CT and MV CBCT were considered

Radiotherapy and Oncology 94 (2010) 129–144

Imaging doses in radiation therapy: Dose Measurement, Calculation, and Inclusion in the treatment Plan







Imaging in IGRT

- ➢ Precise daily positioning of the patient before treatment
  - MV portal imaging
  - dual kV planar imaging
  - in-room fan-beam and cone-beam CT

- ➢ Intra-fraction motion monitoring
  - kV radiography and fluoroscopy

- ➢Daily plan adaptation
  - fan-beam and cone-beam

Difficulties in determining imaging dose during IGRT

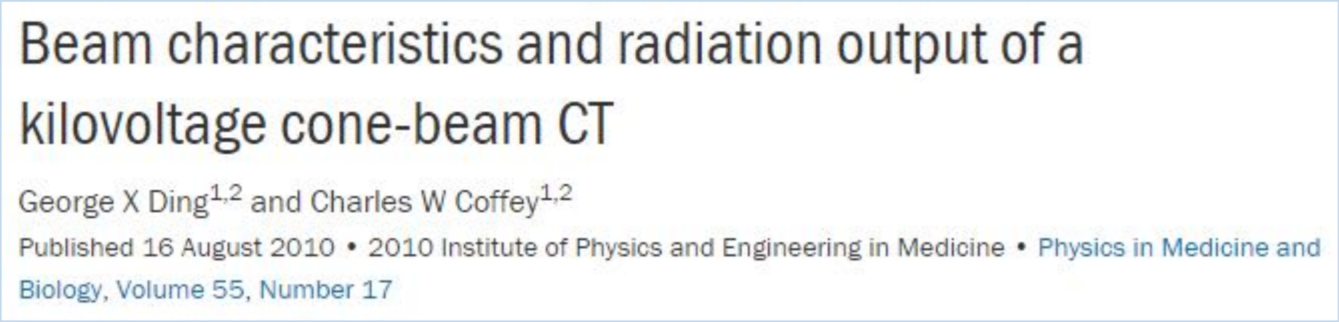
✓ Data from literature on dose delivered by different imaging modalities used during radiation therapy are very inhomogeneous, thus resulting difficult to estimate the total dose received by the patient during treatment

✓ IGRT is performed in many ways

Dose calculation: methods

✓ MV imaging: same dosimeters and protocols used for MV dosimetry and beam data acquisition

✓ kV imaging: various detectors such as ion chambers, thermoluminescent dosimeters (**TLD**), metal-oxide-semiconductor field-effect transistor (**MONSFET**), radiographic and radiochromic films, optically simulated luminescence dosimeters (OSLD), glass dosimeters



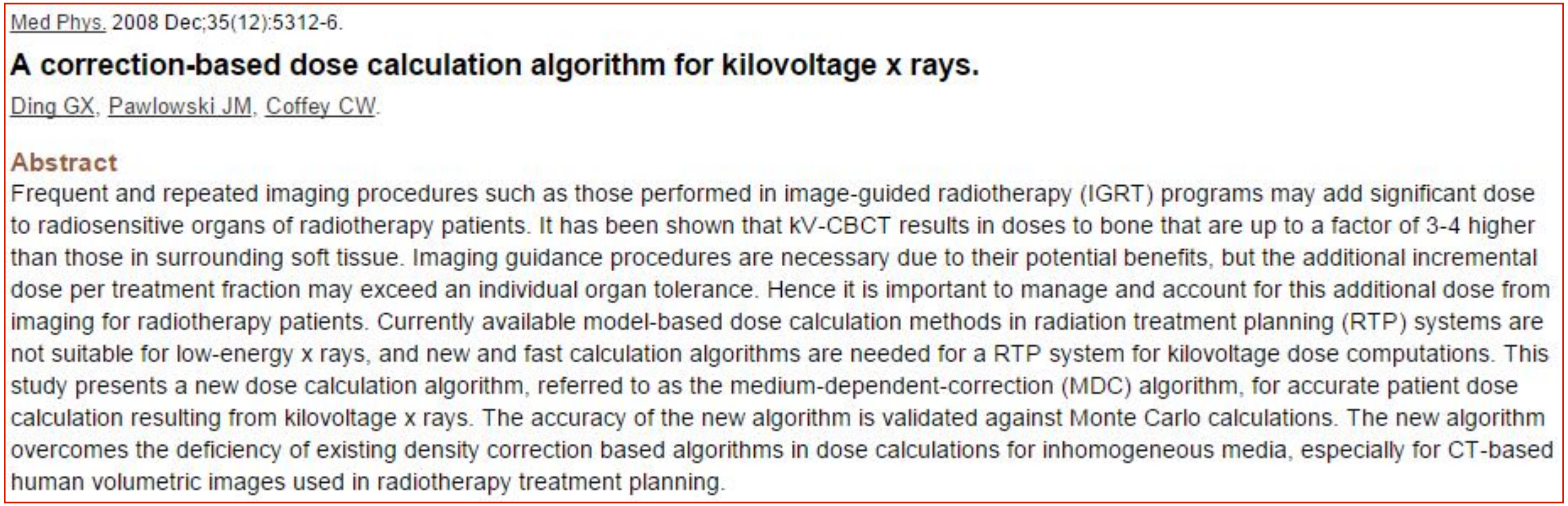
Beam characteristics and radiation output of a kilovoltage cone-beam CT

George X Ding[1,2] and Charles W Coffey[1,2]

Published 16 August 2010 • 2010 Institute of Physics and Engineering in Medicine • Physics in Medicine and Biology, Volume 55, Number 17

Dose calculation: methods

- Monte Carlo Method
- Medium dependent correction (MDC) algorithm



Med Phys. 2008 Dec;35(12):5312-6.

A correction-based dose calculation algorithm for kilovoltage x rays.

Ding GX, Pawlowski JM, Coffey CW.

Abstract

Frequent and repeated imaging procedures such as those performed in image-guided radiotherapy (IGRT) programs may add significant dose to radiosensitive organs of radiotherapy patients. It has been shown that kV-CBCT results in doses to bone that are up to a factor of 3-4 higher than those in surrounding soft tissue. Imaging guidance procedures are necessary due to their potential benefits, but the additional incremental dose per treatment fraction may exceed an individual organ tolerance. Hence it is important to manage and account for this additional dose from imaging for radiotherapy patients. Currently available model-based dose calculation methods in radiation treatment planning (RTP) systems are not suitable for low-energy x rays, and new and fast calculation algorithms are needed for a RTP system for kilovoltage dose computations. This study presents a new dose calculation algorithm, referred to as the medium-dependent-correction (MDC) algorithm, for accurate patient dose calculation resulting from kilovoltage x rays. The accuracy of the new algorithm is validated against Monte Carlo calculations. The new algorithm overcomes the deficiency of existing density correction based algorithms in dose calculations for inhomogeneous media, especially for CT-based human volumetric images used in radiotherapy treatment planning.

Dose calculation: methods

❑ Measurement dose in phantom or patient

➢Taking in vivo dose measurements in a Rando phantom and using the data as a predictor of patient dose

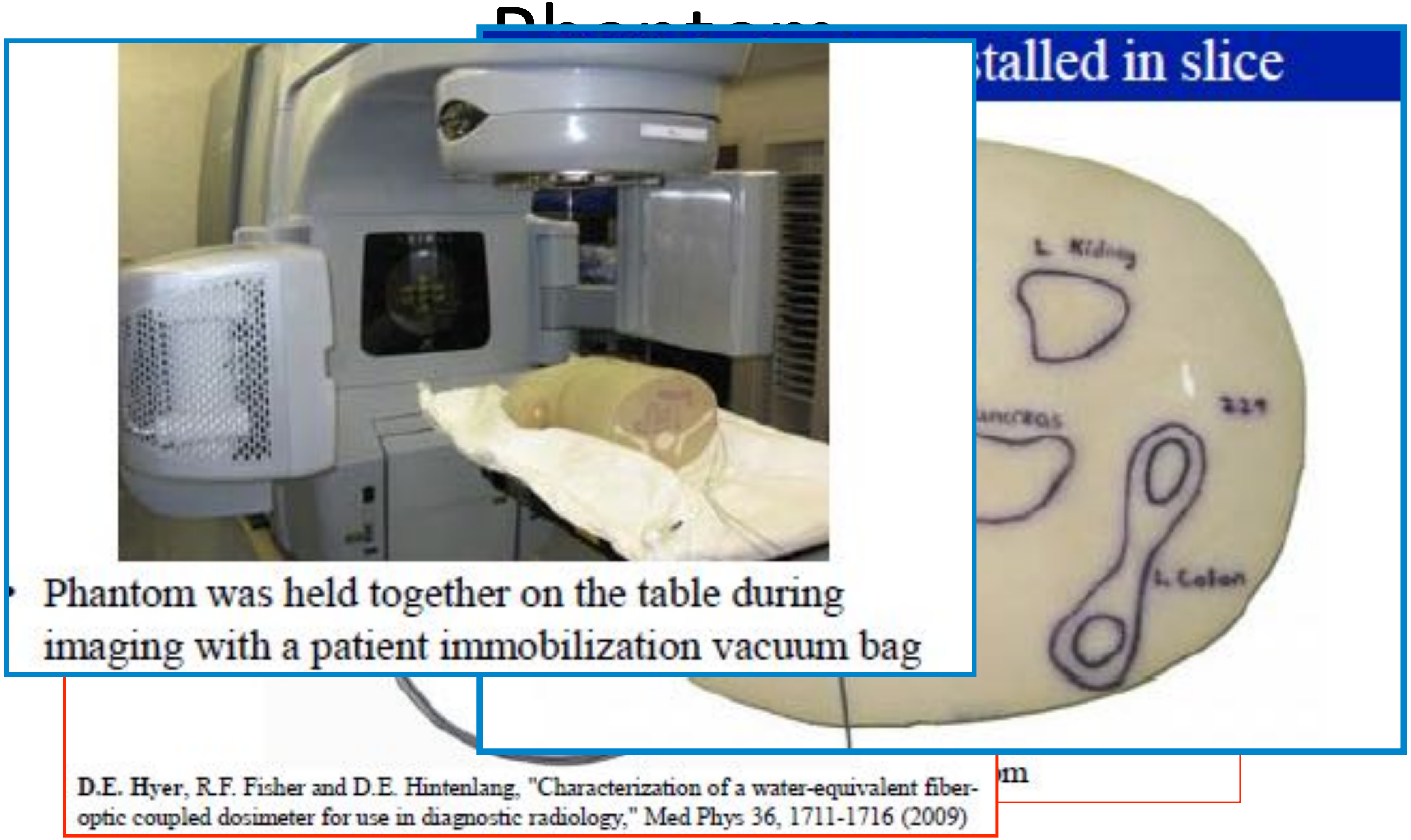
➢ Taking dose measurements directly on patients undergoing CBCT using TLD

❑ CT Dose Index (CTDI)/Cone beam Dose Index (CBDI)

➢ CTDI used for CT dose specification and is a measure of scanner output

➢ Defining a dosimetric parameter for the cone beam dose index (CBDI) and taking dose measurements with a standard cylindrical CT Phantom

Phantom



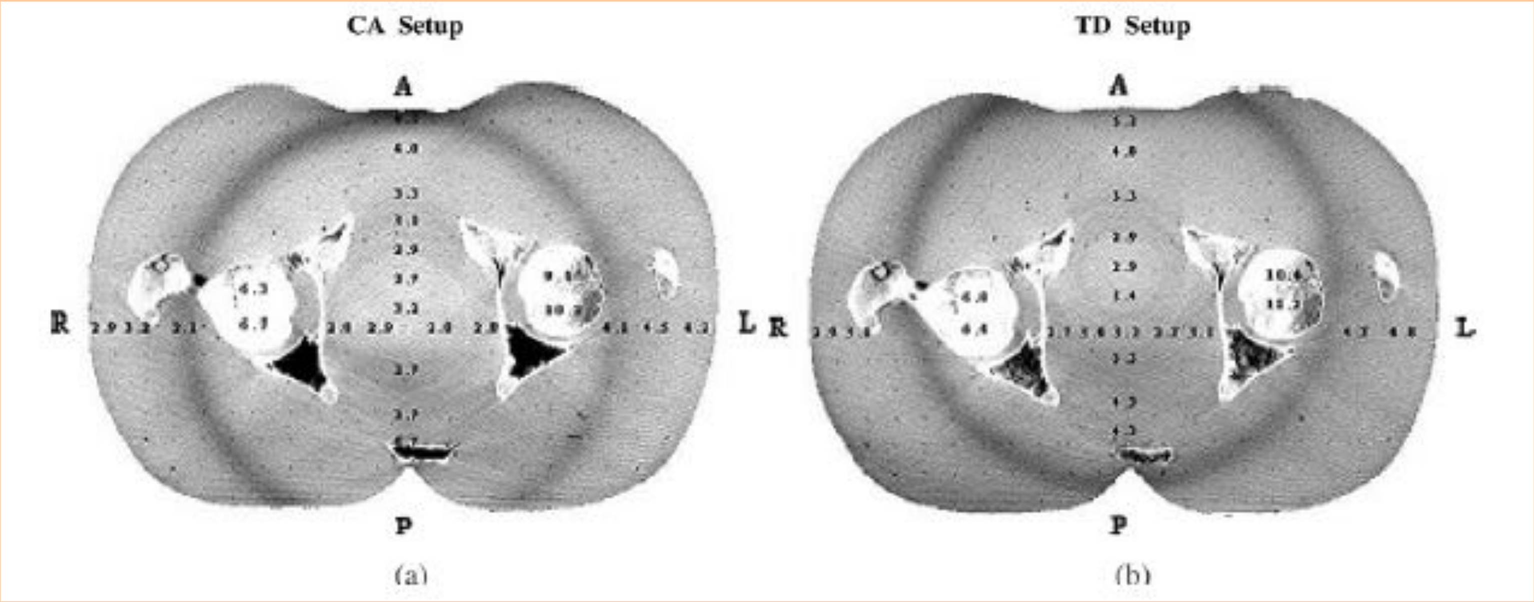
talled in slice

- Phantom was held together on the table during imaging with a patient immobilization vacuum bag

m

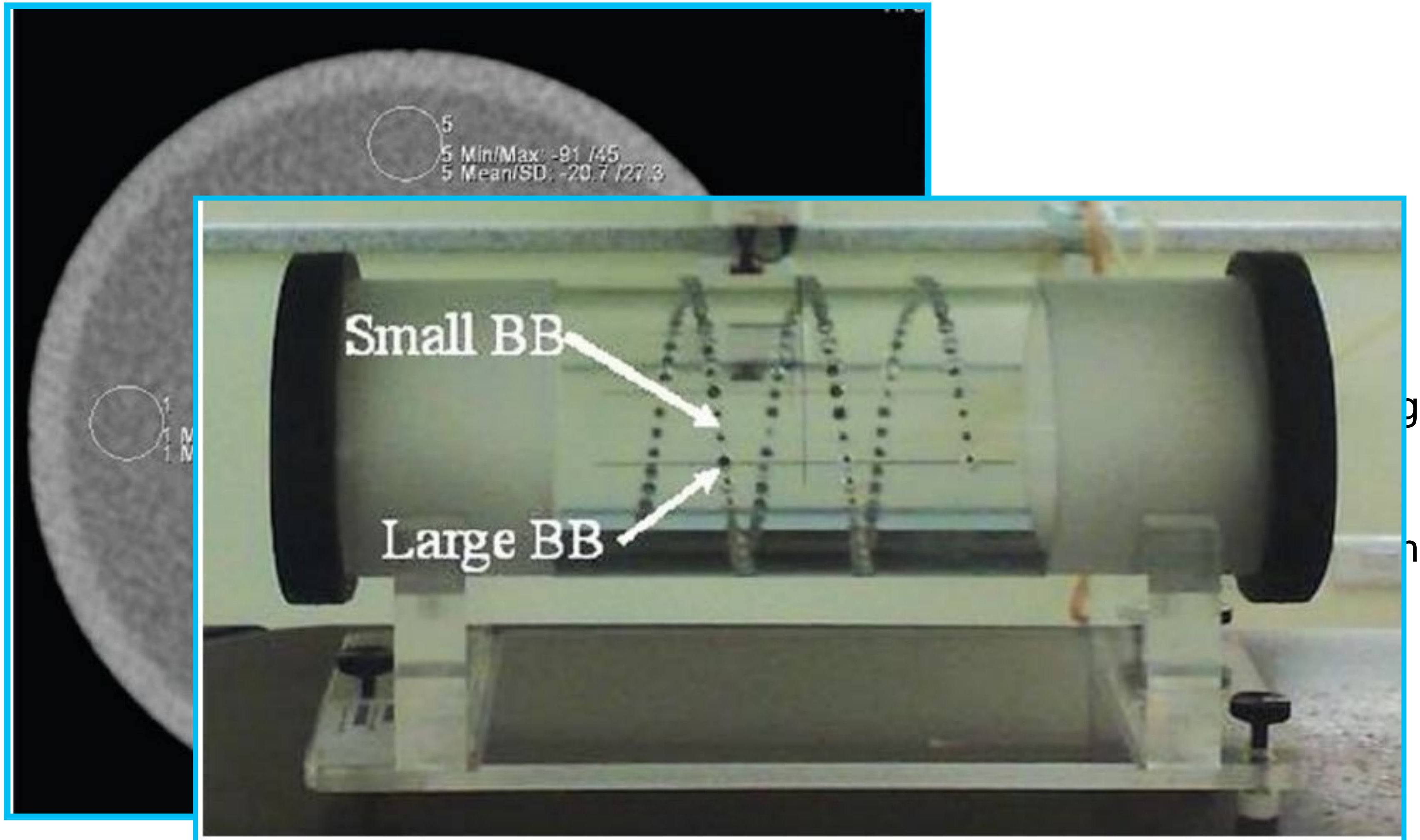
D.E. Hyer, R.F. Fisher and D.E. Hintenlang, "Characterization of a water-equivalent fiber-optic coupled dosimeter for use in diagnostic radiology," Med Phys 36, 1711-1716 (2009)

J.F. Winslow, D.E. Hyer, R.F. Fisher, C.J. Tien and D.E. Hintenlang. Construction of anthropomorphic phantoms for use in dosimetry studies.
J Appl Clin Med Phys 10, 195-204 (2009)



- Taking in vivo dose measurements in a Rando phantom and using the data as a predictor of patient dose
- Taking dose measurements directly on patients undergoing CBCT using TLD
- Technique used: 125 kVp, 80 mA, 25 ms (2 mA s)
- AP skin doses ranged from 3-6 cGy for 20-23 separation
- Central dose was ~3.0 cGy
- The left hip received 10-11 cGy while the right received 6-7 cGy

Wen *et al. Phys. Med. Biol*. 52 (2007)



The geometrical phantom of the MVCB-CT

J Med Phys 2011 36(4)

PATIENT DOSE FROM KILOVOLTAGE CBCT TOMOGRAPHY IMAGING IN RADIATION THERAPY

Islam MK, Purdie TG et al.

- Ion chamber and MOSFET measurements in phantom on a prototype Elekta XVI unit 17
- Dose measured for 330 projections
- Maximum dose for body phantom: 1.8-2.3 cGy (120 kVp) and 2.8-3.5 cGy (140 kVp)
- Maximum dose for head phantom: 1.5-2.0 cGy (100 kVp) and 2.6-3.4 cGy (120 kVp)

Med. Phys. 2006 Jun;33(6)

PATIENT DOSE AND IMAGE QUALITY FROM MV CBCT TOMOGRAPHY IMAGING THERAPY

O. Gayou, D. Parda, M. Johnson, M. Miften

- Dose measured using clinical delivery protocols
- Minimum dose of 5-9 cGy and maximum dose of 9-17 cGy, depending on the anatomical site and patient thickness
- Lower doses if localization is done using bone anatomy

Med. Phys. 2006 34 (2), Feb 2007

Dose delivered to the acrylic phantoms measured, with the 10 MU and 15 MU, using a small volume ion chamber along with the XiO treatment planning system (TPS) calculations

Phantom diameter	**16 cm**		**32 cm**	
MU protocol	10 MU		15 MU	
Method	Mesured (cGy)	Calculated (cGy)	Mesured (cGy)	Calculated (cGy)
Isocenter	7.9	8.1	9.2	9.3
0°	10.3	10.2	12.1	11.6
90°	8.9	8.7	9.7	9.5
180°	6.9	7.1	4.1	4.1
270°	8.3	8.3	8.2	8.1

Med. Phys. 2006 Jun;33(6)

TLD readings for the pelvis

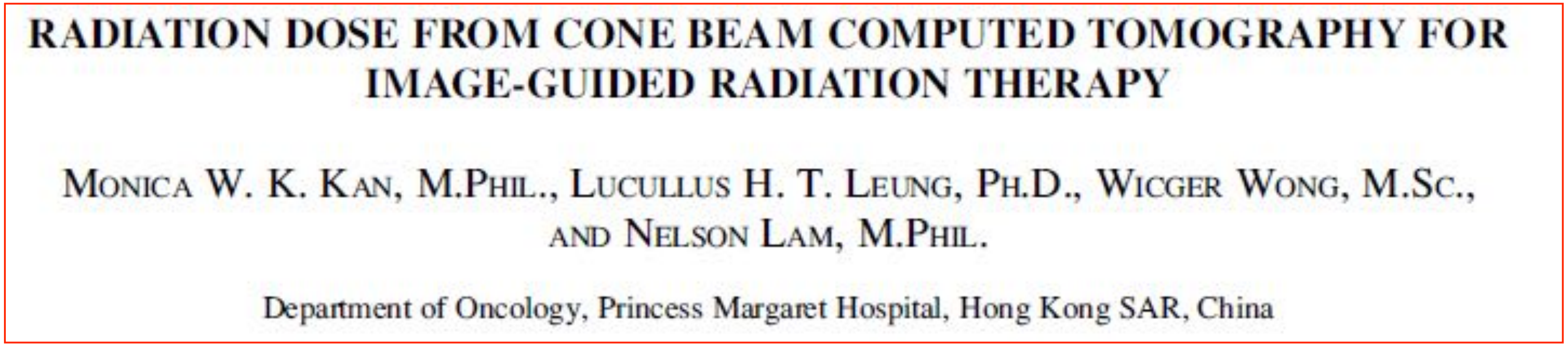
		TLD measurement (cGy)	**XiO calculation (cGy)**
Plane position	Anterior	12.1	11.9
	Midplane	10.3	10.7
	Posterior	9.9	9.9

The measured dose value is the average of the three TLD measurements in the same horizontal plane

Med. Phys. 2006 34 (2), Feb 2007

TLD readings for the head and neck with 8 MU protocol

		TLD measurement (cGy)	**XiO calculation (cGy)**
Plane position	Anterior	7.3	7.1
	Midplane	6.2	6.3
	Posterior	6.0	6.0

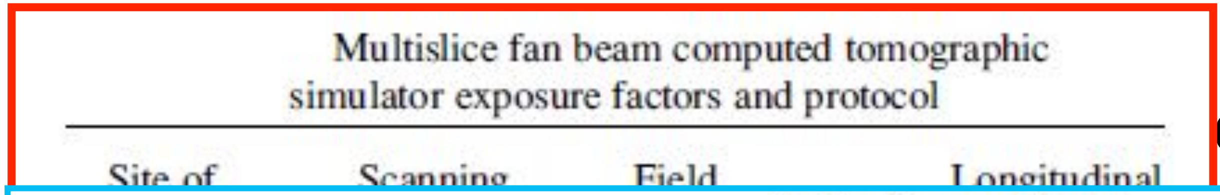


RADIATION DOSE FROM CONE BEAM COMPUTED TOMOGRAPHY FOR IMAGE-GUIDED RADIATION THERAPY

Monica W. K. Kan, M.Phil., Lucullus H. T. Leung, Ph.D., Wicger Wong, M.Sc.,
and Nelson Lam, M.Phil.

Department of Oncology, Princess Margaret Hospital, Hong Kong SAR, China

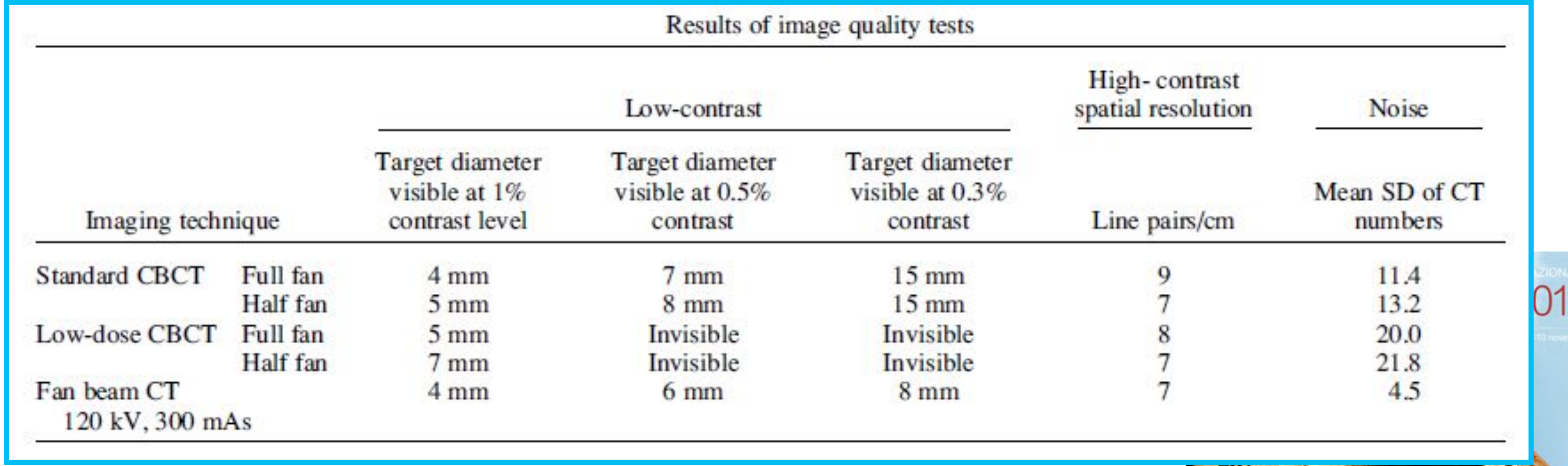
– Dose measured for standard and low-dose modes in and on phantom for three sites



Multislice fan beam computed tomographic simulator exposure factors and protocol

Site of Scanning Field Longitudinal

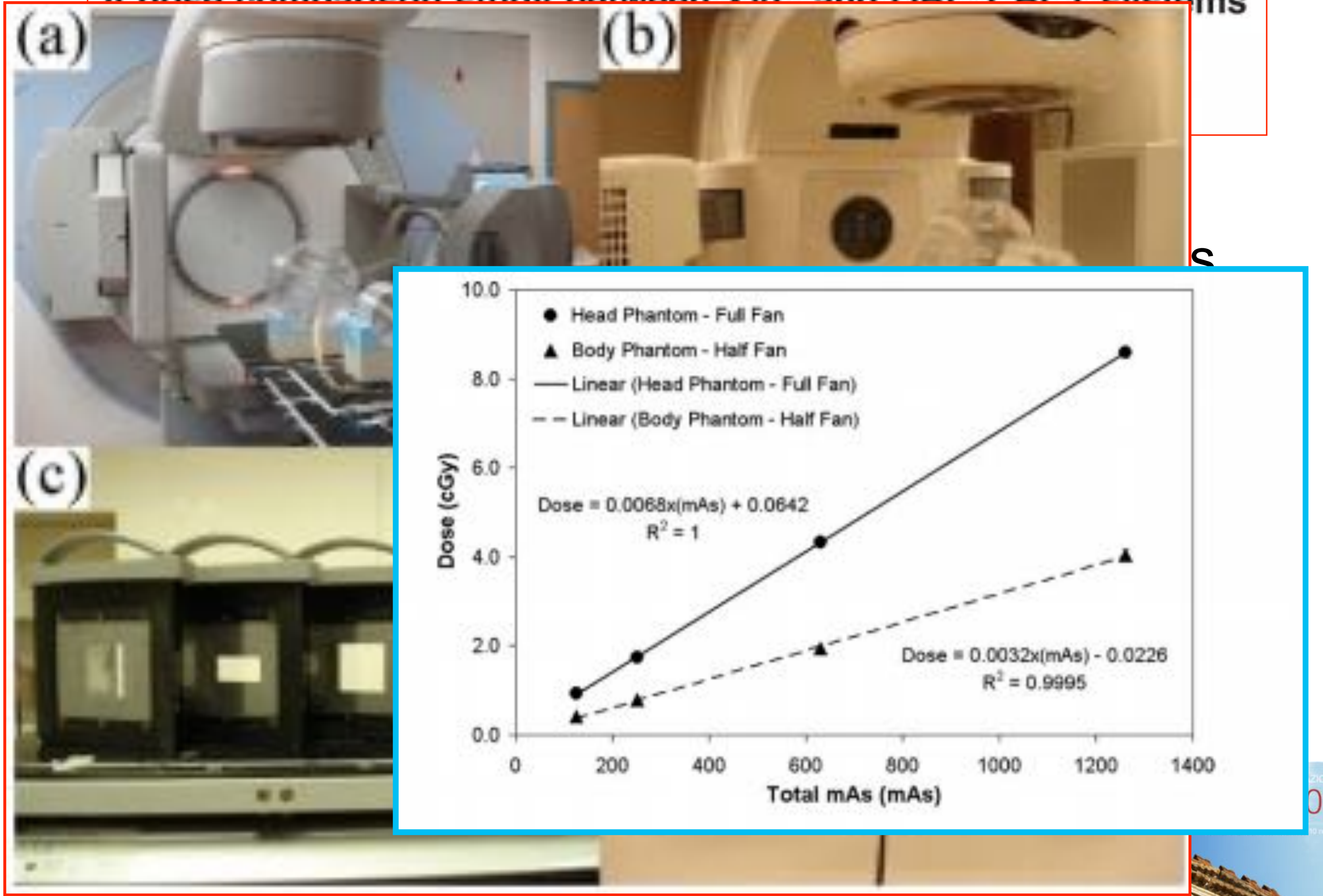
can (650-700



Results of image quality tests

Imaging technique		Low-contrast: Target diameter visible at 1% contrast level	Low-contrast: Target diameter visible at 0.5% contrast	Low-contrast: Target diameter visible at 0.3% contrast	High-contrast spatial resolution: Line pairs/cm	Noise: Mean SD of CT numbers
Standard CBCT	Full fan	4 mm	7 mm	15 mm	9	11.4
	Half fan	5 mm	8 mm	15 mm	7	13.2
Low-dose CBCT	Full fan	5 mm	Invisible	Invisible	8	20.0
	Half fan	7 mm	Invisible	Invisible	7	21.8
Fan beam CT 120 kV, 300 mAs		4 mm	6 mm	8 mm	7	4.5

A dose comparison study between XVI® and OBI® CBCT systems



Medical Physics, Vol. 35, No. 2, February 2008

PATIENT DOSE FROM MEGAVOLTAGE COMPUTED TOMOGRAPHY IMAGING

Amish P. Shah, Ph.D.,* Katja M. Langen, Ph.D.,* Kenneth J. Ruchala, Ph.D.,† Andrea Cox, Ph.D.,†
Patrick A. Kupelian, M.D.,* and Sanford L. Meeks, Ph.D.*

*Department of Radiation Oncology, M. D. Anderson Cancer Center Orlando, Orlando, FL; and †TomoTherapy, Inc., Madison, WI

❑MV a series of
absor hen used to
retros
MVC east, head/
neck,

❑MV age with
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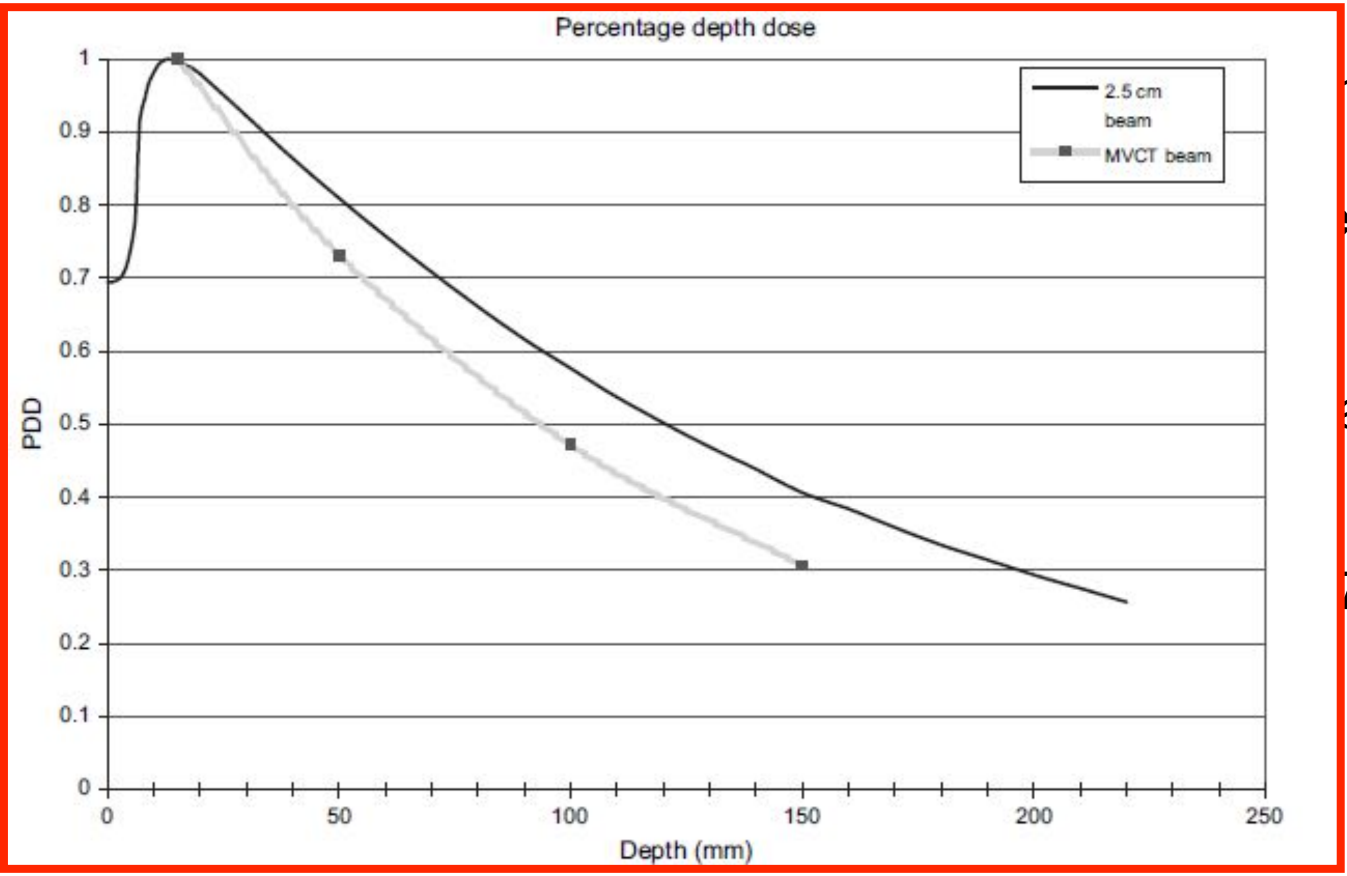

Int. J. Radiation Oncology Biol. Phys., Vol. 70, No. 5

PATIENT DOSE FROM MEGAVOLTAGE COMPUTED TOMOGRAPHY IMAGING

AMISH P. SHAH, PH.D.,* KATJA M. LANGEN, PH.D.,* KENNETH J. RUCHALA, PH.D.,† ANDREA COX, PH.D.,†
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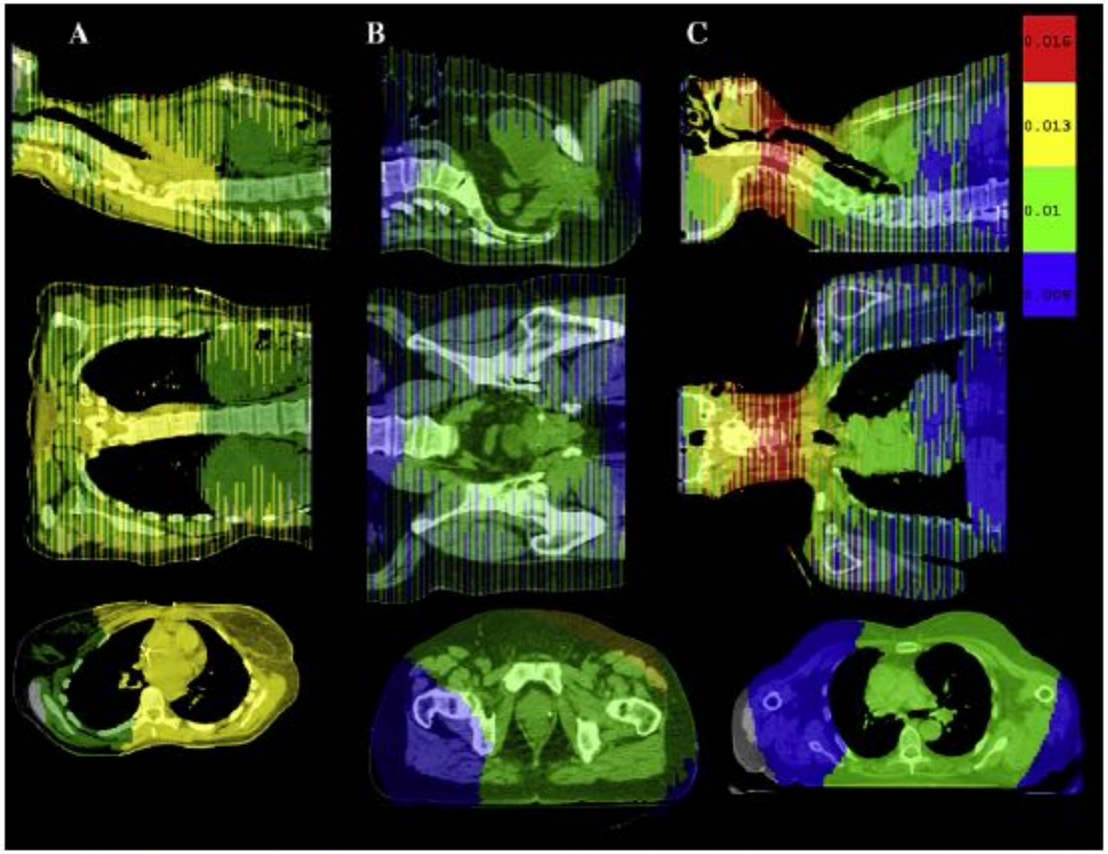
20-cm Cylind

30-cm “Chees

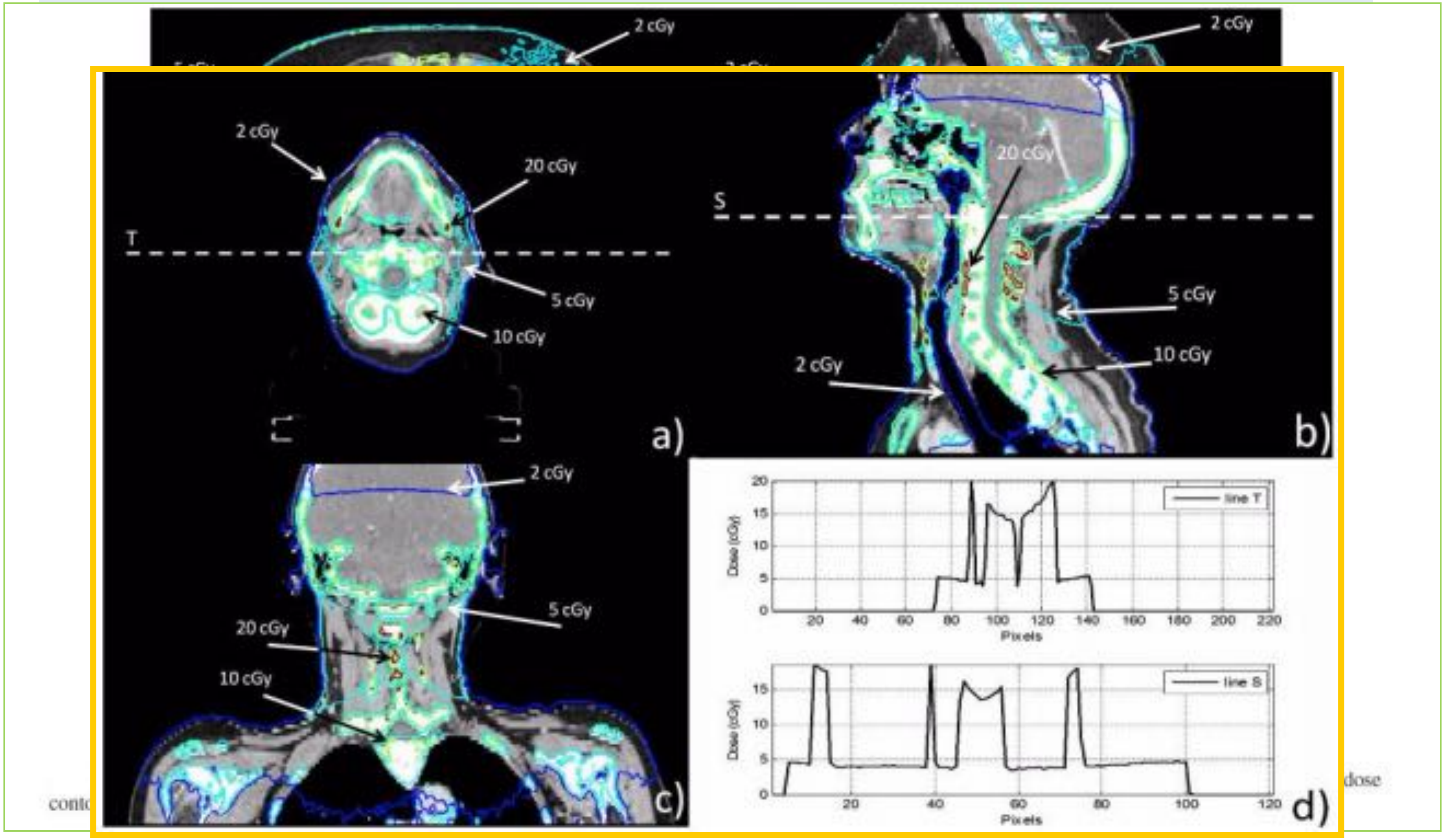
CIRS anthrop



Isodose distribution (in Gray) for (A) a breast cancer patient, (B) a prostate cancer patient, and (C) a lung cancer patient in sagittal, coronal, and transverse planes, crossing through respective regions of interest and imaged with pitch of 2.0 (normal).

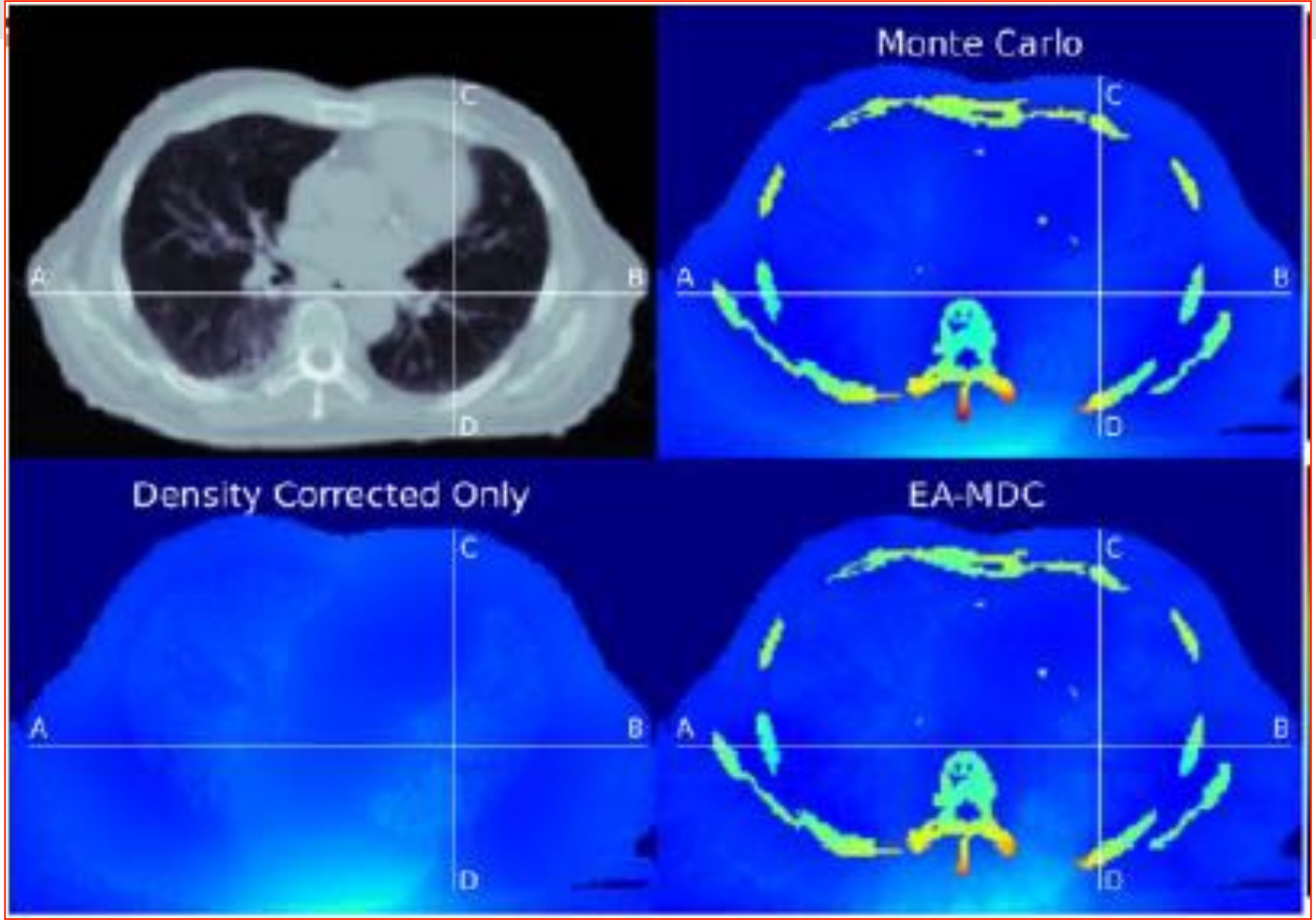
Int. J. Radiation Oncology Biol. Phys., Vol. 70, No. 5

Monte Carlo calculation



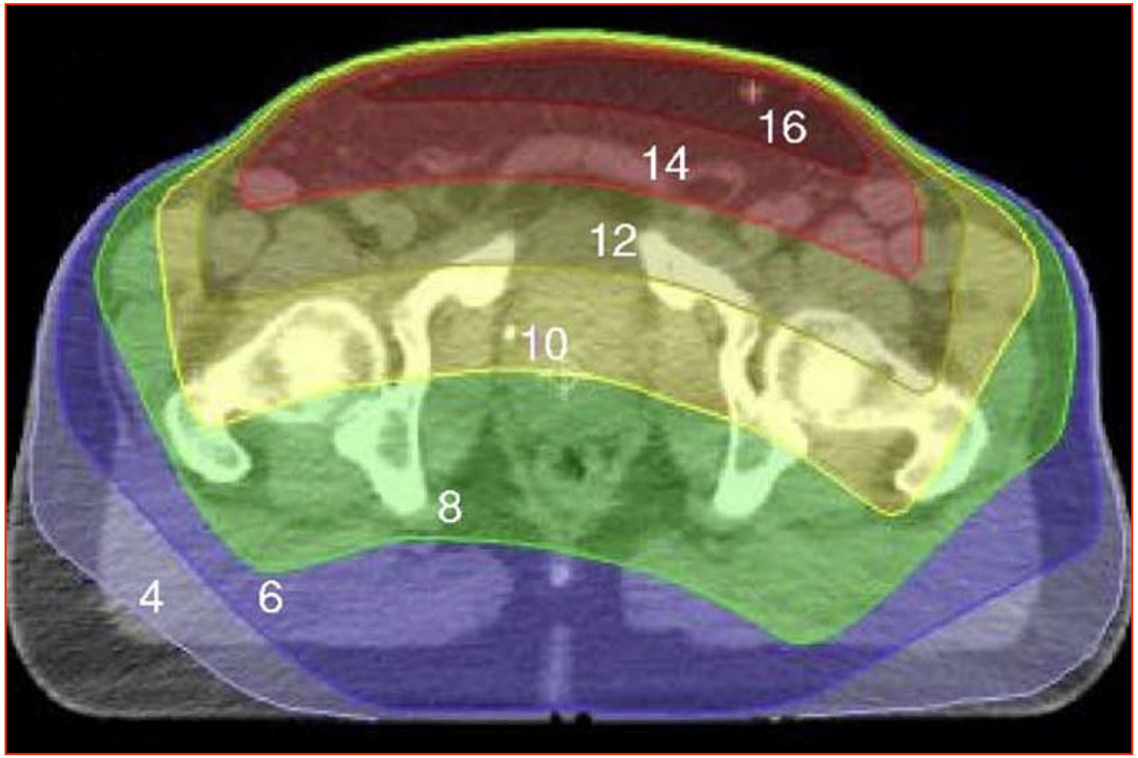
Int J Rad Oncol Biol Phys, 83 (2012)

MDC dose calculation



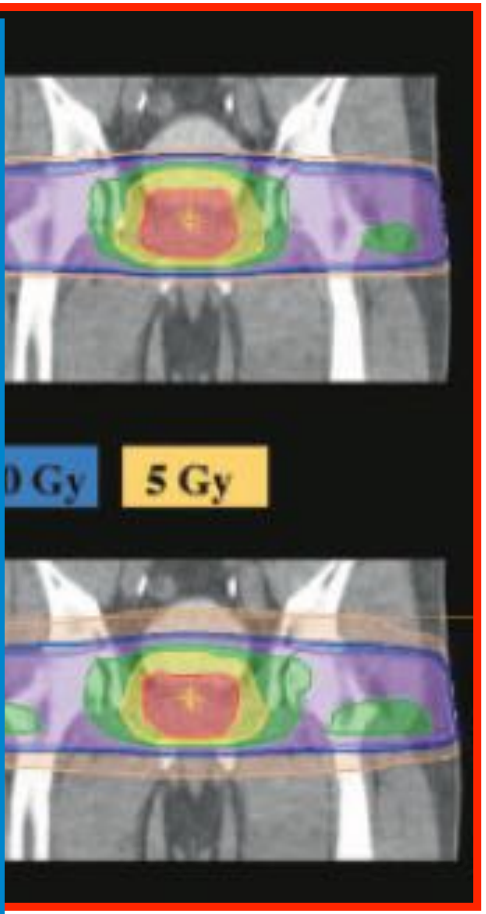
Pawlowski and Ding, *Phis. Med. Biol*. 56 (2011)

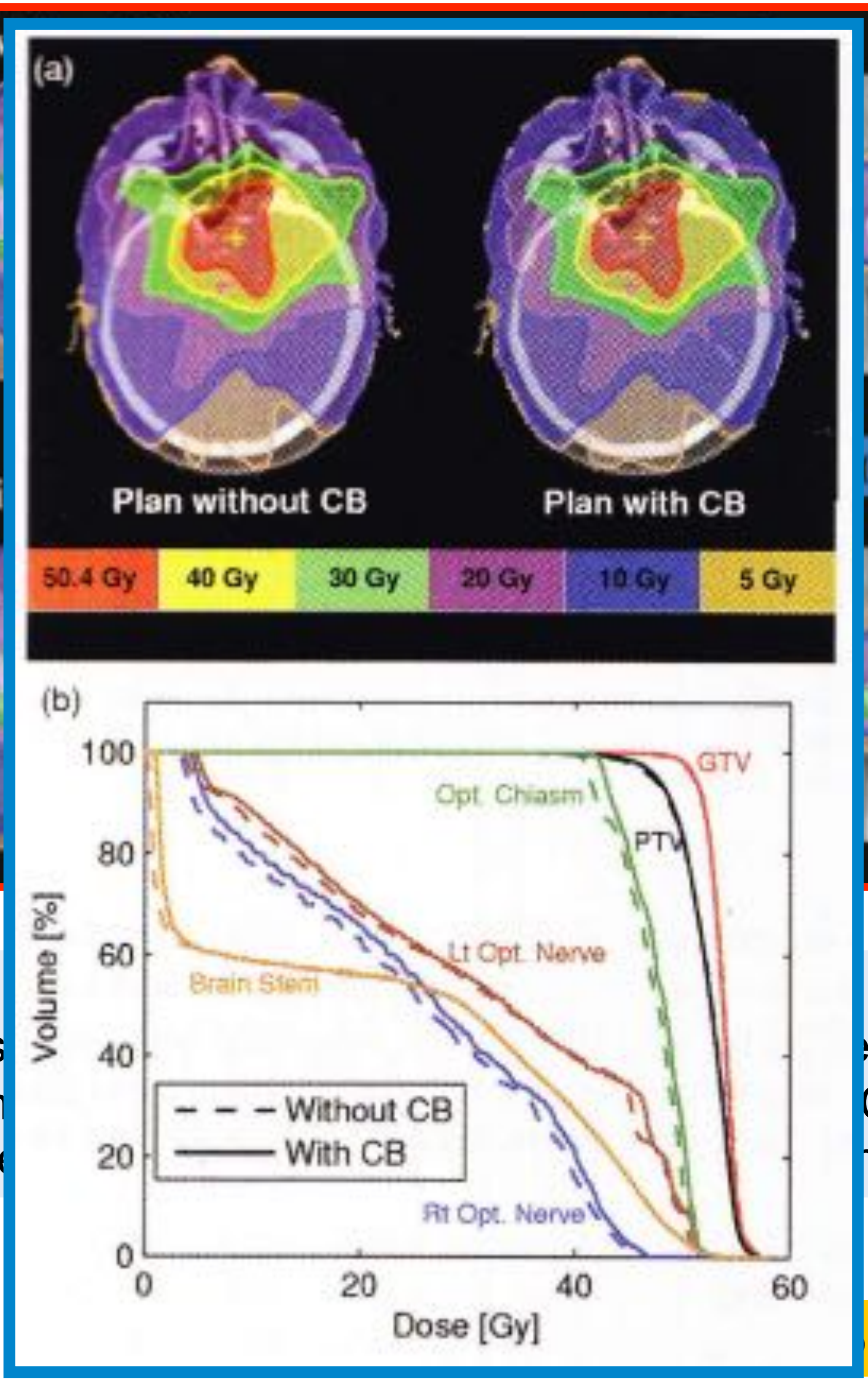
MV CBCT dose



Distribution of dose deposited in the pelvis by a single fraction of MV CBCT imaging for a prostate patient, with 10 cGy at isocenter. The isodose lines are labeled in cGy.

Miften M, Gayou O et al. *Med Phis 2007; 34*

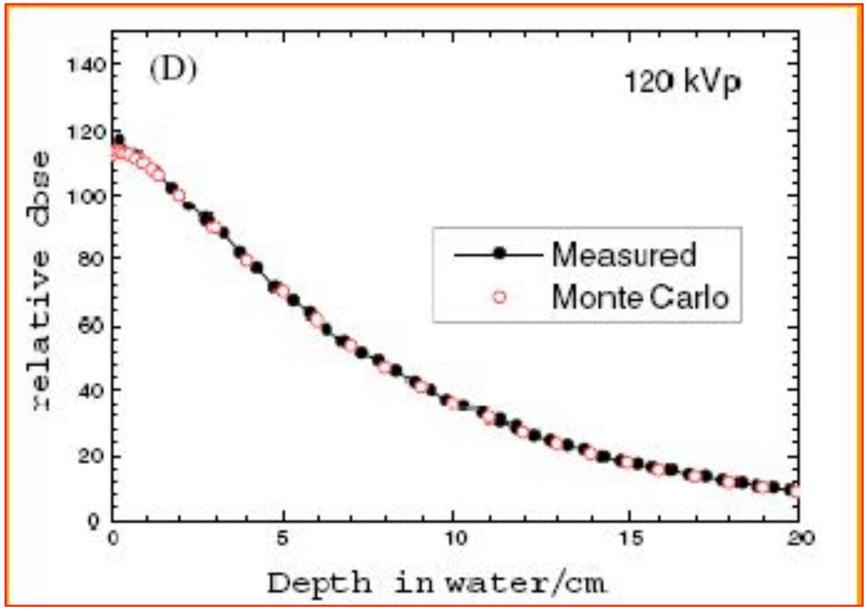


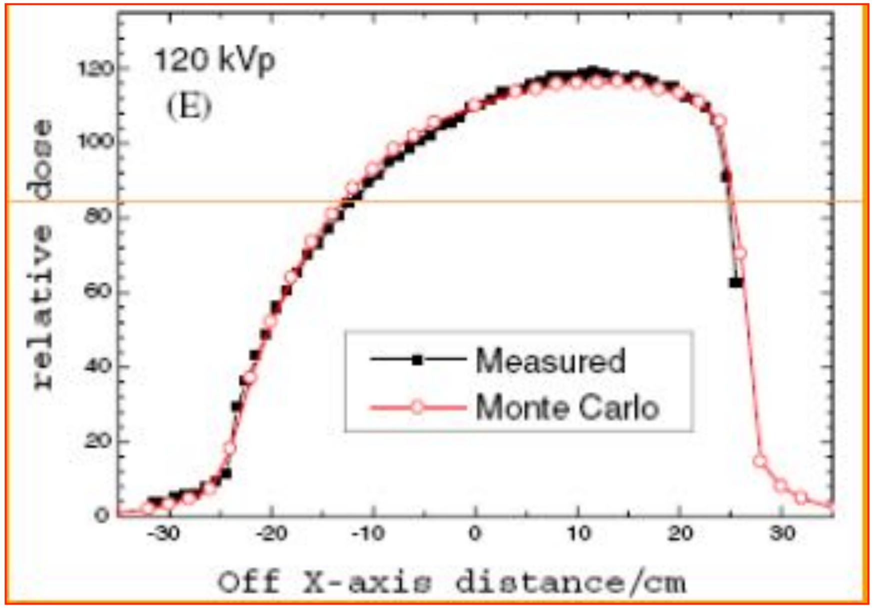


Example 0, and 5 Gy on
transvers IMRT plan (upper
panel) an CBCT (lower panel) of
a prostat nt.

u O et al. *Med Phis 2007; 34*

kV CBCT dose

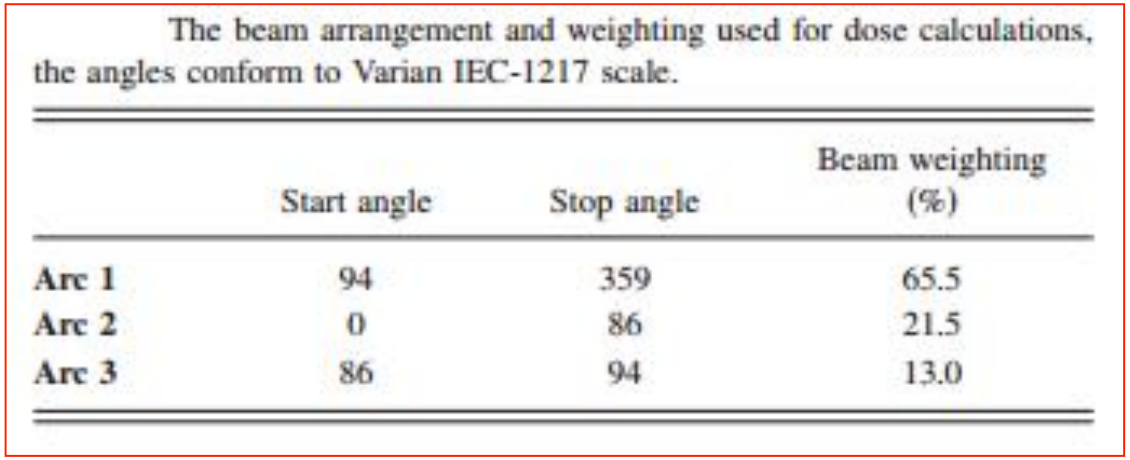




Ding et al., Phys. Med. Biol. 52: 1595-1615 (2007)

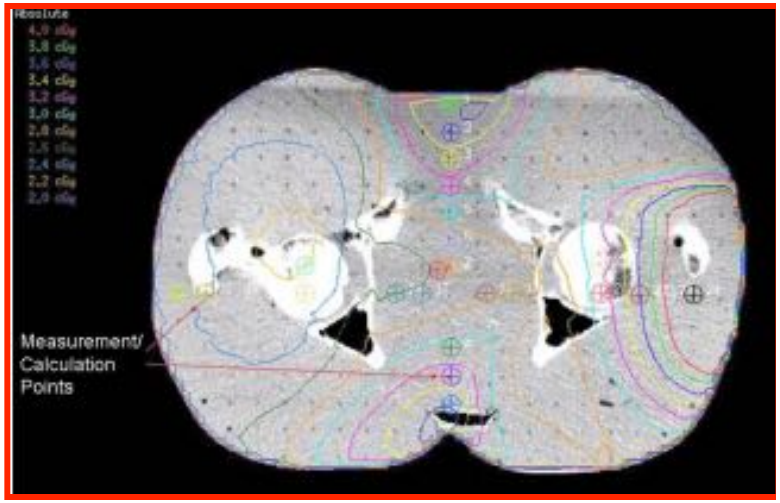
Kv CBCT dose

Dose calculation using the three-arc beam arrangement indicate a difference in the range of 0% to 19% between planned and measured doses for points within the soft tissue portion of phantom.



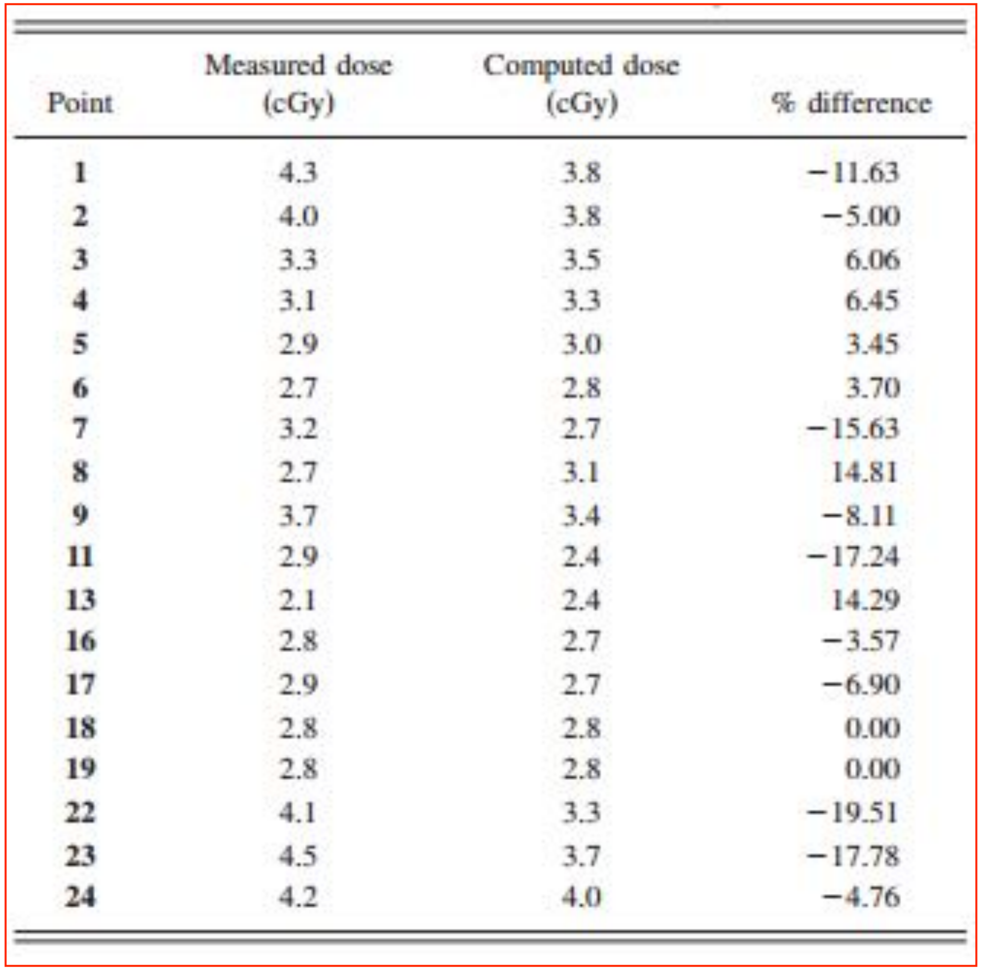
The beam arrangement and weighting used for dose calculations, the angles conform to Varian IEC-1217 scale.

	Start angle	Stop angle	Beam weighting (%)
Arc 1	94	359	65.5
Arc 2	0	86	21.5
Arc 3	86	94	13.0

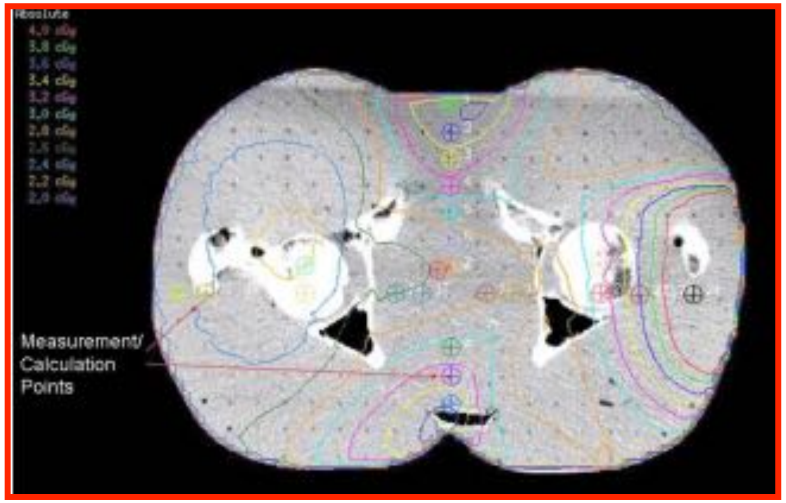


Alaei et al. Med Phys. 37 (1) 2010

Comparisons of measured and computed point doses in “soft tissue” areas of Rando phantom (Varian OBI)

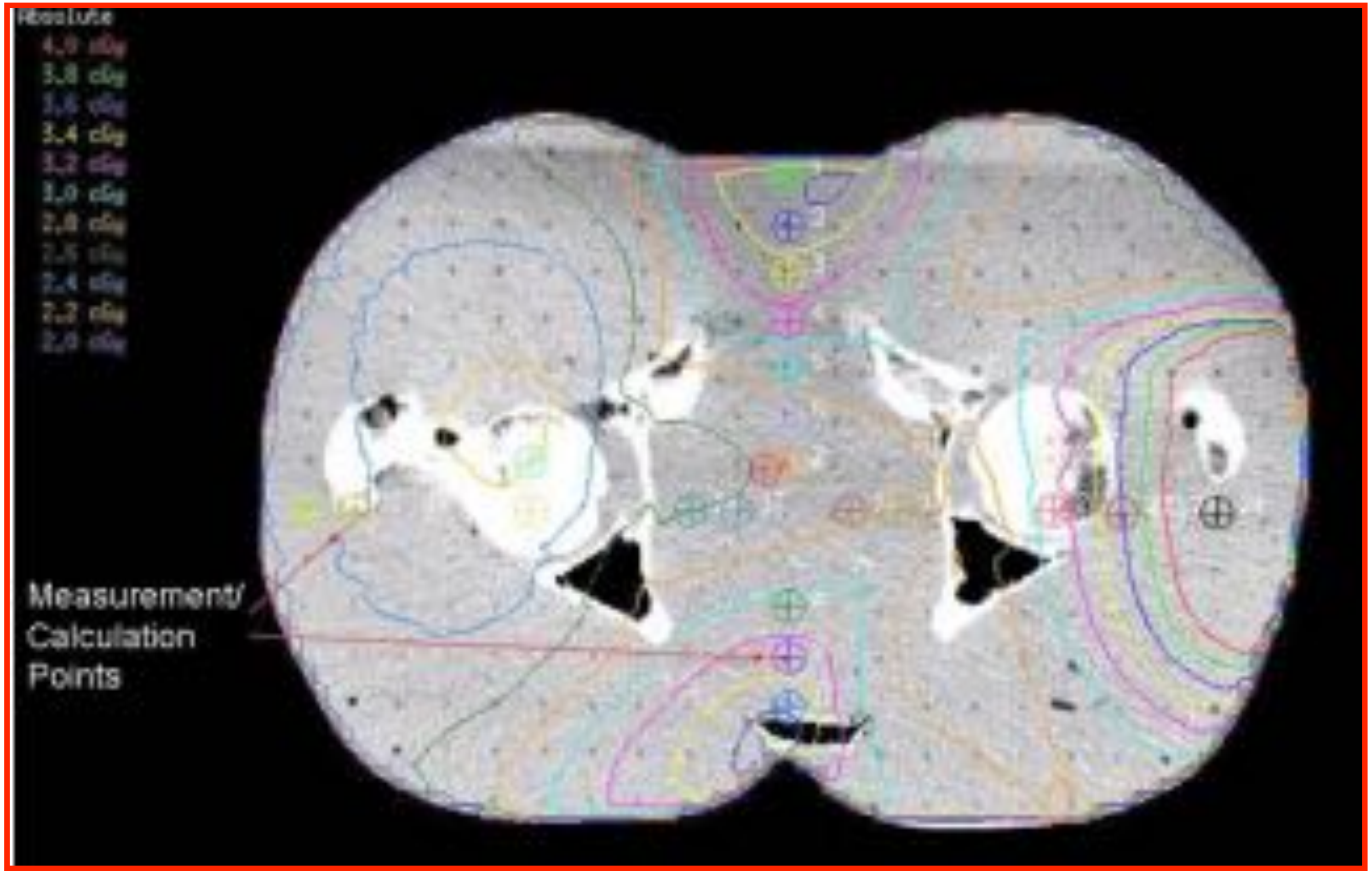


Point	Measured dose (cGy)	Computed dose (cGy)	% difference
1	4.3	3.8	−11.63
2	4.0	3.8	−5.00
3	3.3	3.5	6.06
4	3.1	3.3	6.45
5	2.9	3.0	3.45
6	2.7	2.8	3.70
7	3.2	2.7	−15.63
8	2.7	3.1	14.81
9	3.7	3.4	−8.11
11	2.9	2.4	−17.24
13	2.1	2.4	14.29
16	2.8	2.7	−3.57
17	2.9	2.7	−6.90
18	2.8	2.8	0.00
19	2.8	2.8	0.00
22	4.1	3.3	−19.51
23	4.5	3.7	−17.78
24	4.2	4.0	−4.76



Alaei et al. Med Phys. 37 (1) 2010

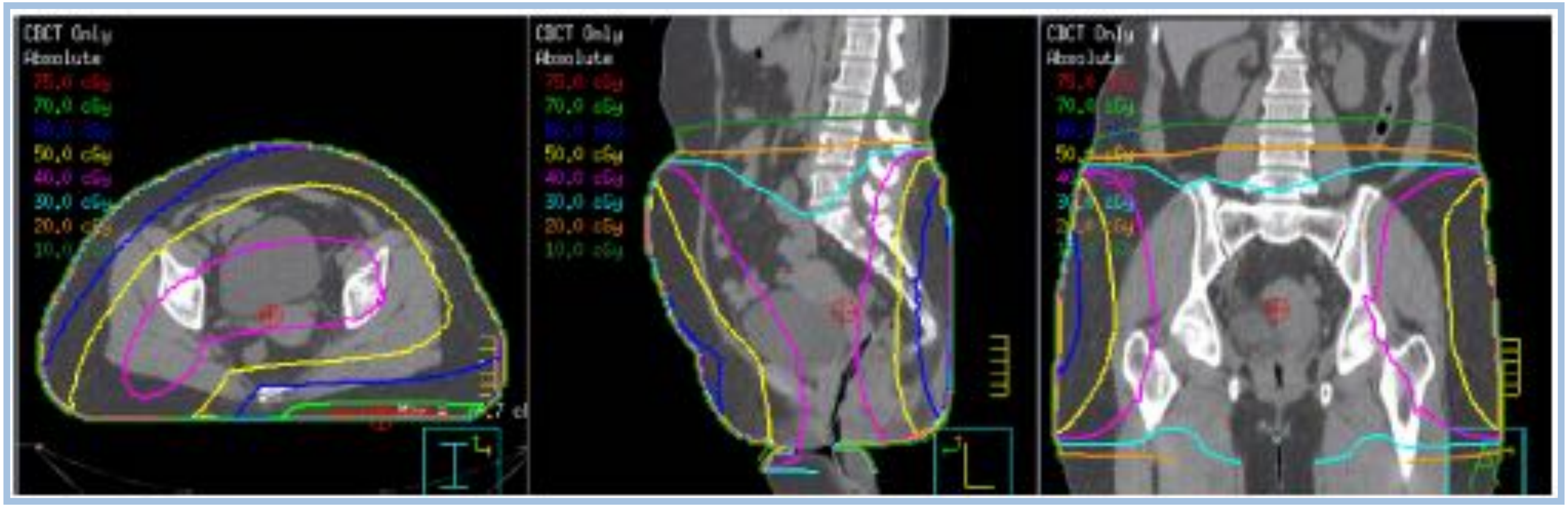
The locations of the TLDs as indicated in the CT image of the Rando phantom and the isodose distribution generated by calculating the dose from the 125 kVp CBCT beam



The calculated dose around each point was investigated and there is essentially no dose gradient within the approximate area occupied by each TLD chip

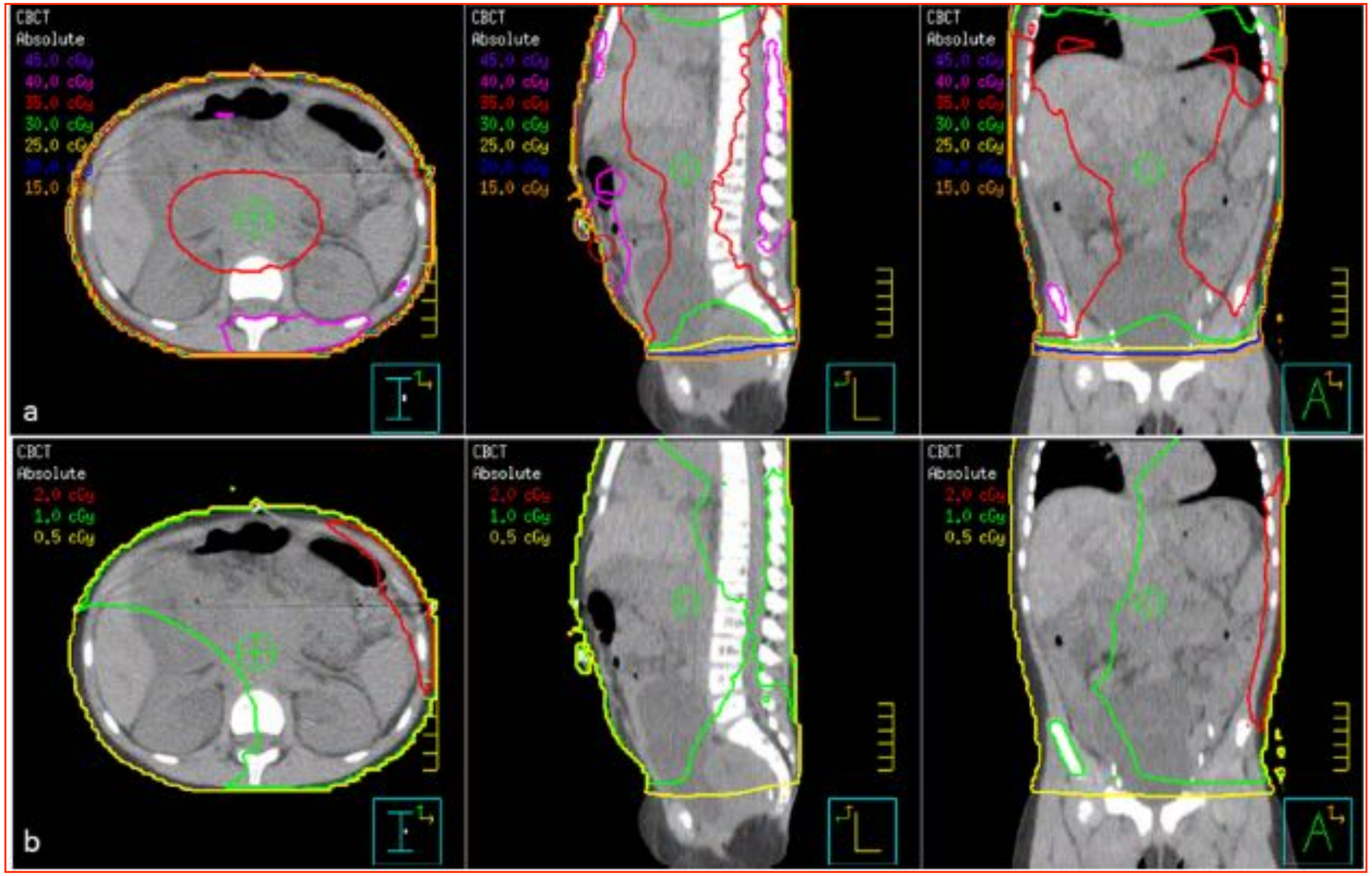
Alaei et al. Med Phys. 37 (1) 2010

Kv CBCT dose



Isodose distribution demonstrating imaging dose from 25 fractions of pelvic imaging for one patient using Elekta XVI pelvis imaging protocol (120 kVp, 1 mAs, 650 projections) and calculated using Pinnacle treatment planning system.

Alei P, Spezi E. Imaging dose from CBCT in radiation therapy. Phisica Medica 2015



The TPS-calculated dose distribution from 11 daily CBCT imaging using:

a) the standard protocol used for pelvic imaging

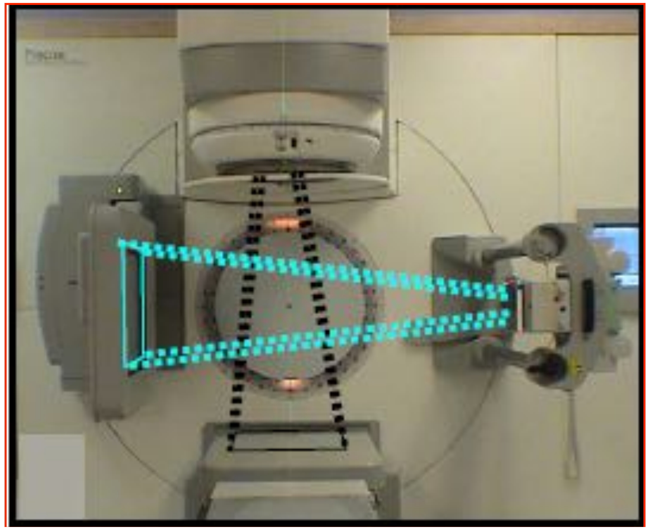
b) b) the standard protocol used for head and neck imaging demonstrating an 18-fold reduction in dose.

Alei P, Spezi E. Imaging dose from CBCT in radiation therapy. Phisica Medica 2015

QUESTIONS

During CBCT, how more dose is delivered in addition to that of the treatment?

Adding further dose what risks for the patient?



For the differing qualities of kV, CT, and MV exposures, the doses should only be compared and summed in units of “effective dose”, which represent the approximate biological detriment associated with a given integral dose

EFFECTIVE DOSE

Equivalent dose for tissue/organ T (Sieverts)

$$H_T = \sum_R W_R \cdot D_{T,R}$$

where W_R is the weighting factor for radiation type R and $D_{T,R}$ is the absorbed dose for tissue T by radiation type R

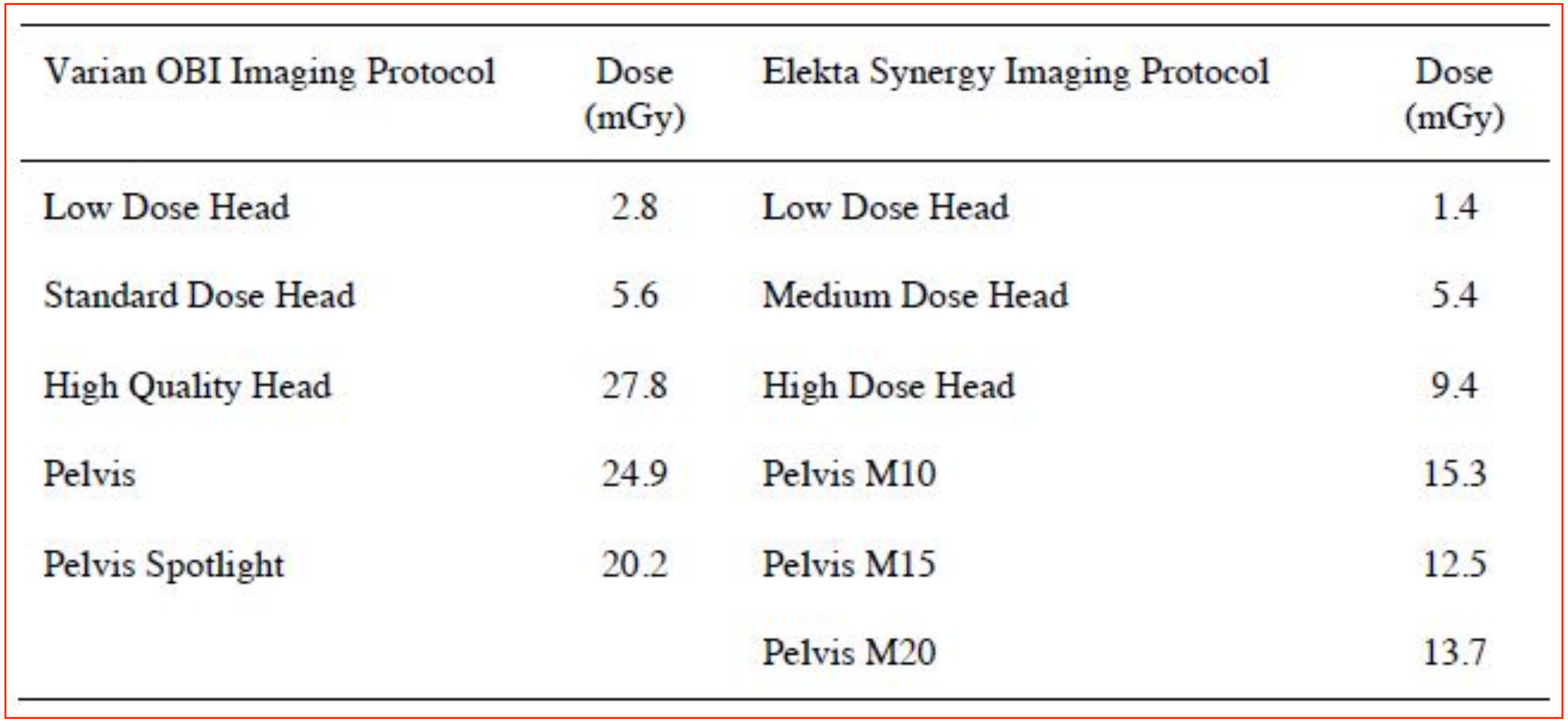
EFFECTIVE DOSE
(SIEVERTS)

$$E = \sum_T W_T \cdot H_T$$

W_T is the weighting factor as given by ICRP 103 [37] and H_T is the equivalent dose for tissue or organ type T

JR Sykes and al. Dosimetry of CBCT: methods, doses and clinical consequences. Journal of Physics: Conference Series 444

Cone Beam dose measurements (similar to CTDIw) for standard imaging protocols on the Varian OBI and Elekta Synergy CBCT systems published in the ***UK Centre of Evidence Based Purchasing report***



Varian OBI Imaging Protocol	Dose (mGy)	Elekta Synergy Imaging Protocol	Dose (mGy)
Low Dose Head	2.8	Low Dose Head	1.4
Standard Dose Head	5.6	Medium Dose Head	5.4
High Quality Head	27.8	High Dose Head	9.4
Pelvis	24.9	Pelvis M10	15.3
Pelvis Spotlight	20.2	Pelvis M15	12.5
		Pelvis M20	13.7

JR Sykes and al. Dosimetry of CBCT: methods, doses and clinical consequences. Journal of Physics: Conference Series 444

IGRT EXAMPLES

- ✓ daily pre-treatment CTs for 30 fractions:
  60 - 400 mSv

- ✓ two pairs of MV portal images daily for 30 fractions:
  40 - 400 mSv

- ✓ two minutes of daily kV fluoroscopy for 30 fractions:
  40 - 120 mSv

- ✓ 100 dual kV planar images daily for 5 fractions:
  10 - 100 mSv

AAPM Task Group 75, Medical Physics 34 (10): 2007

DOSE REDUCTION

The management of imaging dose during Image-guided radiotherpy:

Report of the AAPM Task Group 75

M. Murphy, J. Balter *et al.*

To respect philosophy of **ALARA**

- Compile an overview of image-guidance techniques with enough dose levels, to provide the clinician using a particular set of image guidance techniques with enough data to estimate the total diagnostic dose for a specific treatment scenario

- **Identify ways to reduce total imaging dose without sacrificing essential imaging information**

- Recommend optimization strategies to trade off imaging dose with improvements in therapeutic dose delivery

Med Phys. 34 (10) October 2007

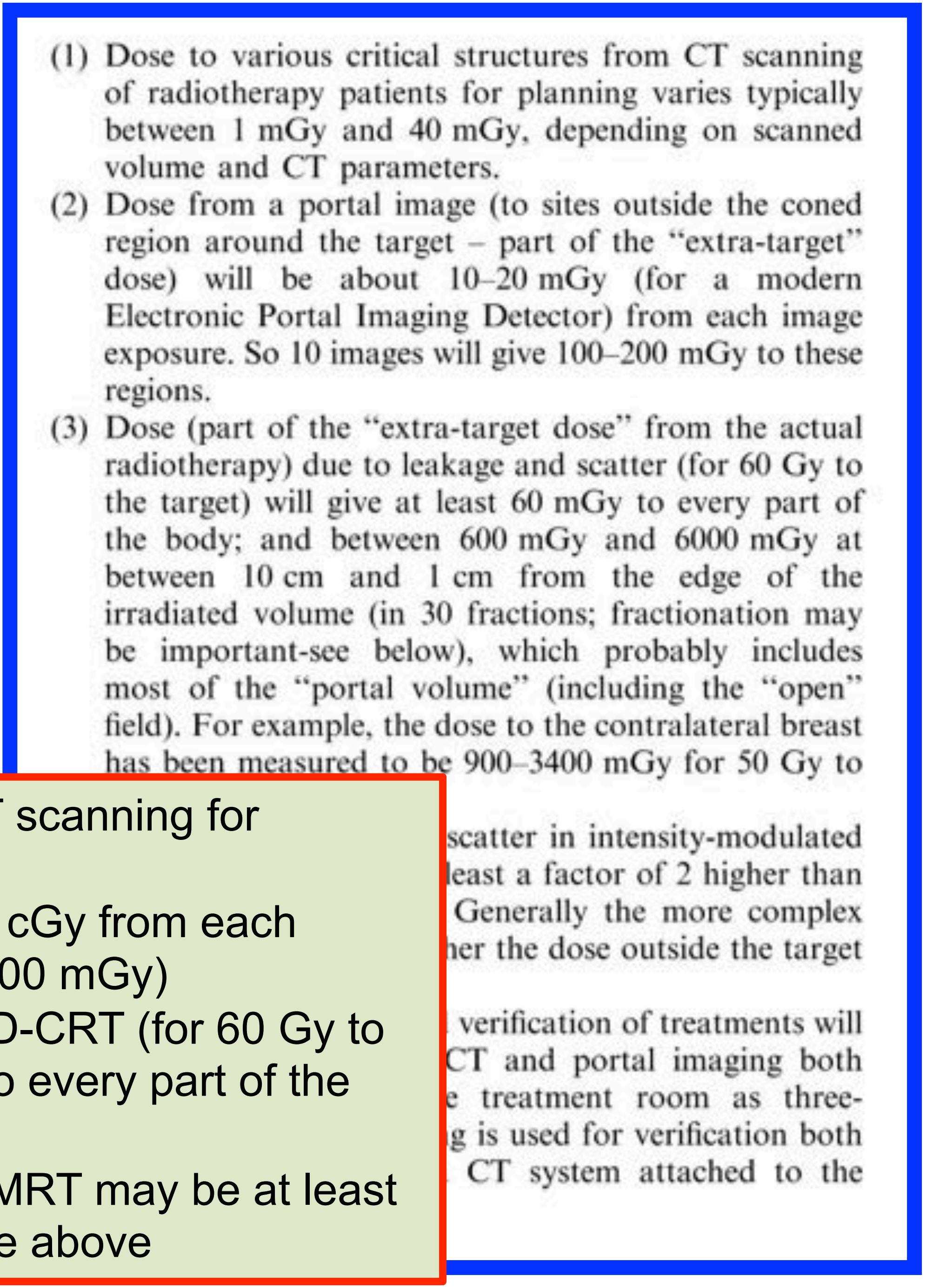
The British Journal of Radiology, 77 (2004)

Editorial

Second cancer risk, concomitant exposures and IRMER(2000)

E G A AIRD

What do we know about doses in radiotherapy?



(1) Dose to various critical structures from CT scanning of radiotherapy patients for planning varies typically between 1 mGy and 40 mGy, depending on scanned volume and CT parameters.

(2) Dose from a portal image (to sites outside the coned region around the target – part of the "extra-target" dose) will be about 10–20 mGy (for a modern Electronic Portal Imaging Detector) from each image exposure. So 10 images will give 100–200 mGy to these regions.

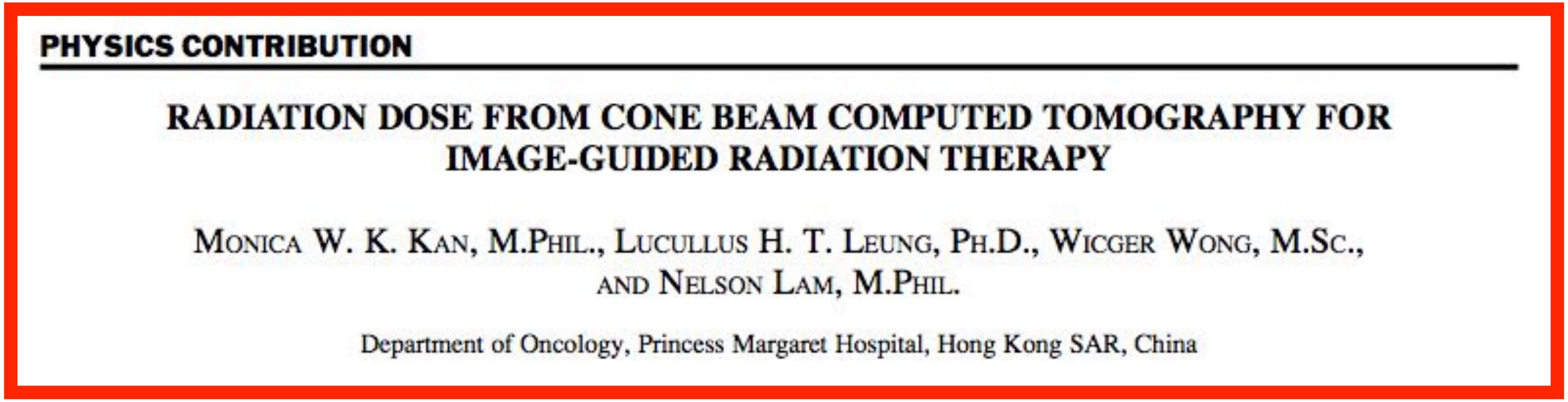
(3) Dose (part of the "extra-target dose" from the actual radiotherapy) due to leakage and scatter (for 60 Gy to the target) will give at least 60 mGy to every part of the body; and between 600 mGy and 6000 mGy at between 10 cm and 1 cm from the edge of the irradiated volume (in 30 fractions; fractionation may be important-see below), which probably includes most of the "portal volume" (including the "open" field). For example, the dose to the contralateral breast has been measured to be 900–3400 mGy for 50 Gy to

scatter in intensity-modulated
least a factor of 2 higher than
Generally the more complex
her the dose outside the target

verification of treatments will
CT and portal imaging both
e treatment room as three-
g is used for verification both
CT system attached to the

- ✓ Doses to critical structures from CT scanning for planning = 0.1 cGy to 4 cGy
- ✓ Doses from portal image about 1-2 cGy from each image exposure (10 images=100-200 mGy)
- ✓ Dose due to leakage and scatter 3D-CRT (for 60 Gy to target-30 fractions) at least 6 cGy to every part of the body
- ✓ Dose from leakage and scatter in IMRT may be at least a factor of 2 higher than figures give above

The British Journal of Radiology, 77 (2004)



PHYSICS CONTRIBUTION

RADIATION DOSE FROM CONE BEAM COMPUTED TOMOGRAPHY FOR IMAGE-GUIDED RADIATION THERAPY

Monica W. K. Kan, M.Phil., Lucullus H. T. Leung, Ph.D., Wicger Wong, M.Sc.,
and Nelson Lam, M.Phil.

Department of Oncology, Princess Margaret Hospital, Hong Kong SAR, China

◆ According to ICRP 60: probability to inducing a fatal cancer from a single radiographic exposure 5 x 10^{-5} per mSv

◆ Patient position verification by standard mode CBCT acquired by OBI on daily basis could increase the secondary cancer risk up to 2% to 4%

Int. J. Radiation Oncology Biol. Phys., Vol. 70, No. 1

Conclusions

IGRT is an essential tool for Radiotherapy

Comparison between different IGRT system is difficult: different Linac, different methods of measurements, different exposure results (mGy, mSv or CTDI)

During CBCT the additional dose to patient is low

Additional doses may increase the risk of occurrence of probabilistic damage

Thank you!