Radiation Dose Reduction Strategies in Coronary CT Angiography

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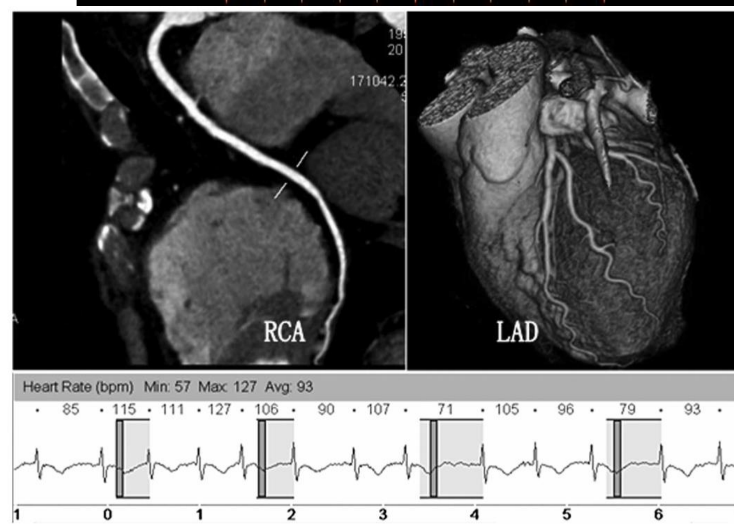
Contents:

- Introduction
- Radiation dosimetry in CT
- Radiation risk associated with coronary CT angiography
- Dose reduction strategies
- Coronary CTA for paediatric patients



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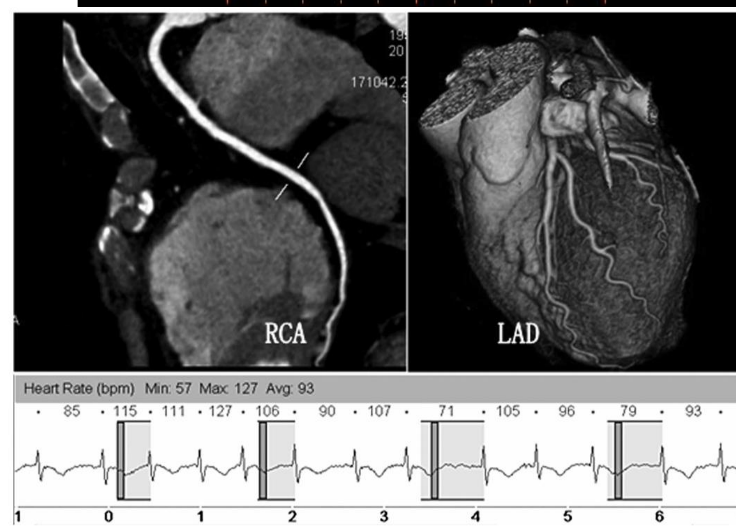
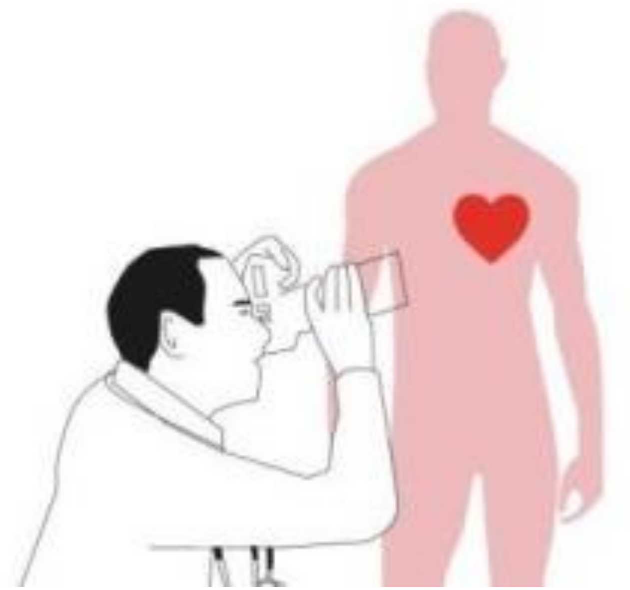


Introduction

Cardiac CT Imaging

Cardiac CT is a painless, non-invasive test that allows high-resolution, 3D visualization of the heart coronary arteries and other adjacent structures.



The two main types of cardiac CT imaging:

- Coronary artery calcium scoring (CASc)
- Coronary CT angiography (CTCA)

Coronary artery calcium scoring (CASc)

→ A CT scan to examine or measure the amount of calcified, or hardened, plaques in the arteries, which is usually explained as a calcium score of low, moderate or high. Unlike a CT angiogram, a calcium score doesn't involve contrast.

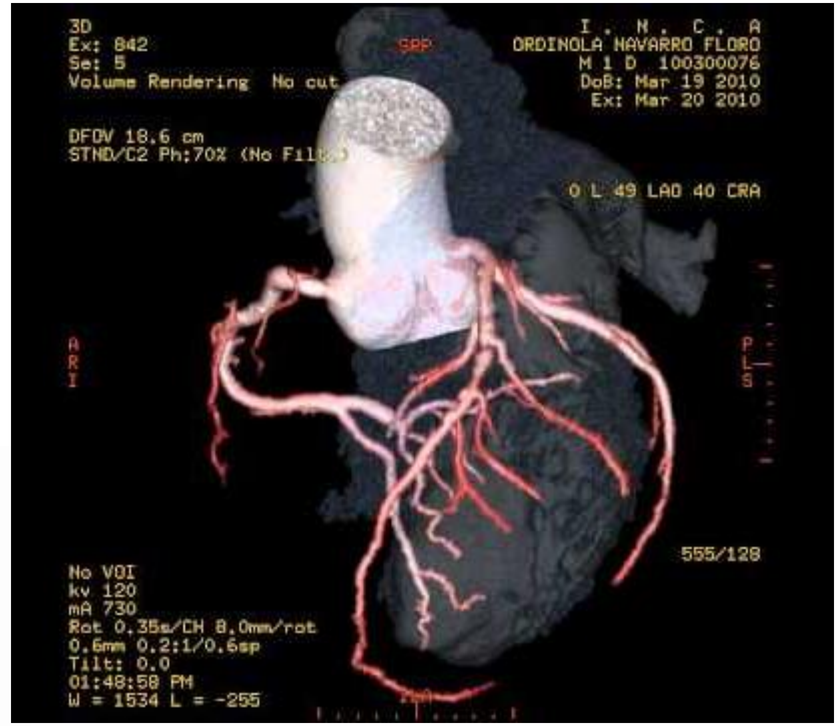
Coronary CT Angiography (CCTA)

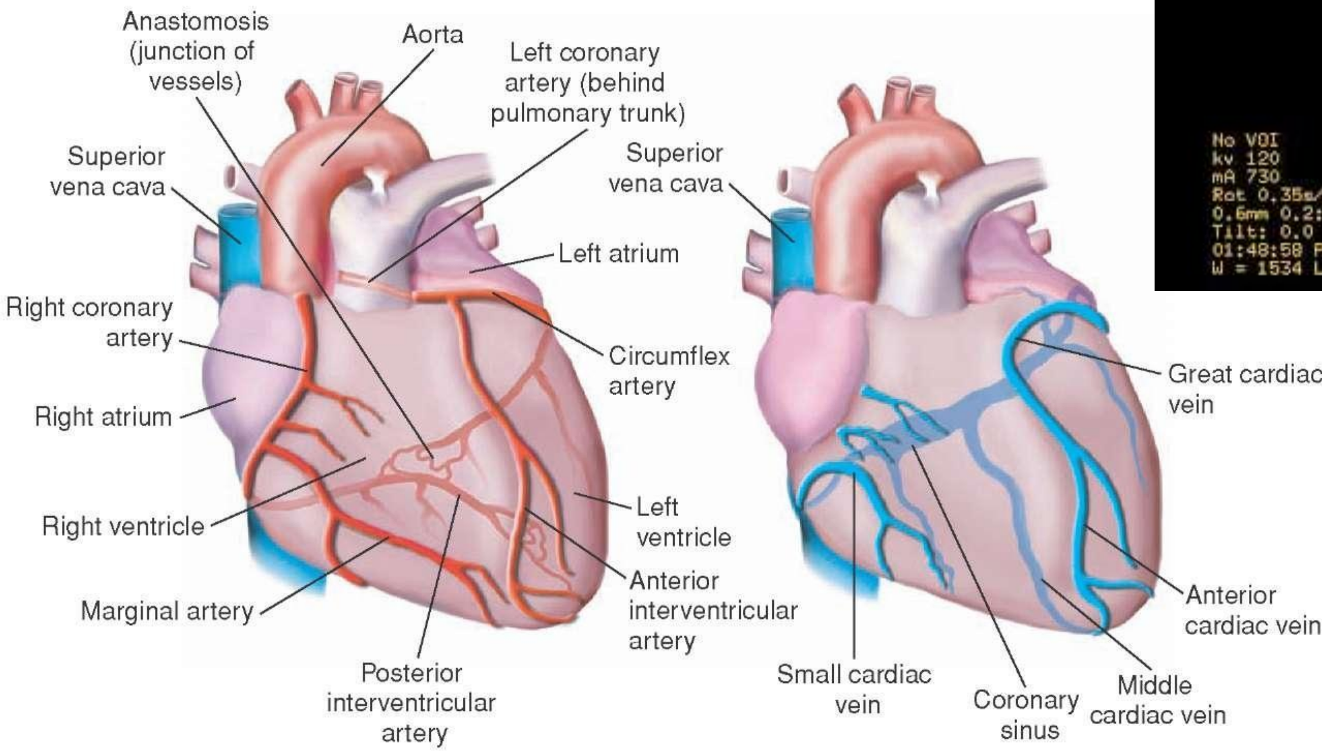
→ **Cardiac CTA** is an exam used to evaluate the structure and function of the heart, coronary arteries and large vessels of the chest.

→ **Coronary CTA** is a non-invasive method to image the coronary arteries with the use of contrast. Applications include the following:

- Diagnosis of coronary artery disease (CAD)
- Diagnosis of in-stent restenosis
- Evaluation of coronary bypass graft patency

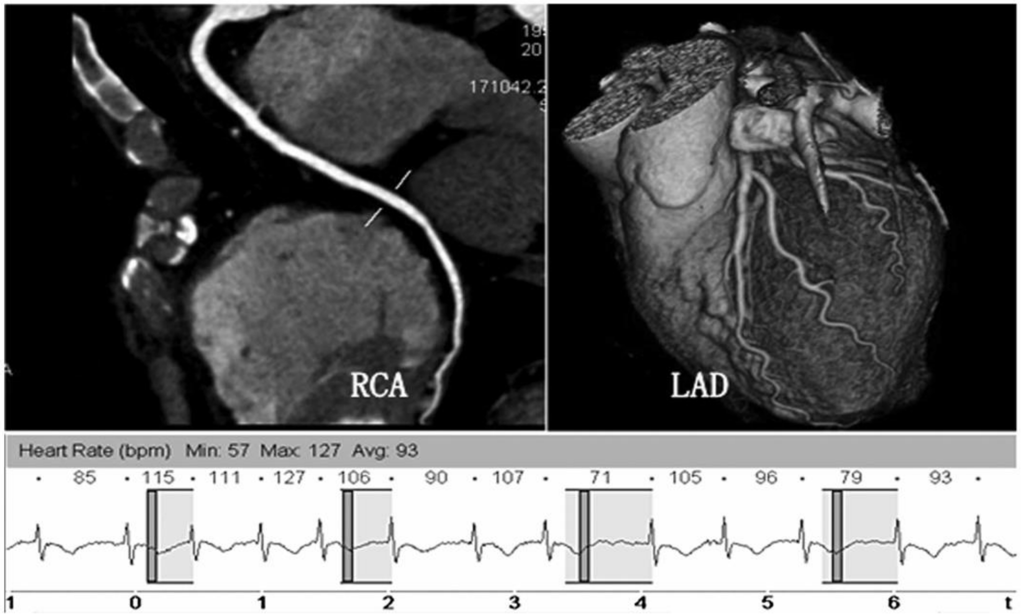
Coronary CT Angiography





Coronary CT Angiography (CCTA)

Coronary CT angiography is currently regarded as the diagnostic imaging method of choice for evaluating coronary arteries.



Conventional vs. Modern Angiography

Conventional coronary angiography (conventional cardiac catheterization)	Coronary CT angiography (CTCA)
→ Invasive methods (ICA)	→ Non – invasive
→ Expensive	→ Improved spatial & temporal resolution
→ Superior spatial & temporal resolution	→ Higher dose to patients

Studies have shown that coronary CT angiography has a high diagnostic accuracy for the detection of significant CAD (≥ 50% lumen stenosis) when compared to ICA (Sun Z, et.al., 2011).

Radiology

ORIGINAL RESEARCH ■ CARDIAC IMAGING

Coronary CT Angiography versus Conventional Cardiac Angiography for Therapeutic Decision Making in Patients with High Likelihood of Coronary Artery Disease[1]

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Rozemarijn Vliegenthart, MD, PhD
U. Joseph Schoepf, MD
John W. Nance, Jr, MD
Peter L. Zwerner, MD
Mathias Meyer, BS
Jacob C. Townsend, MD

Table 2

Performance of Coronary CT Angiography in Determining the Appropriate Treatment Strategy

Parameter	Patients with CAD (*n* = 143)	All Patients (*n* = 185)
Accuracy (%)	95.1	96.2
Sensitivity (%)	100 (94.6, 100)	100 (95.7, 100)
Specificity (%)	90.1 (83.2, 97.0)	93.8 (89.3, 98.2)
Negative predictive value (%)	100 (93.9, 100)	100 (96.5, 100)
Positive predictive value (%)	91.1 (84.8, 97.4)	91.1 (84.8, 97.4)
No. of true-positive findings	72	72
No. of false-positive findings	7	7
No. of true-negative findings	64	106
No. of false-negative findings	0	0

Note.—Numbers in parentheses are 95% confidence intervals. Conventional cardiac catheterization was used as the standard of reference.

Online Submissions: http://www.wjgnet.com/esps/
bpgoffice@wjgnet.com
doi:10.4330/wjc.v5.i12.442

World J Cardiol 2013 December 26; 5(12): 442-443
ISSN 1949-8462 (online)

TOPIC HIGHLIGHT

Zhonghua Sun, PhD, Associate Professor, *Series Editor*

Coronary CT angiography: State of the art

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Akmal Sabarudin, Diagnostic Imaging and Radiotherapy Program, School of Diagnostic and Applied Health Sciences, Faculty of Health Sciences, University Kebangsaan Malaysia, Kuala Lumpur 50300, Malaysia
Author contributions: Both authors wrote the paper.

Core tip: This article provides an overview of a series of articles that focus on individual topic highlight related to coronary computed tomography (CT) angiography. In particular, use of beta-blocker protocol, radiation dose measurements, dose-reduction strategies, diagnostic and prognostic value of coronary CT angiography will be described in detail in each series.

With latest MSCT (≥ 64 slice CT), CTCA has been reported to have high diagnostic value & can be used as reliable alternative to invasive coronary angiography in selected patients.

Journal of the American College of Cardiology
© 2006 by the American College of Cardiology Foundation
Published by Elsevier Inc.

Vol. 47, No. 9, 2006
ISSN 0735-1097/06/$32.00
doi:10.1016/j.jacc.2005.11.078

Cardiac Imaging

Comparison of Radiation Doses From Multislice Computed Tomography Coronary Angiography and Conventional Diagnostic Angiography

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Peter Wilde, BSc, BM BCh,‡ Martin Oberhoff, MD,* Karl R. Karsch, MD, FACC,*
Andreas Baumbach, MD*
Bristol, United Kingdom

OBJECTIVES The aim of this study was to quantify and compare effective doses from conventional angiography and multislice computed tomography (MSCT) coronary angiography using a 16-slice scanner.

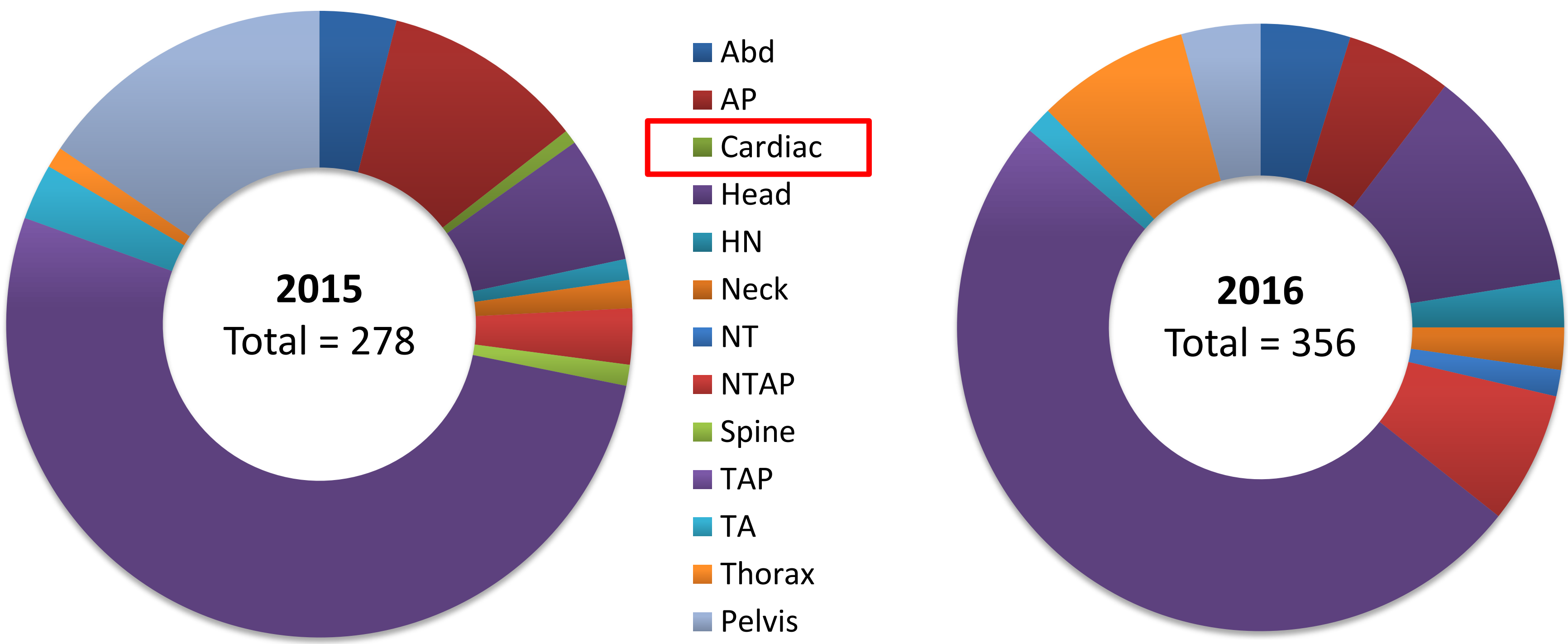
Mean effective dose for MSCT coronary angiography was significantly higher than that for conventional angiography → MSCT angiography (14.7 mSv) vs. conventional angiography (5.6 mSv).

(Duncan R. et.al, 2006)

3.6). A significant difference in effective dose was seen between the two protocols.

CONCLUSIONS The mean effective dose for MSCT coronary angiography was significantly higher than that for conventional angiography. As MSCT cardiac scanners become increasingly available, operators must be aware of the radiation dose and the factors that affect it. (J Am Coll Cardiol 2006;47:1840–5) © 2006 by the American College of Cardiology Foundation

Coronary CT Angiography



In AMDI, only 3 cardiac CT examinations were performed since Jan 2015 → CTA (1 patients) + CAScore (2 patients) – 0.7% of total studies performed in 2015.

Coronary CT Angiography

Study Protocols:

- Siemens SOMATOM Definition AS+ (128 slices/DECT)
- **Tube voltage:** 120 kVp
- **Tube current:** AEC for mAs
- **Scan length:** 15-20 cm (as reported in literature) – depends on patient's height
- **Pitch:** 0.2
- **Scan time:** 0.33 s

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Online Submissions: http://www.wjgnet.com/1949-8462office
wjc@wjgnet.com
doi:10.4330/wjc.v3.i9.303

World J Cardiol 2011 September 26; 3(9): 303-310
ISSN 1949-8462 (online)

BRIEF ARTICLE

Coronary computed tomography angiography in coronary artery disease

Zhonghua Sun, Kwan-Hoong Ng

(85%) of the studies. Figure 1 shows the distribution of different generations of MSCT scanners that were identified in the analysis. Despite rapid technological developments of MSCT scanners, such as the increased availability of 256- and 320-slice CT, single source 64-slice and dual-source CT (DSCT) still dominated 78% of the coronary CT angiography studies. Coronary CT angiography was compared with integrated single photon emission computed tomography/CT and positron emission tomography/CT in two studies to investigate the myocardial perfusion value of coronary CT angiography.

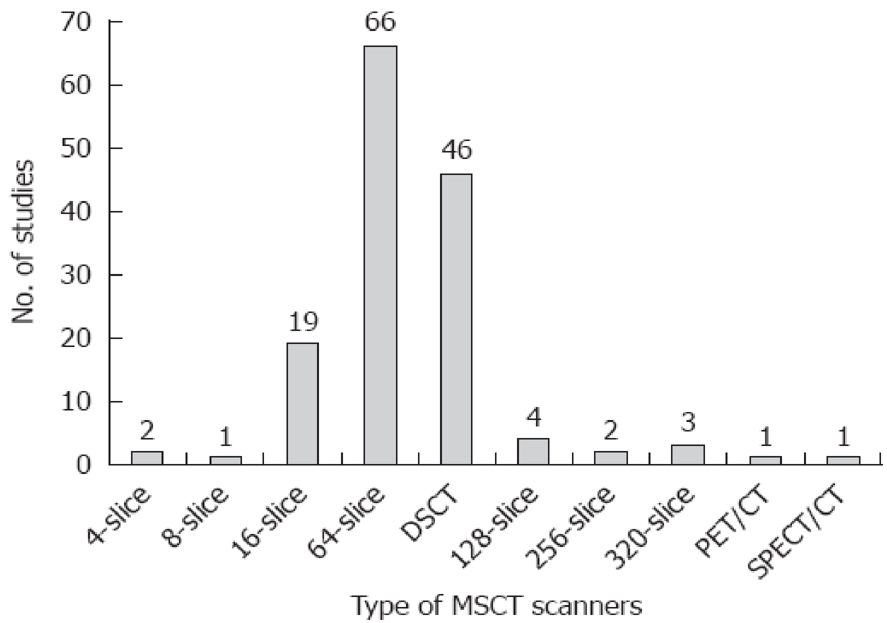

Figure 1 The number of studies performed with different generations of multislice computed tomography scanners. CT: Computed tomography; DSCT: Dual-source CT; MSCT: Multislice CT; PET: Positron emission tomography; SPECT: Single photon emission computed tomography.

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Journal of Medical Imaging and Radiation Oncology **56** (2012) 5–17

RADIOLOGY—REVIEW ARTICLE

A systematic review of radiation dose associated with different generations of multidetector CT coronary angiography

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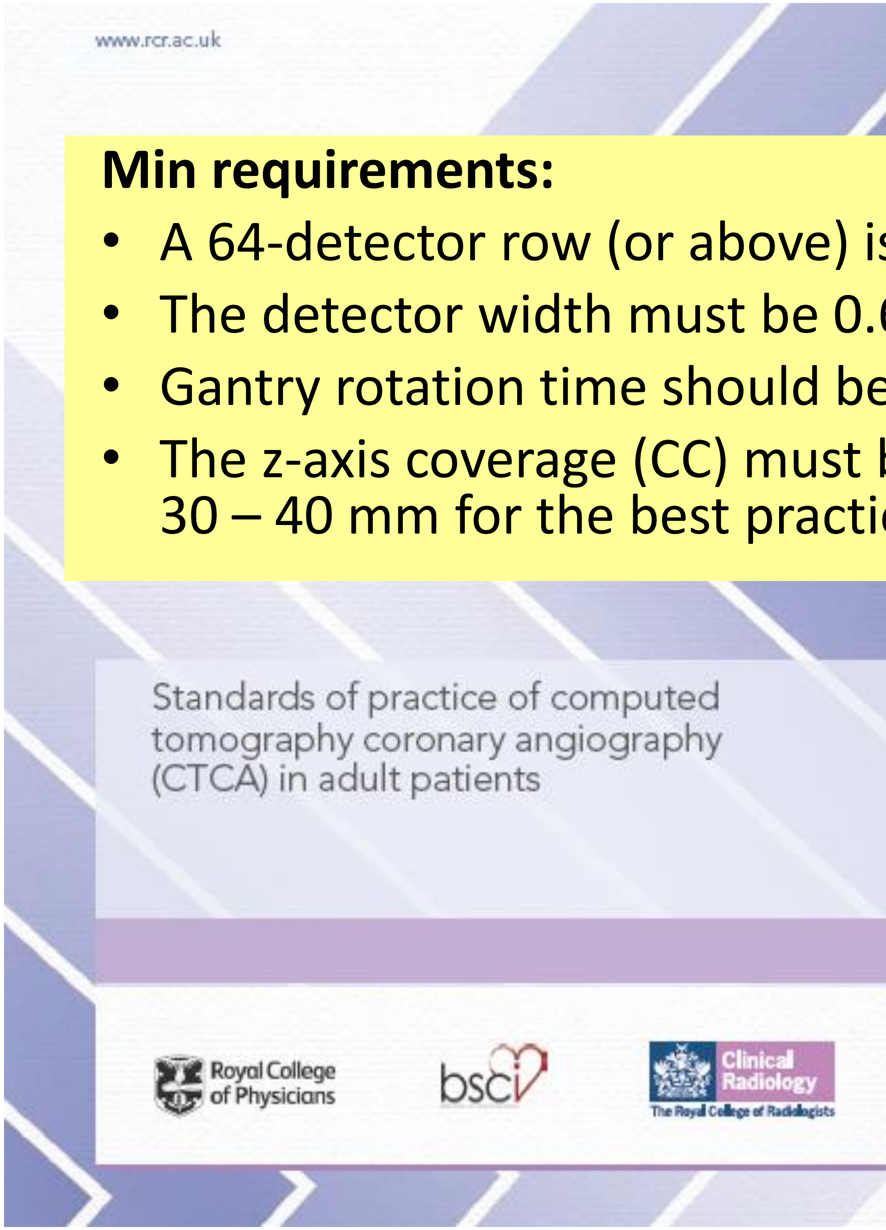
CT scanner	Scanning methods	Slice thickness / collimation (mm)	Pitch	Exposure settings
< 64 slices CTA (4/16/40- slices)	Retrospective/ Prospective/ High pitch/ ECG-controlled tube current modulation	0.625 – 2.5	0.18 – 0.75 (low pitch) 1.5 – 2.0 (high pitch)	100 – 140 kVp 100 – 800 mAs
64-slices CTA	Retrospective/ Prospective/ High pitch/ low kVp/AEC/ tube current modulation	0.6, 0.625	0.2 – 0.44 (low pitch) 3.2 – 3.4 (high pitch) *most of the study used low pitch	80 – 140 kVp 190 – 900 mAs
> 64 slices CTA (128/256/320- slices)	Retrospective/ Prospective/ High pitch/ tube current modulation	0.5, 0.6, 0.625	0.18, 0.2 – 0.5 (low pitch)	100 – 140 kVp 180 – 950 mAs

Min requirements:

- A 64-detector row (or above) is required.
- The detector width must be 0.625 mm or less.
- Gantry rotation time should be <350 ms.
- The z-axis coverage (CC) must be at least 20 mm & 30 mm for DSCT. 30 – 40 mm for the best practice.



7. CT scanner technical requirements

CT technology for cardiac imaging is evolving rapidly. Historically, …

… with dedicated cardiac capability is used.

Choice of technology

The choice of scanner technology will ultimately depend on a number of factors. This is likely to reflect current preferences or service agreements and the requirements of the existing service. It should be recognised that in all but the very highest volume centres, the CT scanner will be used for non-cardiac imaging for a considerable amount, if not the majority, of the time.

General considerations

Minimum requirements

- The department must comply with the Ionising Radiation …

… radiographers and medical physicists (required by UK law).

Scanner capabilities

Minimum requirements

- ECG gating with prospective and retrospective gating capability is required.
- Dose modulation with the ECG phase should be available for retrospectively gated scanning to reduce the radiation dose to the patient.
- Pre-scan contrast timing assessment, either by automated or visual bolus tracking or with assessment of a test bolus, must be possible.

Hardware specification

Minimum requirements

- A 64-detector row (or above) scanner is required. The non-diagnostic rate of scanners with fewer detector rows is 10% greater than those with 64 detectors.
- The detector width must be 0.625 mm or less.
- The gantry rotation time should be <350 milliseconds (ms).

Recommended best practice

- The Z-axis coverage should be approximately 30–40 mm or greater.
- New-generation technology should be available when imaging patients who are difficult to scan. Where this is not available in the department, it must be accessible to a service via a cardiac network or other local arrangement.

Standard 5

The scanner used should be specifically set up for CTCA and be of 64 slices or greater, with cardiac software and ECG gating.

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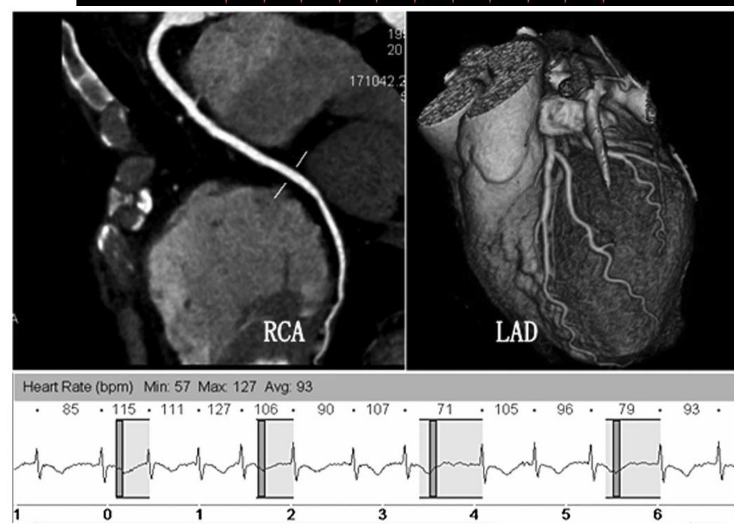

Radiation dosimetry in CT

Total mAs 4334 Total DLP 721 mGycm

	Scan	kV	mAs / ref.	CTDIvol* mGy	DLP mGycm	TI s	cSL mm
Patient Position H-SP							
Topogram	1	120	35 mA	0.13 L	4	3.2	0.6
CaSc	2	120	19 / 40	4.44 L	67	0.33	0.6
Contrast							
TestBolus	3	120	20	13.11 L	13	0.33	10.0
Last scan no.	16						
Contrast							
TestBolus	17	120	20	6.56 L	7	0.33	10.0
Last scan no.	23						
Contrast							
CorCTA	24	120	127 / 160	26.63 L	630	0.33	0.6

Medium	Type	Iodine Conc. mg/ml	Volume ml	Flow ml/s	CM Ratio
Contrast	OMNIPAQUE	350	10	4.9	100%
Saline			20	4.9	

1 of 2 *: L = 32cm, S = 16cm

Dose Display
(Post Study Data Page)

- The dose display is created upon completion of a study → delivered $CTDI_{vol}$, DLP for each series, and phantom size used to calculate these values.

- It is useful to check $CTDI_{vol}$ after a study is performed to ensure that the output of the scanner was as expected

Dose Display (Post Study Data Page)

- **$CTDI_{vol}$** is calculated based on the technique factors used to acquire the data
- **DLP** is calculated based on the technique factors and scan length used

Radiation dosimetry in CT

- **CT dose index (CTDI)** is a standardized measure of radiation dose output of a CT scanner which allows the user to compare radiation output of different CT scanners.

$$CTDI = \frac{1}{NT}\int_{-\infty}^{\infty} D(z)dz$$

- *D(z)* = the radiation dose profile along the z-axis,
- *N* = the number of tomographic sections imaged in a single axial scan.
- *T* = scan width

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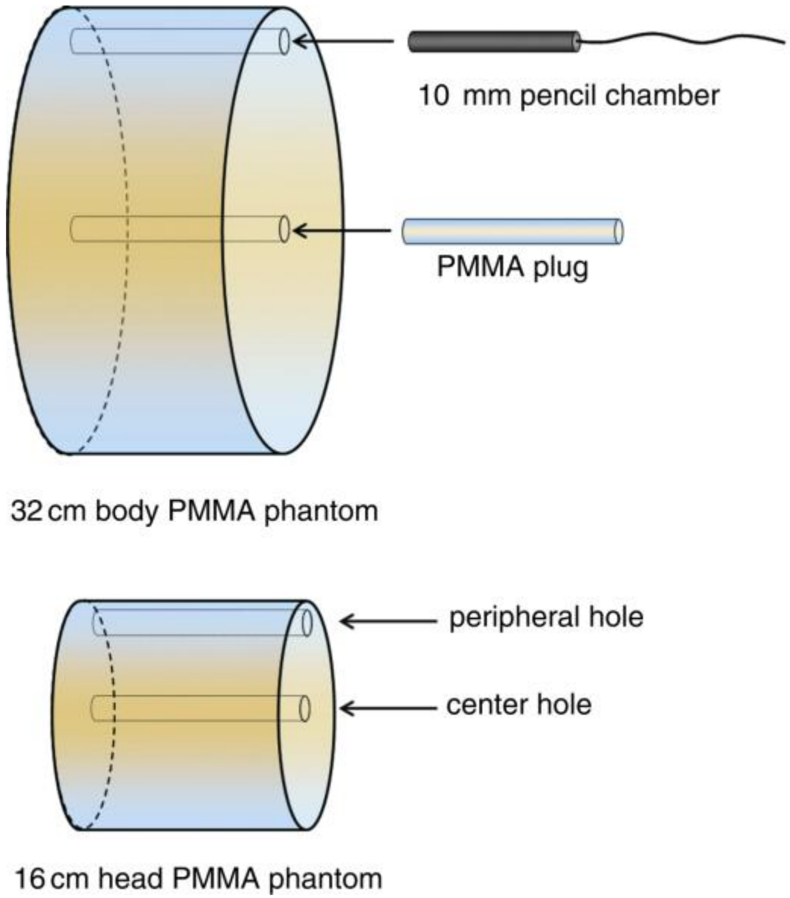
Radiation dosimetry in CT

- Measured in large (32 cm diameter) or small (16 cm or 10 cm diameter) PMMA cylindrical phantom.
- The CTDI measured in large phantom is for **adult CT** (chest, abdomen, and pelvis).
- The CTDI measured in small phantom (16 cm) is for **adult head CT**, and **pediatric body CT** and 10 cm phantom is for **pediatric head**.

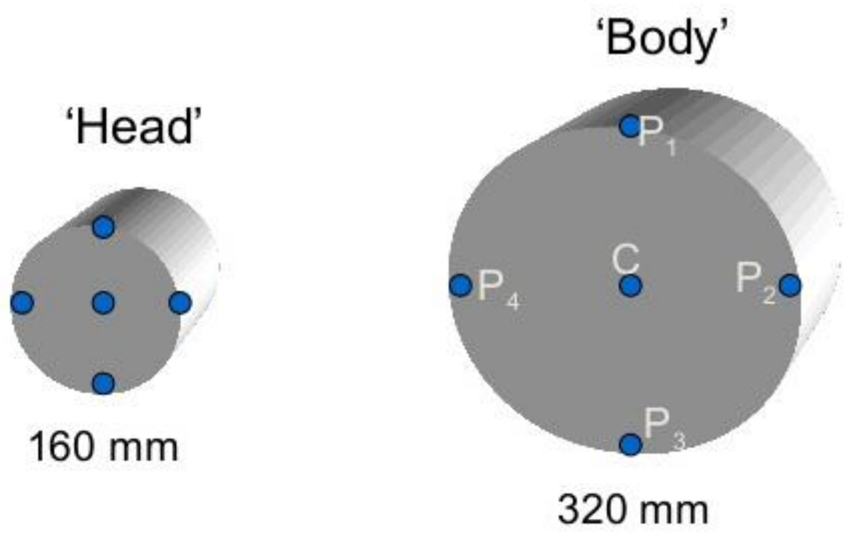


Radiation dosimetry in CT

- **$CTDI_{100}$ is a measure of radiation on a 100cm long pencil ionization chamber.**

- **CTDI weighted, $CTDI_w$:**

$$CTDI_w = \frac{2}{3} CTDI_{peripheral} + \frac{1}{3} CTDI_{center}$$



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Radiation dosimetry in CT

- **CTDI volume, $CTDI_{vol}$** is the approximate average radiation dose over x,y, and z axis of the patient.

$$CTDI_{vol} = \frac{NT}{I} CTDI_w$$

$$CTDI_{vol} = \frac{1}{pitch} CTDI_w$$

- $CTDI_{vol}$ estimates the average radiation dose within the irradiated volume for an object of similar attenuation to the CTDI phantom.

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Radiation dosimetry in CT

$CTDI_{vol}$ → estimation of patient dose (in mGy) – a standardized parameter to measure **Scanner Radiation Output.**

- ✓ **$CTDI_{vol}$** is NOT patient dose!
- ✓ **$CTDI_{vol}$** is slice-specific dose measurement
- ✓ **$CTDI_{vol}$** is based on measurements made by the manufacturer in a factory setting.

$CTDI_{vol}$ does not represent the average dose for objects of substantially different size, shape, or attenuation!

Summary of Acquisition Parameter Settings

Parameter	Relationship to $CTDI_{vol}$
Scan Mode	Changes in the scan mode may affect $CTDI_{vol}$
Table Feed/Increment	Table feed affects $CTDI_{vol}$ through its inclusion in pitch
Detector Configuration	Decreasing the beam collimation typically, but not always, increases the $CTDI_{vol}$
Pitch	$CTDI_{vol}$ relationship to pitch is vendor dependent
Exposure Time Per Rotation	$CTDI_{vol}$ relationship to exposure time per rotation is vendor dependent
Tube Current	$CTDI_{vol}$ µ tube current
Tube Potential	$CTDI_{vol}$ µ $(kVp_1/kVp_2)^n$ n ~ 2 to 3
Tube Current Time Product	$CTDI_{vol}$ µ tube current time product
Effective mAs	$CTDI_{vol}$ µ effective tube current time product
Field of Measurement	Changes in the field of measurement may affect $CTDI_{vol}$
Beam Shaping Filter	Changes in the beam shaping filter may affect $CTDI_{vol}$

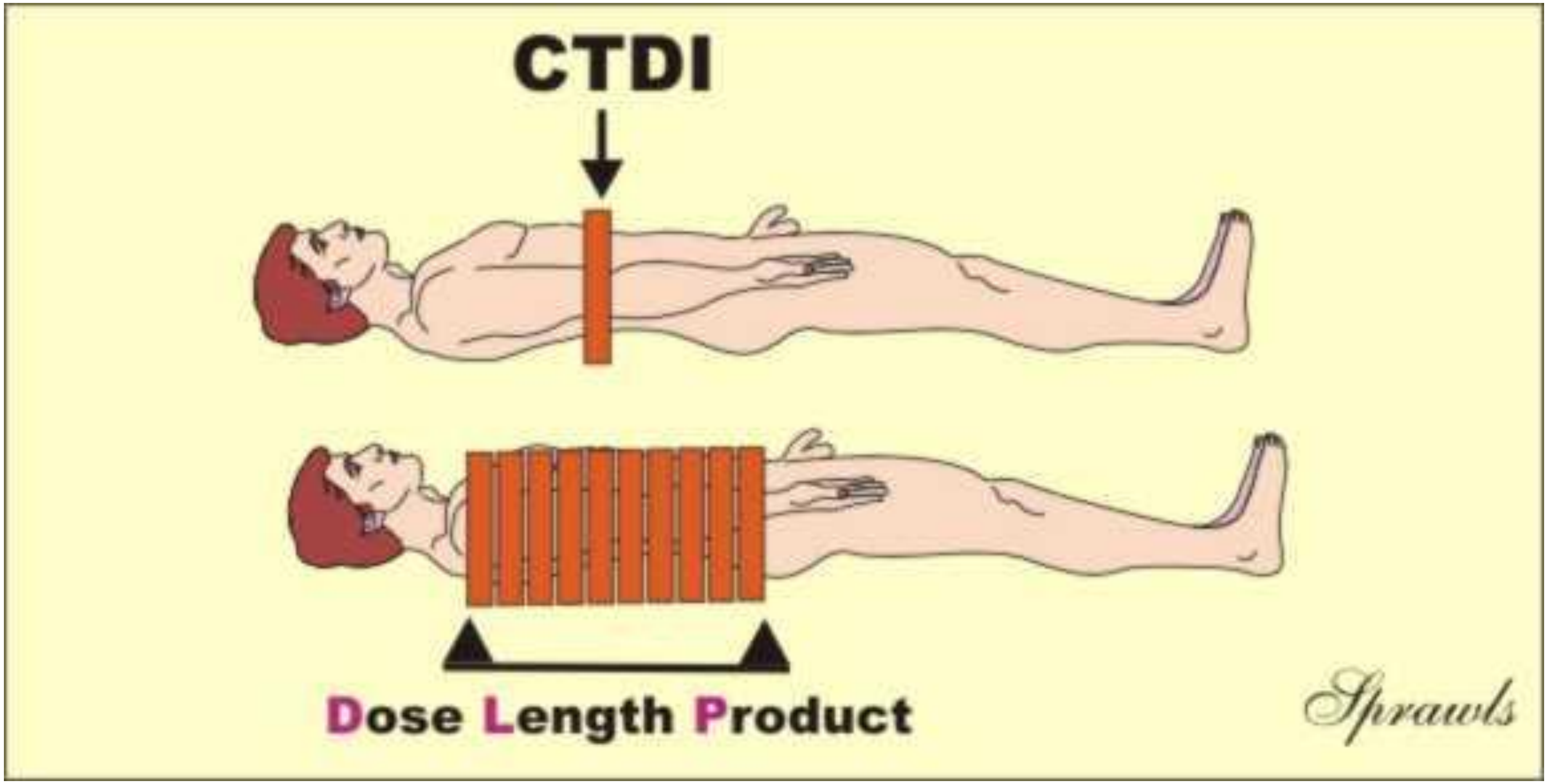
Radiation dosimetry in CT

- **Dose-length product (DLP)** → product of the length of the irradiated scan volume and the average $CTDI_{vol}$ over that distance

$$\boldsymbol{DLP = CTDI_{vol} \text{ x } scan\ length}$$

- **Unit:** mGy.cm

CTDI vs. DLP



Radiation dosimetry in CT

- **Effective dose, E** is a measure of radiation and organ system specific damage in humans (in unit sievert, Sv)

- **E** is the **DLP multiplied by conversion factor, k** (takes into account organ size and radiosensitivity)

Radiation dosimetry in CT

$$Effective\ Dose = E = \sum_{T} w_T \ H_T$$

- $\boldsymbol{H_T}$ are the tissue-specific equivalent doses in tissues $\boldsymbol{T}$
- $\boldsymbol{w_T}$ are committee-defined dimensionless tissue-specific weighting factors

Table shows tissue weighting factor (as published by ICRP)

Tissue or organ	Weighting Factor, w_T		
	ICRP 26 (1977)	ICRP 60 (1990)	ICRP 103 (2007)
Bone marrow (red)	0.12	0.12	0.12
Breast	0.15	0.05	0.12
Lung	0.12	0.12	0.12
Stomach	-	0.12	0.12
Colon	-	0.12	0.12
Gonads	0.25	0.20	0.08
Thyroid	0.03	0.05	0.04
Bladder	-	0.05	0.04
Liver	-	0.05	0.04
Oesophagus	-	0.05	0.04
Bone surface	0.03	0.01	0.01
Skin	-	0.01	0.01
Salivary glands	-	-	0.01
Brain	-	-	0.01
Remainder	0.30	0.05	0.12

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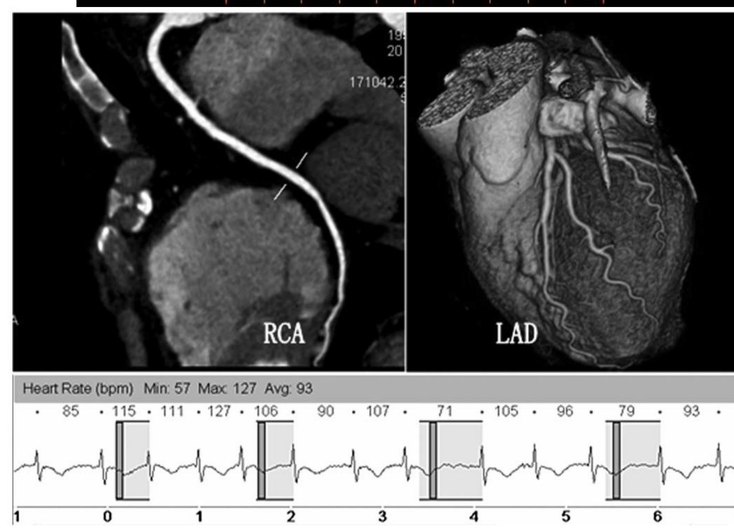
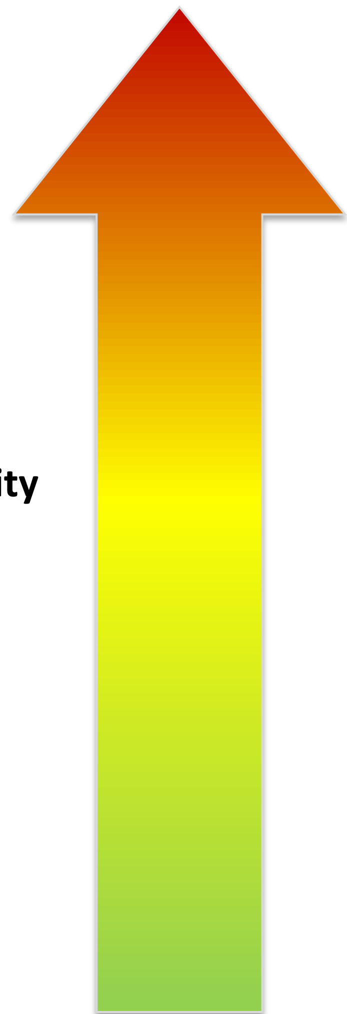


Cell Radiosensitivity

- **Radiosensitivity** →relative susceptibility of cells, tissues & organs to the injurious action of radiation.
- Cell radiosensitivity is **directly proportional** to cell division rate and **inversely proportional** to cell differentiation degree.
- The most radiosensitive (most at risk from radiation) cells are:
  - **actively dividing cells (high division rate)**
  - **not fully mature or non-specialized type**
  - **cells that have a high metabolic rate**
  - **well nourished cells**

Tissues radiosensitivity



Increasing radiosensitivity

High Radiosensitivity

Lymphoid organs, bone marrow, blood, testes, ovaries, intestines

Fairly High Radiosensitivity

Skin and other organs with epithelial cell lining (cornea, oral cavity, esophagus, rectum, bladder, vagina, uterine cervix, ureters)

Moderate Radiosensitivity

Optic lens, stomach, growing cartilage, fine vasculature, growing bone

Fairly Low Radiosensitivity

Mature cartilage or bones, salivary glands, respiratory organs, kidneys, liver, pancreas, thyroid, adrenal and pituitary glands

Low Radiosensitivity

Muscle, brain, spinal cord

Computed Tomography — An Increasing Source of Radiation Exposure

David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., D.Sc.

THE ADVENT OF COMPUTED TOMOGRAPHY (CT) HAS REVOLUTIONIZED DIagnostic radiology. Since the inception of CT in the 1970s, its use has increased rapidly. It is estimated that more than 62 million CT scans per year are currently obtained in the United States, including at least 4 million for children.[1]

By its nature, CT involves larger radiation doses than the more common, conventional x-ray imaging procedures (Table 1). We briefly review the nature of CT scanning and its main clinical applications, both in symptomatic patients and, in a more recent development, in the screening of asymptomatic patients. We focus on the increasing number of CT scans being obtained, the associated radiation doses, and the consequent cancer risks in adults and particularly in children. Although the risks for any one person are not large, the increasing exposure to radiation in the population may be a public health issue in the future.

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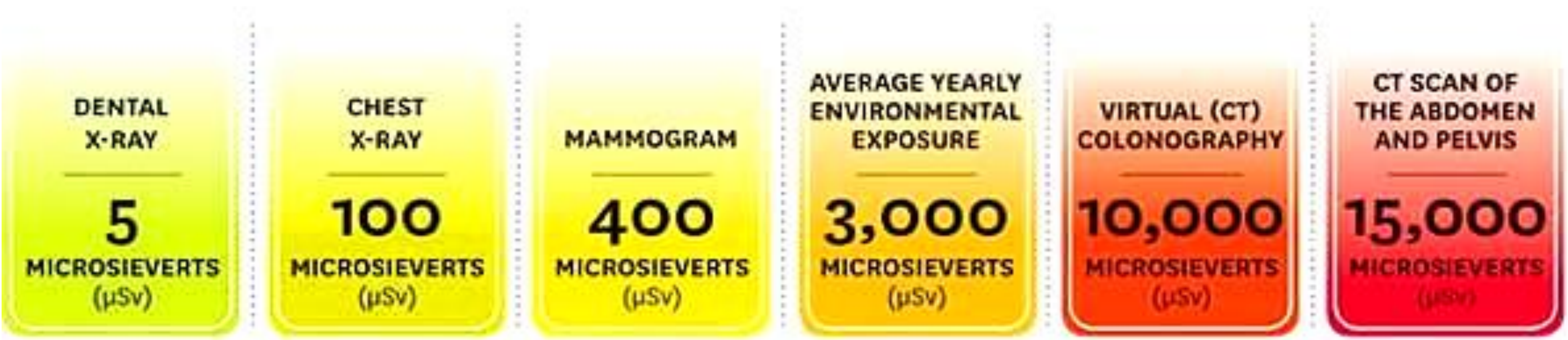
N Engl J Med 2007;357:2277-84.

CT has become the single largest contributor to man-made radiation exposure.

Increased patient radiation dose from CT!

CT scans delivers ~500 times the radiation of standard X-ray!!!



Radiation dose from common imaging tests

Test	Radiation
Echocardiogram	0 mSV
MRI	0 mSV
Chest x-ray	0.05 mSV
Mammogram	0.7 mSv
Calcium scoring test	**1-2 mSv**
Cardiac catheterization	7 mSv
Chest CT	10 mSv
Coronary CT angiography	**3-14 mSv**
Radionuclide sestamibi stress test	10-12 mSv
Radionuclide dual isotope myocardial perfusion imaging	25 mSv

Computed Tomography — An Increasing Source of Radiation Exposure

David J. Brenner, Ph.D., D.Sc., and Eric J. Hall, D.Phil., D.Sc.

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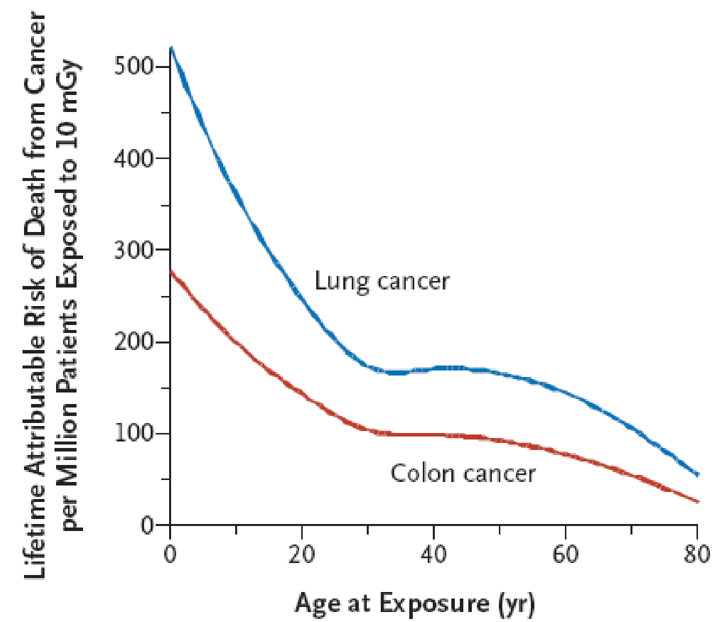

Figure 4. Estimated Dependence of Lifetime Radiation-Induced Risk of Cancer on Age at Exposure for Two of the Most Common Radiogenic Cancers.

Cancer risks decrease with increasing age both because children have more years of life during which a potential cancer can be expressed (latency periods for solid tumors are typically decades) and because growing children are inherently more radiosensitive, since they have a larger proportion of dividing cells. These risk estimates, applicable to a Western population, are from a 2005 report by the National Academy of Sciences[25] and are ultimately derived from studies of the survivors of the atomic bombings. The data have been averaged according to sex.

Journal of Medical Imaging and Radiation Oncology **56** (2012) 5–17

RADIOLOGY—REVIEW ARTICLE

A systematic review of radiation dose associated with different generations of multidetector CT coronary angiography

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Conflict of interest: None.

Submitted 28 February; accepted 17 July 2011

Summary

The purpose of this paper is to perform a sy
reduction in coronary computed tomograph
using different generations of multidetector
four-slice to 320-slice CTs, and have differ
method followed was to search for referen
(CTA) that had been published in English b
The effective radiation dose reported in ea
erations of MDCT scanners was analysed an
scanners, gender, exposure factors and sca
were eligible for inclusion in this analysis

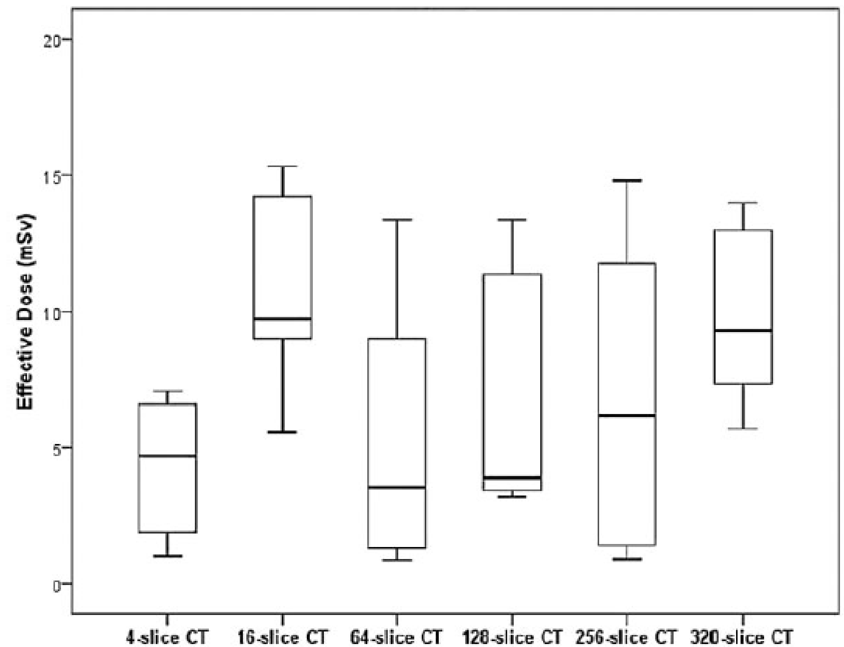

Fig. 4. Distribution of mean effective dose between 4-, 16-, 64-, 128-, 256- and 320-slice multidetector CT scanners is displayed in the box plot. Radiation dose increases with the increase of number of slices; in particular, this is apparent when comparing 4-slice with 16- and 64-slice CT. With latest models such as 128-, 256- and 320-slice CT, radiation dose was reduced to some extent as prospective gating is commonly used. Horizontal line in each box shows median and top and bottom lines of boxes show interquartile range (IQR). Whiskers show lowest value still within 1.5 IQR of lower or upper quartile; however, the highest value for 16-slice CT studies is outside 1.5 IQR of upper quartile.

Radiation risk associated with CCTA

Although we only scan 15-20 cm of the chest for most cardiac CT exams, particularly CCTA, the doses are **relatively higher** because we're looking at very fine structures with overlapping data acquisition and matching the data with the cardiac cycle or the motion of the heart.

Higher dose due to higher image quality → higher resolution and thinner slices is needed.

(Cristen C. B., 2008)

The British Journal of Cardiology

MDCT coronary angiography: does the benefit justify radiation burden?

September 2010 Br J Cardiol 2010;17:207–08 Leave a comment

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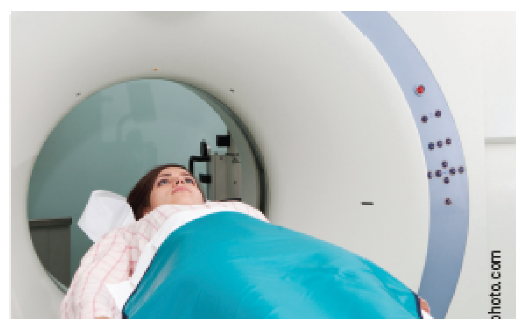
Authors: Khaled Alfakih, Mathew Budoff Show details

Recent technical developments in multi-detector computed tomography (MDCT), and particularly the introduction of 64-slice MDCT, have made the non-invasive imaging of coronary arteries a clinical reality. Beta blockers are used to decrease the heart rate to 65 bpm, sublingual glyceryl trinitrate (GTN) can be used to dilate the coronary arteries, and the patient is only required to breath-hold for a few seconds. Fast or irregular heart rates, extensive calcium blooming artefacts and patients with high body mass index (BMI) are the only limiting factors. The temporal resolution is faster with dual-source MDCT, reducing the need for beta blockers, and the 320-slice MDCT can image the heart in one heart beat.



MDCT coronary angiography (CTCA) has been shown to be highly accurate at detecting coronary artery disease (CAD) with more than 30 studies and several meta-analyses confirming excellent sensitivity and negative predictive value (NPV), when compared with invasive X-ray coronary angiography.[1] This was confirmed in three multi-centre trials: Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary

Estimated Radiation Dose Associated With Cardiac CT Angiography

Jörg Hausleiter, MD
Tanja Meyer, MD
Franziska Hermann, MD
Martin Hadamitzky, MD
Markus Krebs
Thomas C. Gerber, MD
Cynthia McCollough, PhD
Stefan Martinoff, MD
Adnan Kastrati, MD
Albert Schömig, MD
Stephan Achenbach, MD

Context Cardiac computed tomography (CT) angiography (CCTA) has emerged as a useful diagnostic imaging modality in the assessment of coronary artery disease. However, the potential risks due to exposure to ionizing radiation associated with CCTA have raised concerns.

Objectives To estimate the radiation dose of CCTA in routine clinical practice as well as the association of currently available strategies with dose reduction and to identify the independent factors contributing to radiation dose.

Design, Setting, and Patients A cross-sectional, international, multicenter, observational study (50 study sites: 21 university hospitals and 29 community hospitals) of estimated radiation dose in 1965 patients undergoing CCTA between February and December 2007. Linear regression analysis was used to identify independent predictors associated with dose.

Main Outcome Measure Dose-length product (DLP) of CCTA.

Results The median DLP of 1965 CCTA examinations performed at 50 study sites was 885 mGy × cm (interquartile range, 568-1259 mGy × cm), which corresponds to an estimated radiation dose of 12 mSv (or 1.2 × the dose of an abdominal CT study or 600 chest x-rays). A high variability in DLP was observed between study sites (range of median DLPs per site, 331-2146 mGy × cm). Independent factors associated with radiation dose were patient weight (relative effect on DLP, 5%; 95% confidence interval [CI], 4%-6%), absence of stable sinus rhythm (10%; 95% CI, 2%-19%), scan length (5%; 95% CI, 4%-6%), electrocardiographically controlled tube current modulation (−25%; 95% CI, −23% to −28%; applied in 73% of patients), 100-kV tube voltage (−46%; 95% CI, −42% to −51%; applied in 5% of patients), sequential scanning (−78%; 95% CI, −77% to −79%; applied in 6% of patients), experience in cardiac CT (−1%; 95% CI, −1% to 0%), number of CCTAs per month (0%; 95% CI, 0%-1%), and type of 64-slice CT system (for highest vs lowest dose system, 97%; 95% CI, 88%-106%). Algorithms for dose reduction were not associated with deteriorated diagnostic image quality in this observational study.

Conclusions Median doses of CCTA differ significantly between study sites and CT

WITH THE INTRODUCTION OF 64-slice computed tomography (CT), cardiac CT angiography (CCTA) has emerged as a useful diagnostic imaging modality for the assessment of coronary artery disease. It is considered appropriate for selected indications (eg, in patients with a low-to-intermediate pretest probability for obstructive coronary artery disease).[1-3] In addition, CCTA has been proposed to be useful in the rapid evaluation of patients with chest pain in the emergency department.[4] With the con-

Radiation risk associated with CCTA

Comparisons of effective radiation dose in adults for various CT procedures.

Adult Effective Doses for Various CT Procedures

Examination	Average Effective Dose (mSv)	Values Reported in Literature (mSv)
Head	2	0.9–4.0
Neck	3	. . .
Chest	7	4.0–18.0
Chest for pulmonary embolism	15	13–40
Abdomen	8	3.5–25
Pelvis	6	3.3–10
Three-phase liver study	15	. . .
Spine	6	1.5–10
Coronary angiography	16	5.0–32
Calcium scoring	3	1.0–12
Virtual colonoscopy	10	4.0–13.2

FA. Mettler et.al., Radiology: 2008

Estimating Risk of Cancer Associated With Radiation Exposure From 64-Slice Computed Tomography Coronary Angiography

Andrew J. Einstein, MD, PhD

Milena J. Henzlova, MD, PhD

Sanjay Rajagopalan, MD

Context Computed tomography coronary angiography (CTCA) has become a common diagnostic test, yet there are little data on its associated cancer risk. The recent Biological Effects of Ionizing Radiation (BEIR) VII Phase 2 report provides a framework for estimating lifetime attributable risk (LAR) of cancer incidence associated with radiation exposure from a CTCA study, using the most current data available on health effects of radiation.

Objectives To determine the LAR of cancer incidence associated with radiation exposure from a 64-slice CTCA study and to evaluate the influence of age, sex, and scan protocol on cancer risk.

Design, Setting, and Patients Organ doses from 64-slice CTCA to standardized phantom (computational model) male and female patients were estimated using Monte Carlo simulation methods, using standard spiral CT protocols. Age- and sex-specific LARs of individual cancers were estimated using the approach of BEIR VII and summed to obtain whole-body LARs.

Main Outcome Measures Whole-body and organ LARs of cancer incidence.

Results Organ doses ranged from 42 to 91 mSv for the lungs and 50 to 80 mSv for the female breast. Lifetime cancer risk estimates for standard cardiac scans varied from 1 in 143 for a 20-year-old woman to 1 in 3261 for an 80-year-old man. Use of simulated electrocardiographically controlled tube current modulation (ECTCM) decreased these risk estimates to 1 in 219 and 1 in 5017, respectively. Estimated cancer risks using ECTCM for a 60-year-old woman and a 60-year-old man were 1 in 715 and 1 in 1911, respectively. A combined scan of the heart and aorta had higher LARs, up to 1 in 114 for a 20-year-old woman. The highest organ LARs were for lung cancer and, in younger women, breast cancer.

Conclusions These estimates derived from our simulation models suggest that use of 64-slice CTCA is associated with a nonnegligible LAR of cancer. This risk varies markedly and is considerably greater for women, younger patients, and for combined car-

Coronary artery disease (CAD) is the leading cause of death in men and women in the United States, accounting for 1 in 5 deaths, and a major cause of health care expenditures, with annual costs estimated at $142 billion.[1] While the gold standard for CAD diagnosis remains conventional coronary angiography, its associated costs and morbidity, including a 1.7% rate of major complications,[2] have led to the development of noninvasive modalities for CAD diagnosis. Since its approval in 2004, 64-slice computed tomography coronary angiography (CTCA) has generated particular interest due to its visualization of the coronary arteries with a spatial resolution as low as 0.4 mm, resulting in high diagnostic sensitivity and specificity and a per-patient negative predictive value greater than 95% in most series.[3]

Estimating Risk of Cancer Associated With Radiation Exposure From 64-Slice Computed Tomography Coronary Angiography

Andrew J. Einstein, MD, PhD
Milena J. Henzlova, MD, PhD
Sanjay Rajagopalan, MD

Context Computed tomography coronary angiography (CTCA) has become a common diagnostic test, yet there are little data on its associated cancer risk. The recent Biological Effects of Ionizing Radiation (BEIR) VII Phase 2 report provides a framework for estimating lifetime attributable risk (LAR) of cancer incidence associated with ra-

Table 1. Doses From the 8 Computed Tomography Coronary Angiography Protocols

Sex	ECTCM	Aorta	Effective Dose, mSv[b]	Organ Equivalent Doses, mSv[a]									
				Thymus	Breast	Lung	Esophagus	Bone	Adrenals	Marrow	Liver	Small Intestine	Stomach
Female	No	No	21	79	77	74	47	29	15	13	12	9	8
Male	No	No	15	29		65	37	24	30	10	22	15	14
Female	Yes	No	14	52	50	48	30	19	10	8	8	6	5
Male	Yes	No	9	19		42	24	15	20	7	14	9	9
Female	No	Yes	29	114	80	91	77	47	16	21	12	9	8
Male	No	Yes	23	107		90	63	41	31	18	23	16	14
Female	Yes	Yes	19	74	52	59	50	31	10	14	8	6	6
Male	Yes	Yes	15	69		58	41	26	20	12	15	10	9

Abbreviation: ECTCM, electrocardiographically controlled tube current modulation.
[a]Organ equivalent doses reported here only for organs with a dose >10 mSv for standard male or female patient; the doses are displayed here as integers, although more significant figures were retained for calculations.
[b]Effective dose determined using International Commission on Radiological Protection Publication 60 tissue weighting factors.[13]

Radiation risk associated with CCTA

One study estimated that one in every 270 women aged 40 years who undergo a CT coronary angiogram will develop cancer from the procedure.

(Smith-Bindman R, et al., 2009)

Radiation risk associated with CCTA

Comparisons of effective radiation dose in adults with background radiation exposure for several radiological procedures.

CT PROCEDURES	* An adult's approximate effective radiation dose is:	Comparable to natural background radiation for:
ABDOMINAL REGION:		
CT Abdomen + Pelvis	10 mSv	3 years
CT Abdomen + Pelvis, repeated with and without contrast	20 mSv	7 years
CT Colonography	6 mSv	2 years
CENTRAL NERVOUS SYSTEM:		
CT Head	2 mSv	8 months
CT Head, repeated with and without contrast	4 mSv	16 months
CT Spine	6 mSv	2 years
CHEST:		
CT Chest	7 mSv	2 years
CT-Lung Cancer Screening	1.5 mSv	6 months
DENTAL:		
Intraoral X-ray	0.005 mSv	1 day
HEART:		
Coronary CTA	12 mSv	4 years
Cardiac CT for Calcium Scoring	3 mSv	1 year

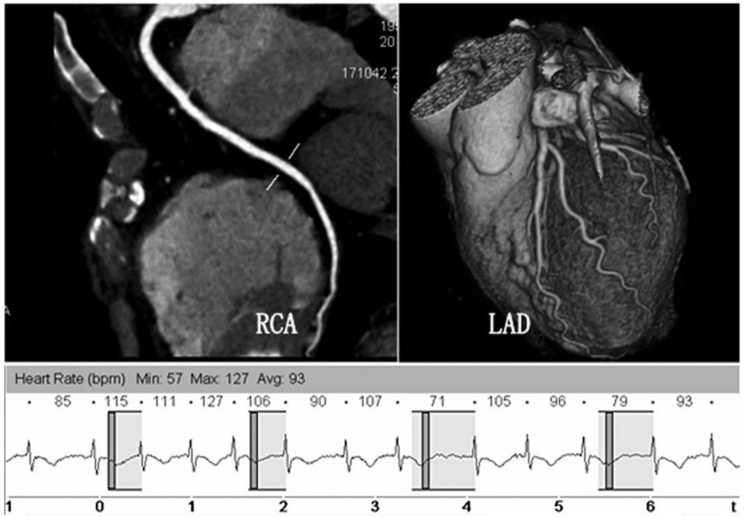
Note: Paediatric patients vary in size. Doses given to paediatric patients will vary significantly from those given to adults.

* The effective doses are typical values for an average-sized adult. The actual dose can vary substantially, depending on a person's size as well as on differences in imaging practices.

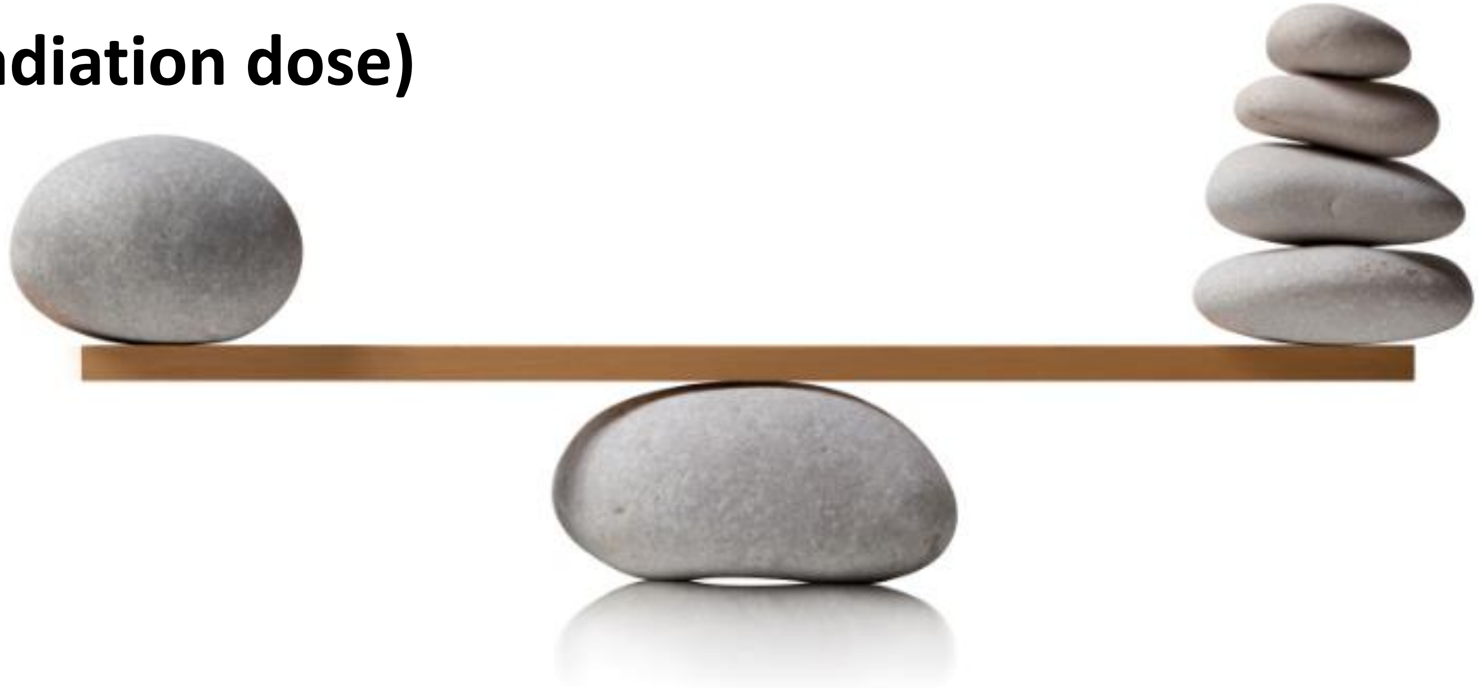
http://www.radiologyinfo.org/en/info.cfm?pg=safety-xray

Contents:

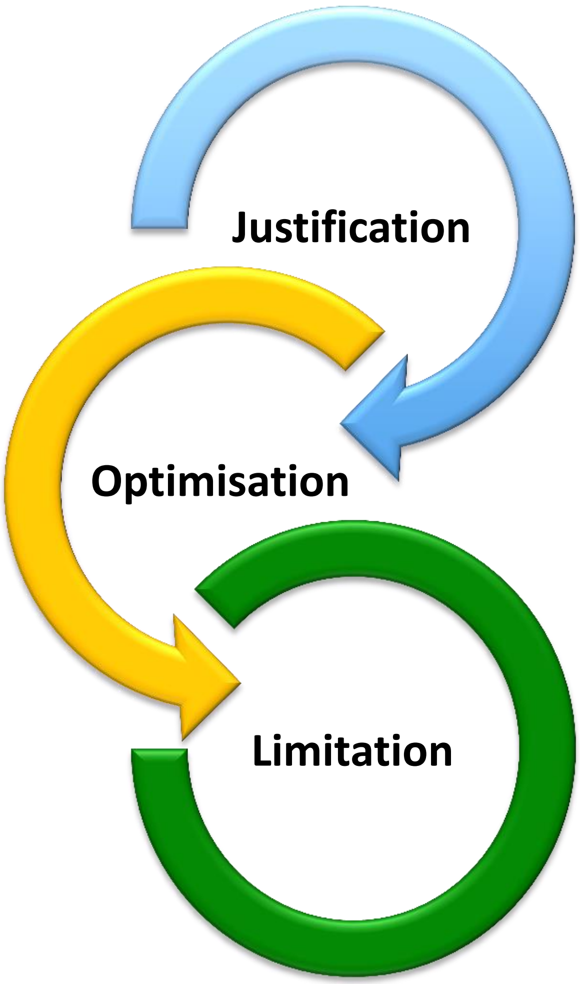
- Introduction
- Radiation dosimetry in CT
- Radiation risk associated with coronary CT angiography
- **Dose reduction strategies**
- Coronary CTA for paediatric patients



The big challenges!



Principles of radiation protection



(ICRP 1999)

JUSTIFICATION → radiation exposures should not be performed unless it demonstrates significant benefit – **benefit exceeds the risk**

OPTIMISATION → the dose should be ***As Low As Reasonably Practicable*** **(ALARP)**

LIMITATION → **dose limits** apply to those who work with radiations and members of the public

Dose reduction strategies:

3 immediate ways to reduce the radiation burden of CT:

- **Review your CT imaging protocols** → radiation dose per examination is optimized, and minimized where appropriate. Avoid delivering higher radiation dose than what is necessary for optimal image quality.

- **Ensure proper utilization of CT** → avoid inappropriate ordering of imaging procedures (variability between referring physicians). By using standards-based ordering decision support, referring clinicians can enter a patient's symptoms and qualify the effectiveness of their exam choice (e.g. Nuance's Radport is a decision support system for diagnostic image ordering).

- **There are always alternative to CT** → go for nonionizing radiation based modalities (e.g. MRI and ultrasound).

(**Cristen C. Bolan**, *2008)*

What we already have?

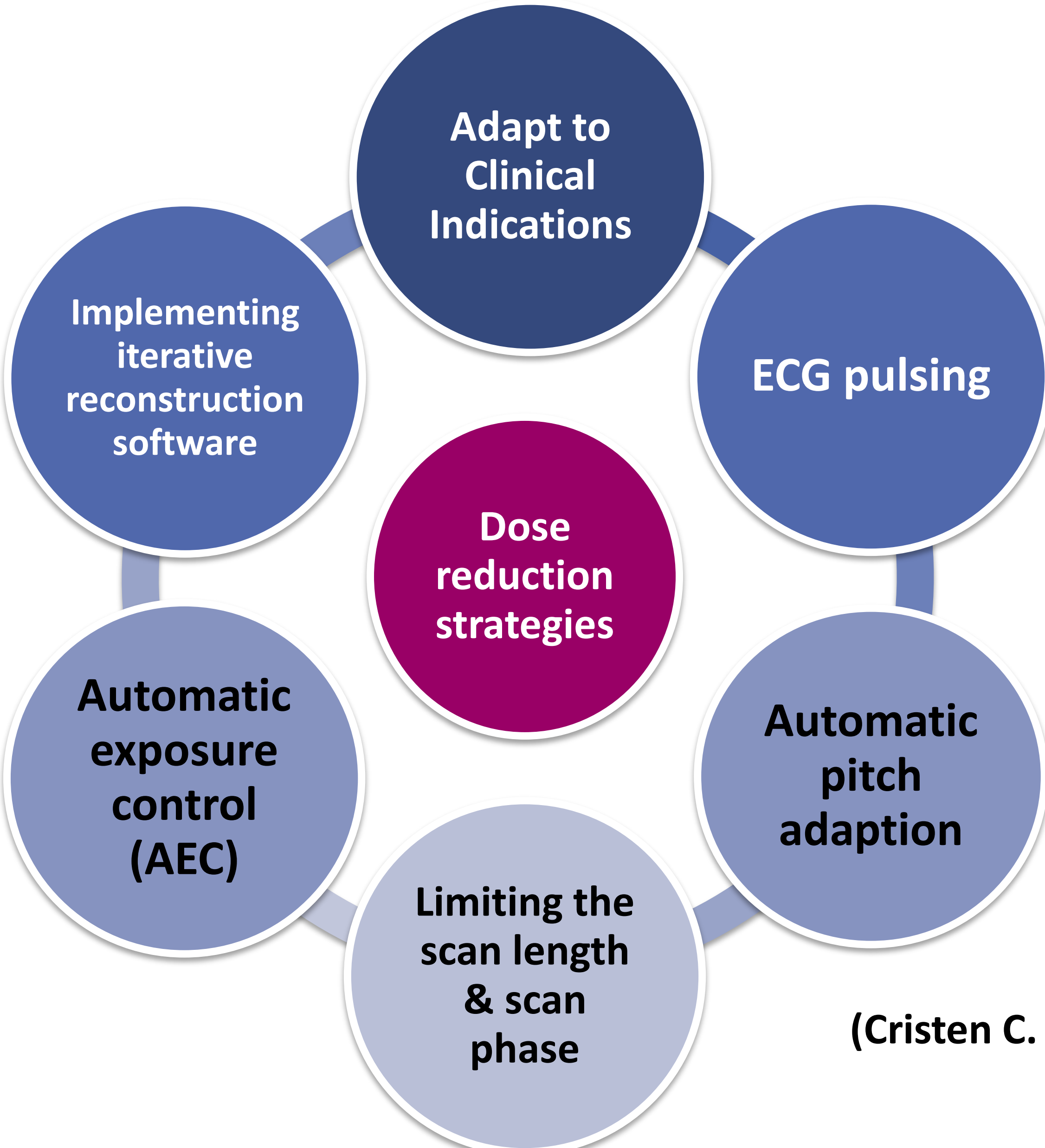
- MDCT scanner
- Dual-energy CT
- Helical /Spiral CT
- Iterative image reconstruction
- Automatic exposure control (AEC)

http://rpop.iaea.org

Are we FULLY UTILIZE the technology advancements that we have?

Are these technologies utilized appropriately so that their benefits ultimately reach our patients?

CCTA dose reduction strategies



(Cristen C. Bolan, 2008)

CCTA dose reduction strategies

Patient Preparation

- Appropriate imaging indications
- Shield non-imaged organs

Scanner Technology

- Iterative recostruction
- Dual energy
- Tube current modulation software
- Cardiac ECG-gating

Acquisition Parameters

- Appropriate coverage
- Limit no. of acquisition
- Lowest possible kVp & mAs
- High pitch, fast gantry rotation time
- Thick detector width
- Iodine dose optimization

Sun Z *et al*. Coronary CT angiography in coronary artery di:

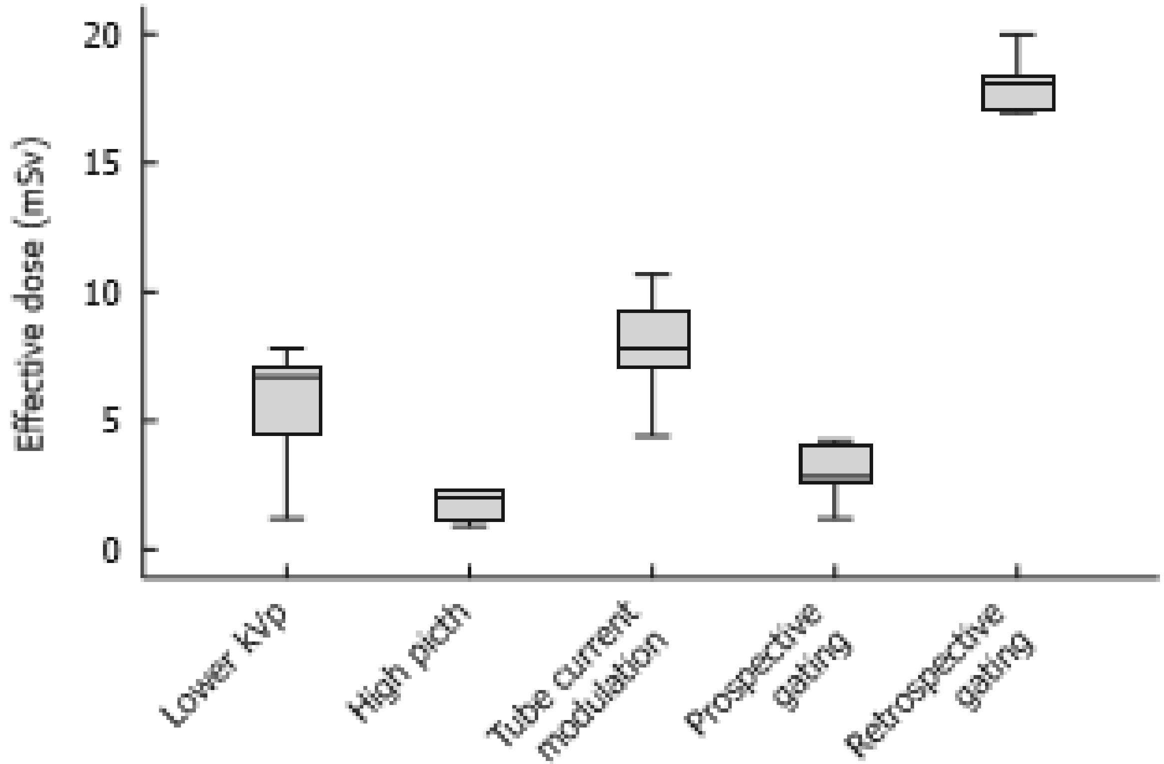


Figure 2 Box plot shows the mean effective dose associated with different dose-reduction techniques. Coronary computed tomography angiography with the use of high pitch and prospective electrocardiography-triggering leads to the lowest radiation dose. The boxes indicate the first to third quartiles, and each midline indicates the median (second quartile) and the whiskers represent the maximum and minimum values of effective dose.

CCTA dose reduction strategies

Int J Cardiovasc Imaging (2013) 29:453–461
DOI 10.1007/s10554-012-0096-3

ORIGINAL PAPER

Effect of dose reduction on image quality and diagnostic performance in coronary computed tomography angiography

Noortje van der Bijl · Raoul M. S. Joemai · Bart J. A. Mertens · Albert de Roos · Wouter J. H. Veldkamp · Jeroen J. Bax · Joanne D. Schuijf · Jacob Geleijns · Lucia J. M. Kroft

Received: 27 February 2012 / Accepted: 5 July 2012 / Published online: 22 September 2012

Abstract To evaluate the effect of radiation dose reduction on image quality and diagnostic accuracy of coronary computed tomography (CT) angiography. Coronary CT angiography studies of 40 patients with ($n = 20$) and without ($n = 20$) significant ($\geq$50 %) stenosis were included (26 male, 14 female, 57 $\pm$ 11 years). In addition 12.5 % of the original dose. Image quality and diagnostic performance in identifying significant stenosis were determined. Receiver–operator-characteristics analysis was used to assess diagnostic accuracy at different dose levels. The identification of patients with significant stenosis decreased consistently at doses of 50, 25 and 12.5 of the

1) ECG-Based Tube Current Modulation

- **Electrocardiogram (ECG) pulsing (or ECG controlled tube current modulation)** → for minimizing dose. If you are looking for coronary arteries and the heart is constantly moving, what we do is segment the heart in order to obtain a measure of the coronary arteries when they are least moving. We only want to acquire coronary arteries when the heart is relatively resting, which is the diastolic phase.

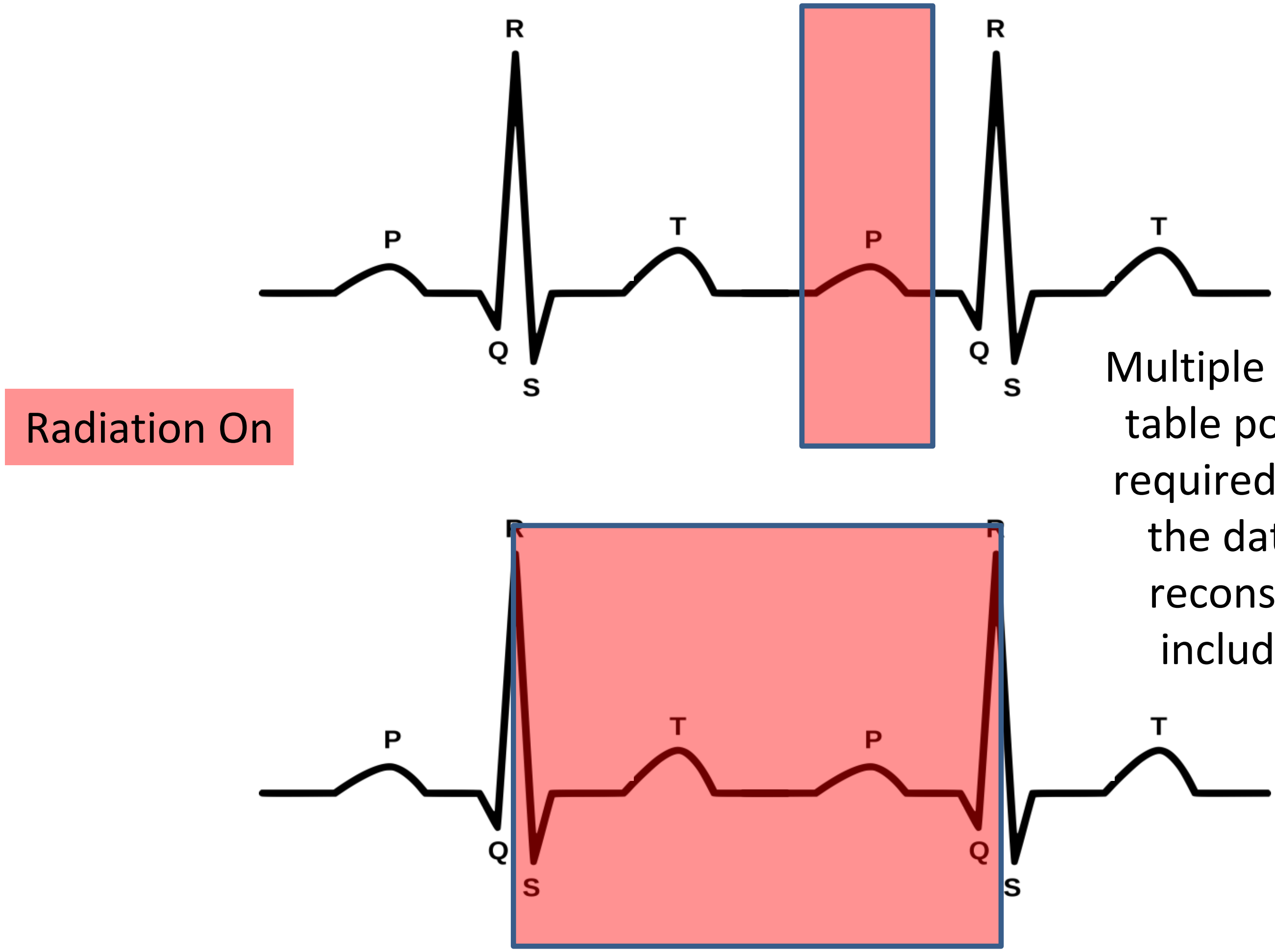
- The tube current is adjusted based on the ECG signal that we obtain. The tube current is increased when at resting phase or diastolic phase and then is reduced during the systolic phase, or when the heart is moving very rapidly.

- If the systolic phase is longer than the diastolic phase (occurs when patient's heart rate is too high) → results in little dose reduction.

ECG-Based Tube Current Modulation

- AEC feature used with prospectively gated cardiac imaging that adjusts the tube current based on the phase within the cardiac cycle
- It is important for heart rate considerations when using prospective gating.

ECG-Based Tube Current Modulation (TCM)



Multiple heart beats and table positions may be required to collect all of the data required to reconstruct the FOV including the heart

The use of ECG-Based Tube Current Modulation with prospective gating will decrease $CTDI_{vol}$ compared to retrospective gating

Traditional way → retrospective ECG-gating with tube modulation

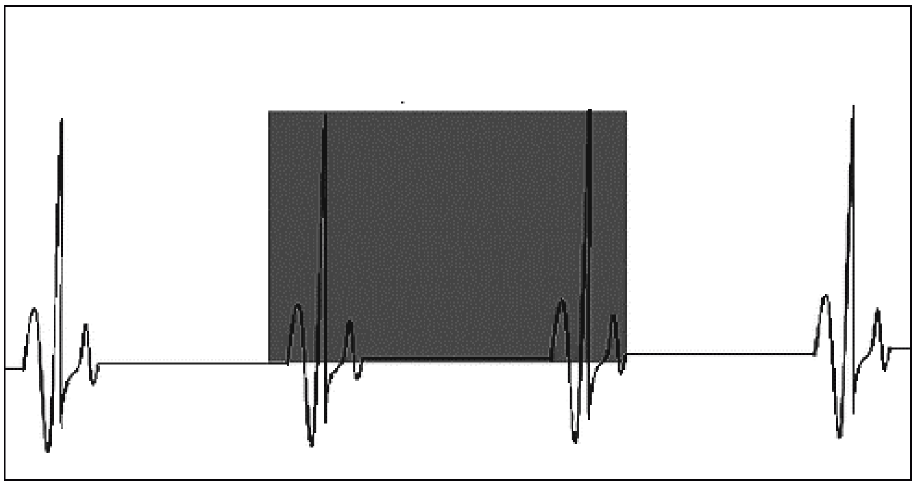


Fig. 1 Normal retrospective electrocardiogram-gating without tube current modulation. The X-ray beam is turned on during the entire cardiac cycle without adjusting the tube current.

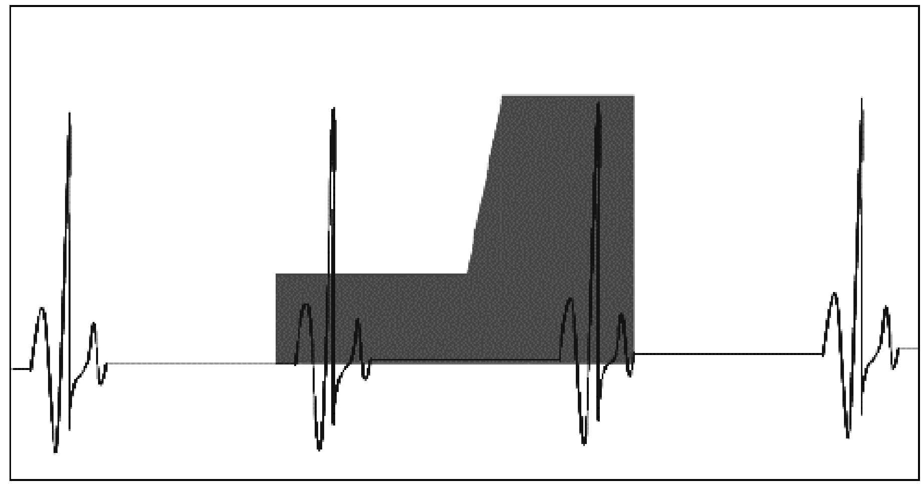


Fig. 2 Retrospective electrocardiogram-gating with tube current modulation. The normal tube current is applied only during the image reconstruction phase (late diastolic phase), while the tube current is reduced during the systolic phase.

Prospective ECG-Based TCM

- More dose reduction through prospective ECG triggering → up to 80% of dose reduction.
- What's the difference between prospective ECG triggering and the ECG tube current modulation?
- In prospective ECG triggering instead of dropping the tube current during the phase when the heart is rapidly moving, we turn off the tube current to obtain much higher dose reduction.
- This technique is commonly employed for coronary CaScore and also coronary CTA, if the patient's heart rate is stable and slow.
- To avoid the tube to be off when the heart is relaxing.

Prospective ECG-Based TCM

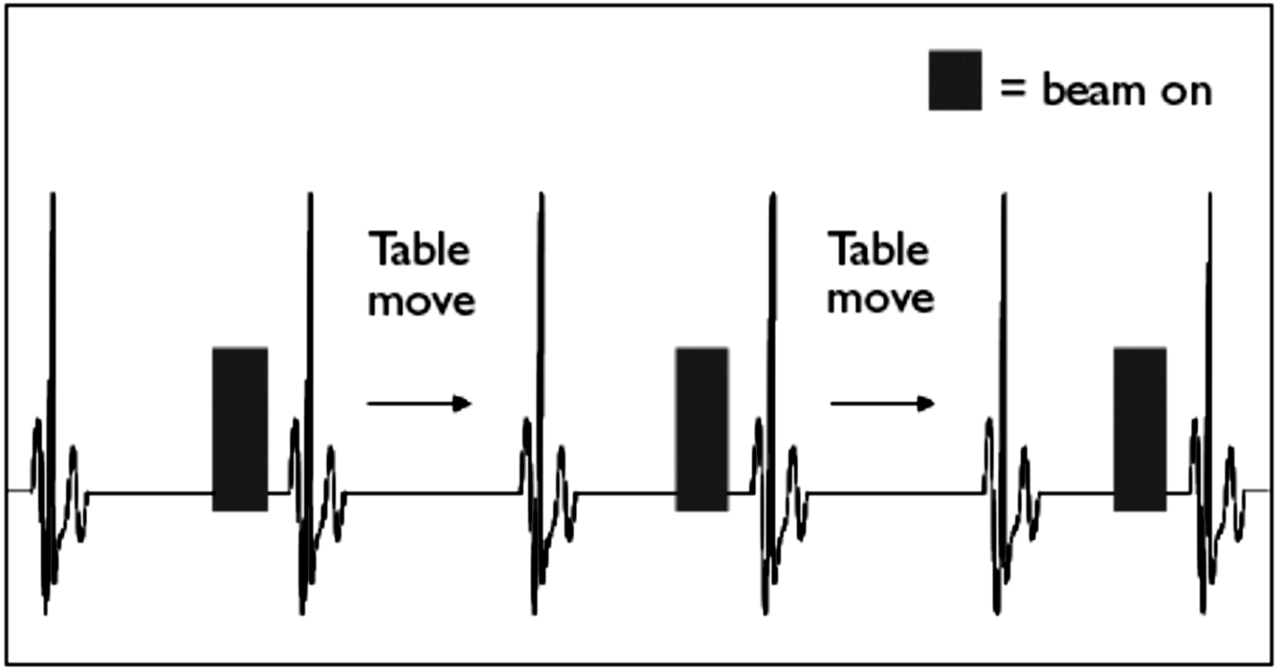


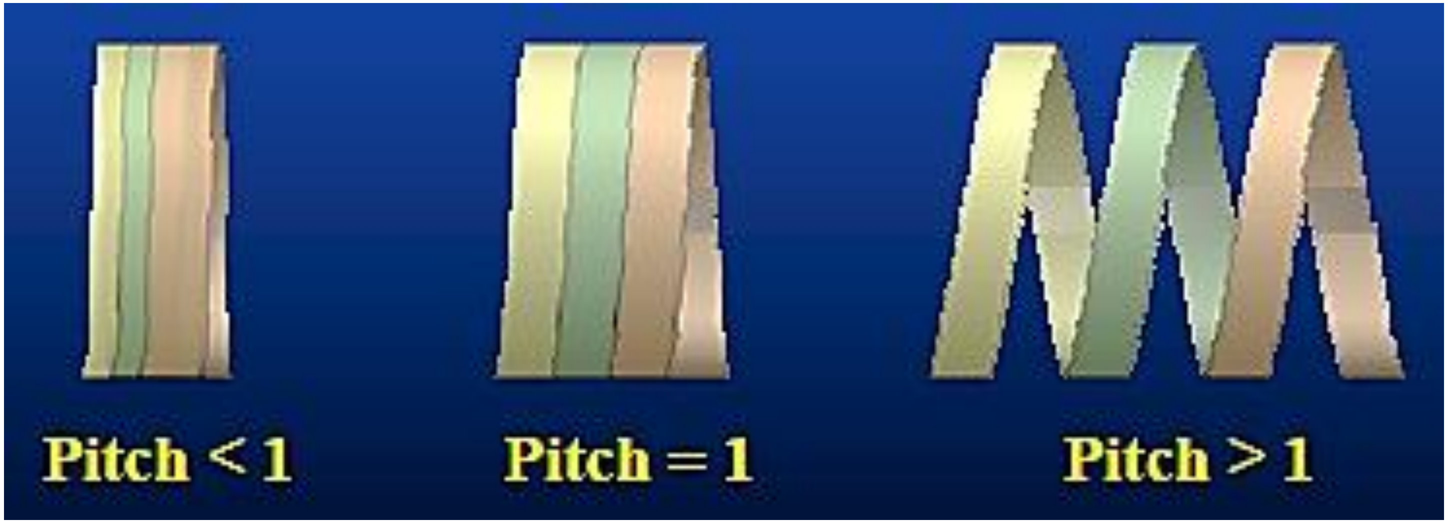
Fig. 3 Prospective electrocardiogram-triggering with X-ray beam turned on during a portion of the cardiac cycle, while in the remaining cardiac phase, the X-ray beam is turned off.

2) Automatic Pitch Adaptation

- Most scanners have this technique. When the heart is moving fast (higher heart rate), the scanner will go faster (higher pitch), less overlapping, and higher pitch during scanning → dose is reduced.

- For dual source MDCT - the extent to change the pitch is much greater. For SSCT (64-slice scanner), pitch change ranged from 0.2–0.35 but for DSCT pith change ranged from 0.2 to 0.55.

- With dual source you don't need the beta blockers because the scanner is faster, and the dose can be reduced using the pitch adaptation.



Pitch < 1 implies overlapping

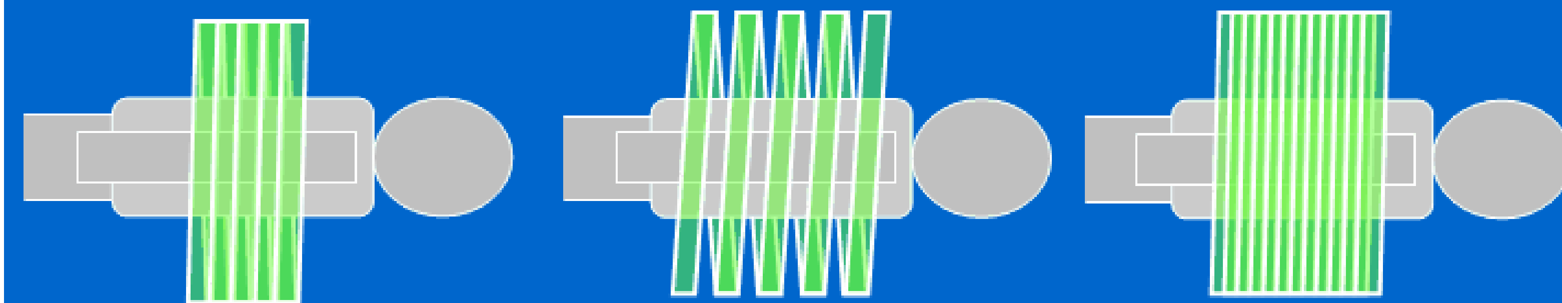
Pitch = 1 same as contiguous axial scanning

Pitch > 1 implies extended imaging (preferable for dose reduction)

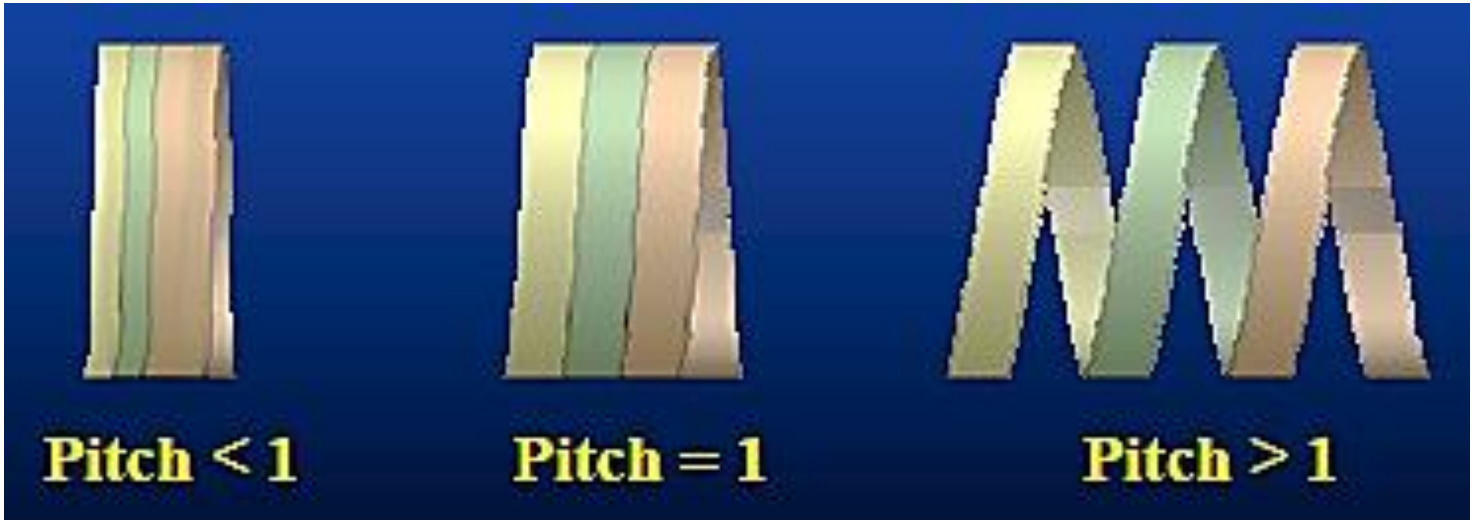
How pitch affect the average dose ?

- Volume CTDI takes account of non-contiguous exposure along z-axis

- $CTDI_{vol} = \frac{CTDI_w}{Pitch}$



Pitch = 1	Pitch = 2	Pitch = 0.5
$CTDI_{vol} = CTDI_w$	$CTDI_{vol} = CTDI_w/2$	$CTDI_{vol} = 2 \times CTDI_w$



The drawbacks:

Higher pitch gives lower dose, but poor image quality (less resolution)!

3) Automatic Exposure Control (AEC)

- This AEC technique, if used appropriately, will allow the radiologist/ cardiologist to reduce does in children by 30-50%. The clinician selects an appropriate level of image quality. The system then calculates the size of the patient (child/adult) and automatically uses the lowest possible dose to obtain the optimal image quality.

- AEC controls the **tube current to adapt to the patient's size** based on what image quality the clinician has specified→ patient dose can be optimized.

- With AEC, the radiologists need to decide based on the clinical indications and level of comfort to assess low radiation dose images. Inappropriate selection of superior image quality can actually increase the dose with AEC technique.

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Redesigning CT acquisition protocols

Decreased kVp	•Low kVp can reduce the radiation dose reduction, improve soft tissue contrast. However, mAs likely have to be increased to compensate the image quality.
Auto mAs	•mA can be adjusted automatically (automatic dose modulation by AEC) based on the patient's size and shape (auto-mA). Decrease mA will reduce patient dose (but must maintain the diagnostic image quality).
Pitch > 1	•Dose inversely proportional to dose. Pitch < 1, beam overlapping, dose increased. Faster pitch (pitch > 1), will reduce radiation dose. But, reducing image quality.

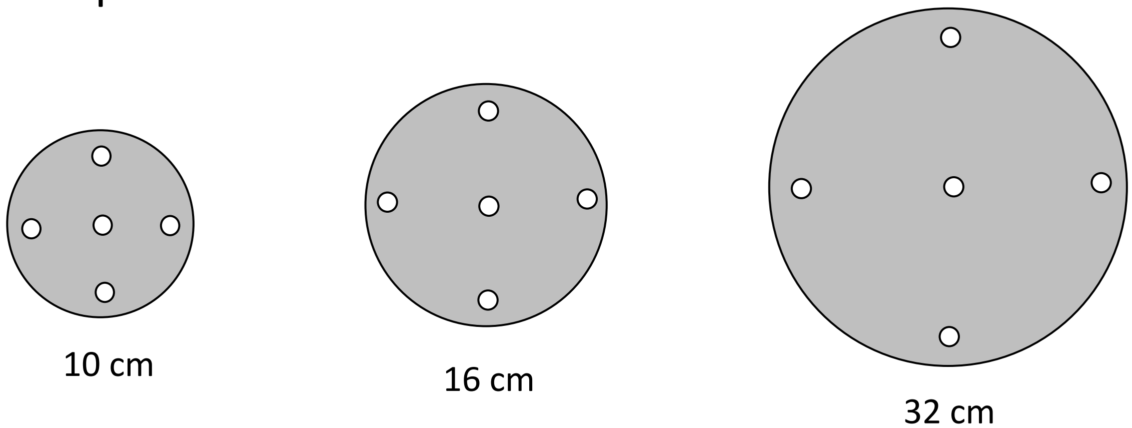
Nelson TR, 2014
http://info.atlantisworldwide.com

Lower tube potential (kVp)

- The use of 100 kV instead of 120 kV (conventionally used) can reduces the dose by 30 - 35%. Reducing the dose, will increase the image contrast and therefore you need higher volumes of contrasts.
- **But it depends on the patient's size!** 100 kV may produce optimal quality for average size but may produce inappropriate image quality for larger patient or else higher dose to smaller patients.
- So, the regional size of the body or large region of interest is very important and avoid doing lower kV with large size patients or patients with a large region of interest.
- Adapt the scanning protocol to the clinical indication and the size of the patient.
- Vendors don't know about the specific clinical indications, and the radiation awareness is a major concern for radiologists and team.

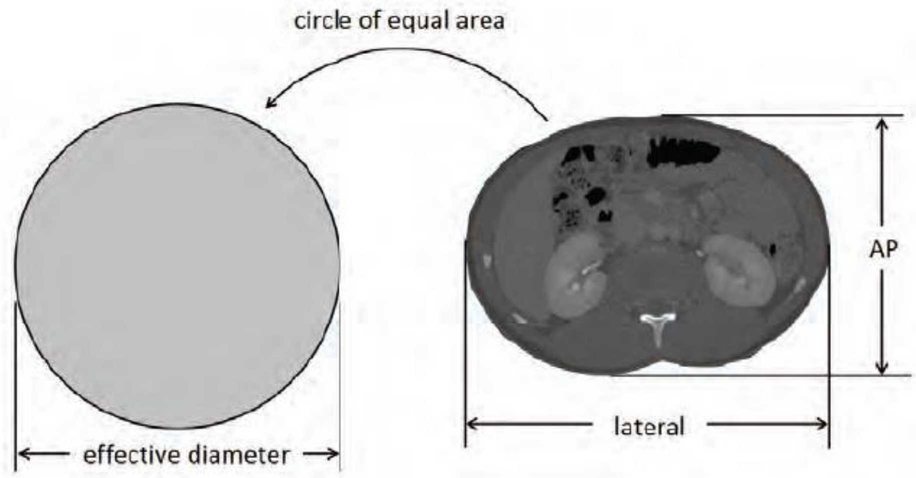
Adjusting CT dose based on size

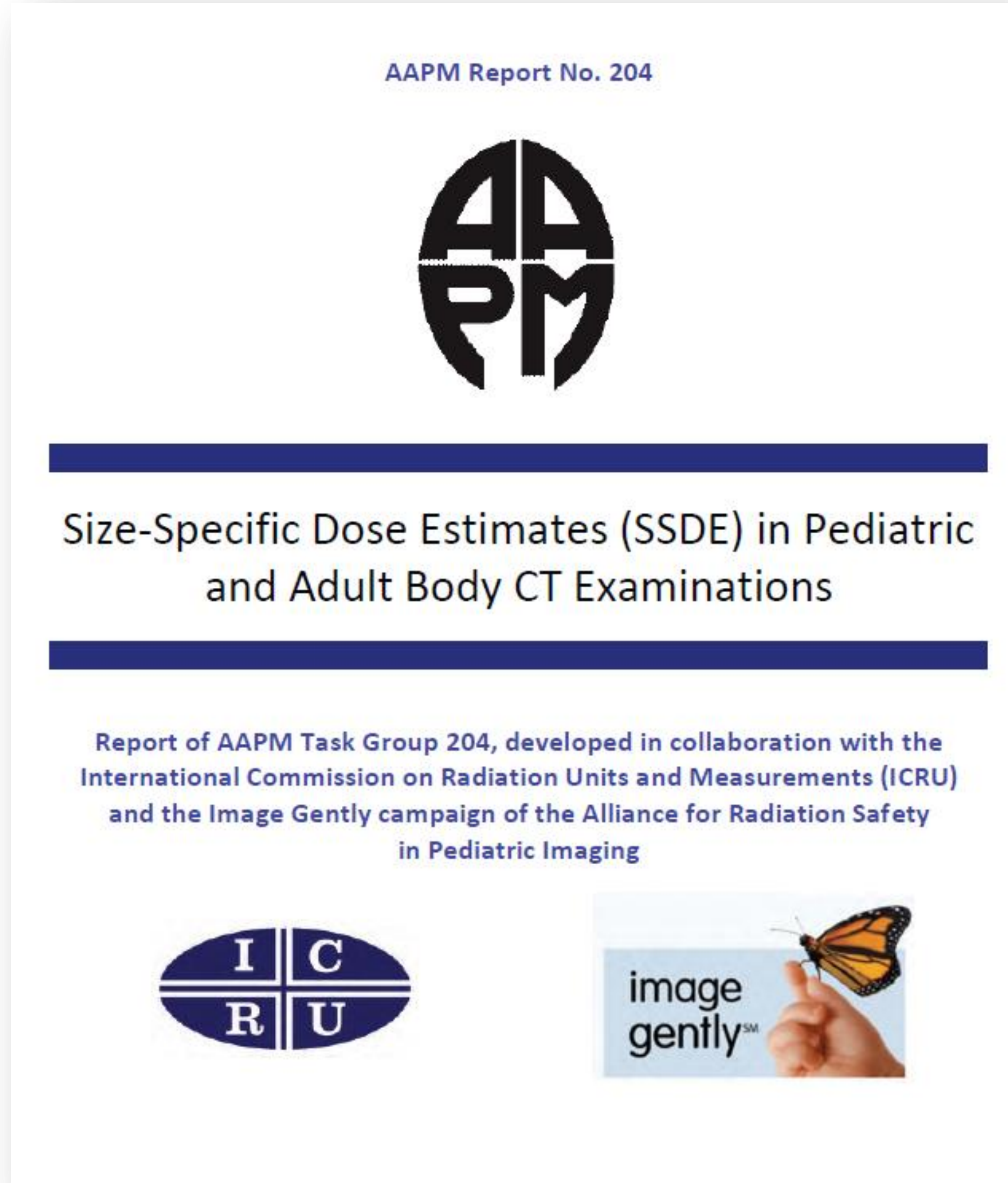
- Adjust exposure based on individual size and shape.
- Standard kVp for adult is 120, but adults vary in size.
- By using a patient's BMI to determine patient size → kVp can be accurately adjusted and optimized for dose reduction.



Measured $CTDI_{vol}$ **= 47 mGy**	**Measured** $CTDI_{vol}$ **= 37 mGy**	**Measured** $CTDI_{vol}$ **= 18 mGy**
Displayed $CTDI_{vol16}$ **= 37 mGy** $CTDI_{vol10}$ **= 47 mGy**	**Displayed** $CTDI_{vol16}$ **= 37 mGy** $CTDI_{vol32}$ **= 18 mGy**	**Displayed** $CTDI_{vol32}$ **= 18 mGy**

Adapted from: Nelson TR, 2014





AAPM Report No. 204

Size-Specific Dose Estimates (SSDE) in Pediatric and Adult Body CT Examinations

Report of AAPM Task Group 204, developed in collaboration with the International Commission on Radiation Units and Measurements (ICRU) and the Image Gently campaign of the Alliance for Radiation Safety in Pediatric Imaging

4) Limiting: Scan length & Scan phase

- **Decreased length of scan coverage:** The scan length is directly proportional to CT dose. Limits the length (z-axis) so that only the anatomy of clinical interest is included in the scan.

- **Limitations on double scans & multi-phase studies:** Whenever possible, eliminates non-contrast scans → provide little additional diagnostic information and increase patient dose. Limits no. of phases (pre- & post-contrast monitoring) in multi-phase examinations.

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Limiting the scan phase!

Total mAs 4334 Total DLP 721 mGycm

	Scan	kV	mAs / ref.	CTDIvol* mGy	DLP mGycm	TI s	cSL mm
Patient Position H-SP							
Topogram	1	120	35 mA	0.13 L	4	3.2	0.6
CaSc	2	120	19 / 40	4.44 L	67	0.33	0.6
Contrast							
TestBolus	3	120	20	13.11 L	13	0.33	10.0
Last scan no.	16						
Contrast							
TestBolus	17	120	20	6.56 L	7	0.33	10.0
Last scan no.	23						
Contrast							
CorCTA	24	120	127 / 160	26.63 L	630	0.33	0.6

Medium	Type	Iodine Conc. mg/ml	Volume ml	Flow ml/s	CM Ratio
Contrast	OMNIPAQUE	350	10	4.9	100%
Saline			20	4.9	

1 of 2

*: L = 32cm, S = 16cm

kami memimpin

How many times you scan the same body part?

By reducing the number of passes that you take of the same part of the body, you will reduce the dose. Reducing the number of phases in CT can help you reduce the dose.

How you position your patients?

It is also important to center the patient right in the center of the gantry. If you don't center the patient right in the center of the gantry, you can increase the dose by 11-15%. This is a very common error.

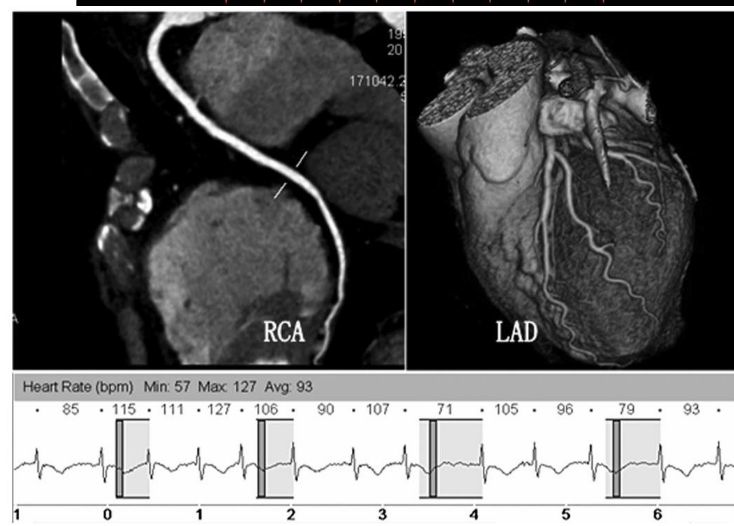
Iterative reconstruction (IR) method

- **Iterative Reconstruction Software / SafeCT:** IR is the newest & effective method for CT image reconstruction.
- **Advantages** →reducing image noise, reduce patient dose by 40% to 50%.
- Faster technique, improves image quality & SNR.

Nelson TR, 2014
http://info.atlantisworldwide.com

Contents:

- Introduction
- Radiation dosimetry in CT
- Radiation risk associated with coronary CT angiography
- Dose reduction strategies
- **Coronary CTA for paediatric patients**



The Critical Group!

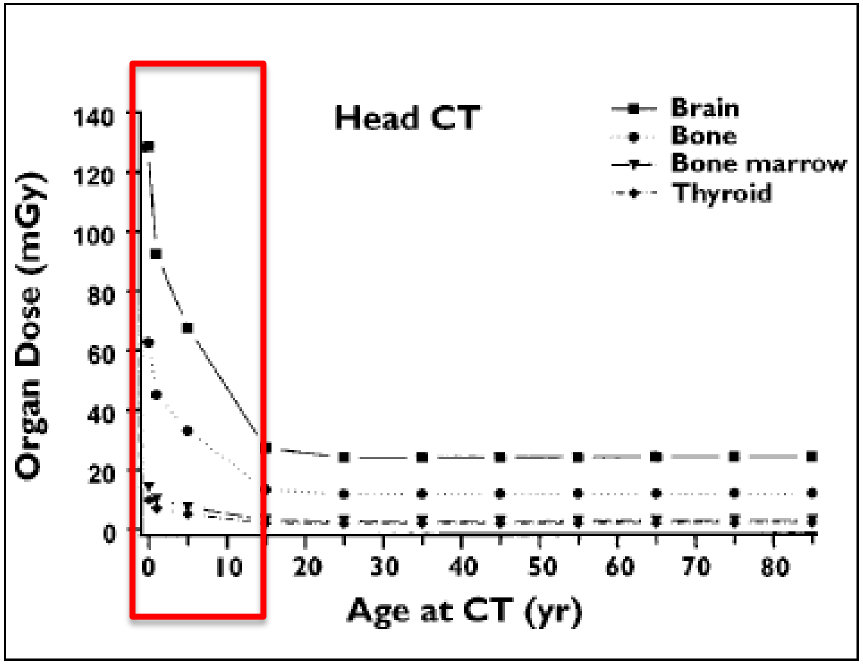
Paediatric patients → inherently more radiosensitive and because they have more remaining years of life during which a radiation-induced cancer could develop.

The Critical Group!

- There is a latent period following radiation exposure and the time it takes for the radiation effects to develop.
- The latent period for development of cancer following low level radiation dose is variable and can be as long as 10-30 years.
- If a person getting a CT scan at age 60, he is unlikely to develop cancer in his remaining lifetime, but children have much longer to live.
- Children’s cells are more susceptible to radiation and they are also likely to live longer than adults.

Estimated age-dependent CT doses to various organs

Estimated age-dependent doses to various organs for typical single CT scan of head (assuming the same exposure techniques for all ages)

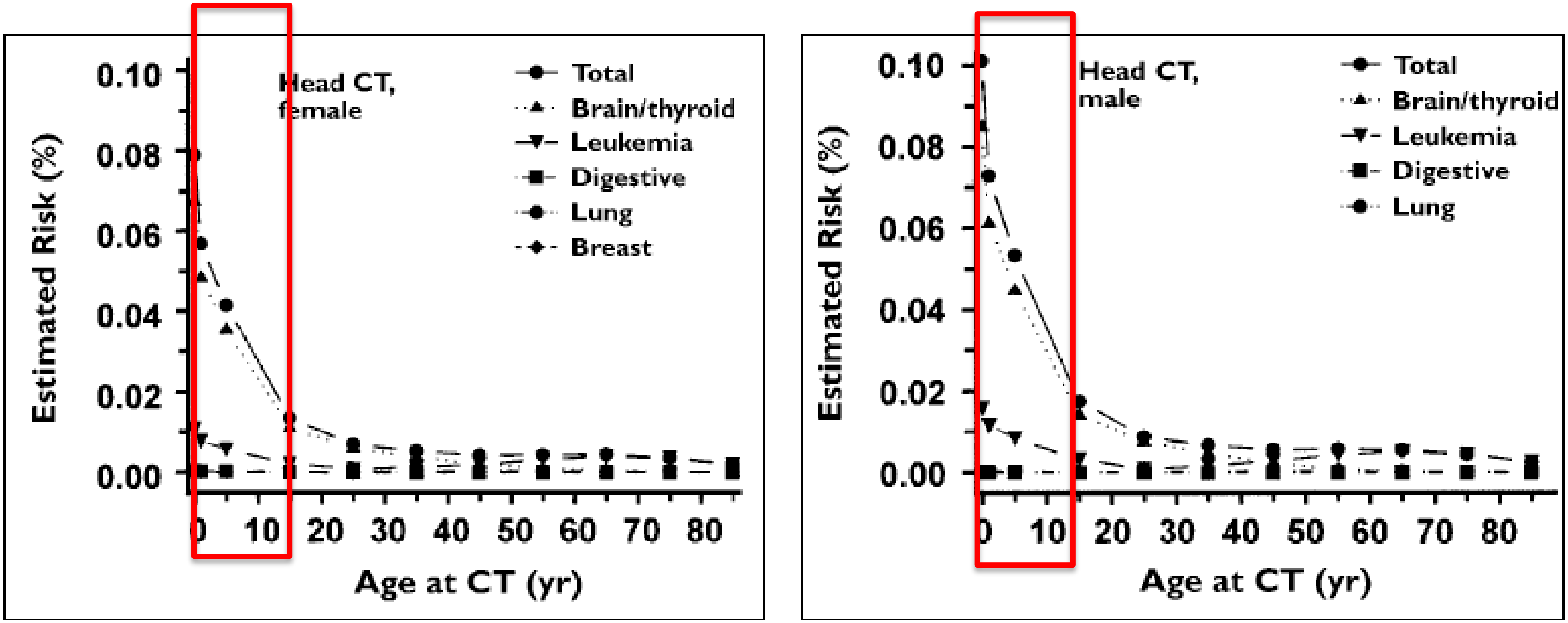


Risk depends strongly on the age at the time of irradiation → the younger the child, the higher the potential risk

(Brenner DJ et.al., 2007)

Estimated risk of death by cancer attributable to a CT scan at different ages

Estimated lifetime CT-attributable cancer mortality risks as a function of age (for different gender)



(Brenner DJ et.al., 2007)

CCTA for Paediatric patient

*Different **imaging needs** for paediatric patients!*

*Child's cells dividing in different ways & **more sensitive** & susceptible to radiation risks!*

(Nelson TR, 2014)

Dose reduction for paediatric patient

One size does not fit all…when imaging paediatric patients, radiation dose matters!

One size does not fit all.

image gently®

Dose reduction strategies for paediatric patient

- Children are more sensitive to radiation. So when we image, **let's image gently.**

- **The right things to do:**
  - **Scan only the indicated area.**
  - **Selection of the kVp and mA → child size.**
  - **One scan (single phase) is often enough.**

Dose reduction strategies for paediatric patient

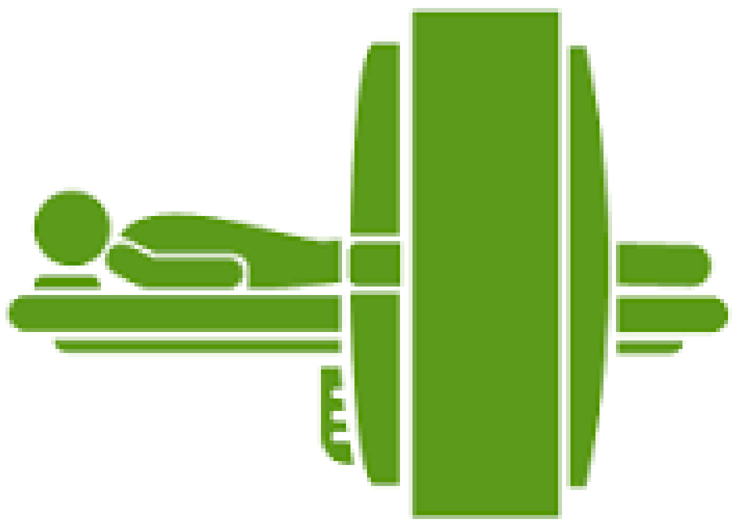
A well-known strategy for reducing radiation exposure for paediatric is to **decrease CT dose based on the patient's weight** (Johnson et.al., 2012).

Appropriate radiation levels for their age and size!

Establishment of Local Diagnostic Reference Levels (DRLs)

Regularly analyse local CT dose values!

Monthly/Annual dose audit.



National DRLs

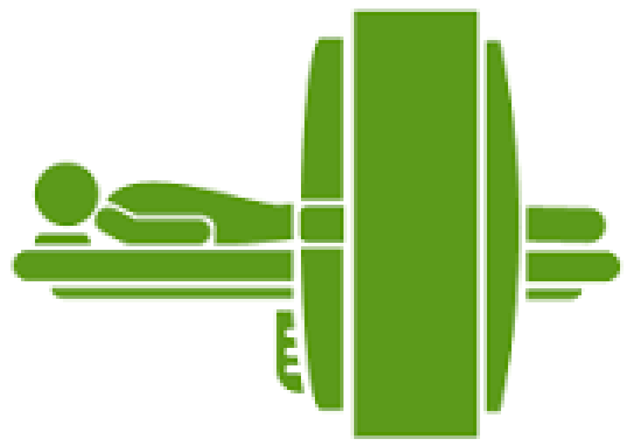
Examination Type	$CTDI_w$ (mGy)	DLP (mGy·cm)
Abdomen	12.8	450
Brain	46.8	1050
Cardiac	11.8	870
Chest	19.9	600
Pelvis	39.1	730
Spine/Musculo-skeletal	16.3	390
Thorax	21.3	420
Others	12.3	380

Recommended Malaysian DRLs for CT examination (MOH, 2013)

Establishment of Local Diagnostic Reference Levels (DRLs)

- **DRLs** are proposed to help manage radiation dose to patients so that the dose is commensurate with the clinical purpose (*ICRP Committee 3*).

- As recommended by MOH, the respective medical institutions are advised to obtain **individual local data** in their setup in order to compare with the national DRLs (*MOH, 2013*).



A single institution study of radiation dose received from CT imaging: A comparison to Malaysian NDRL

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Abstract. Advancement of CT technology has led to an increase in CT scanning as it improves the diagnosis. However, it is important to assess health risk of patients associated with ionising radiation received from CT. This study evaluated current dose distributions at Advanced Medical and Dental Institute (AMDI), Malaysia and was used to establish Local Diagnostic Reference Level (LDRL). Dose indicators such as CT Dose Index ($CTDI_{vol}$ and $CTDI_w$) and Dose-Length Product (DLP) were gathered for all routine CT examinations performed at the Imaging Unit, AMDI from January 2015 to June 2016. The first and third quartile values for each dose indicator were determined. A total of 364 CT studies were performed during that period with the highest number of cases being Thorax-Abdomen-Pelvis (TAP) study (57% of total study). The $CTDI_w$ ranged between 2.0 mGy to 23.4 mGy per procedure. DLP values were ranged between 94 mGy.cm to 1687 mGy.cm. The local dose data was compared with the national DRL to monitor the current CT practice at AMDI and LDRL will be established from the calculated third quartile values of dose distribution. From the results, some of the local dose values exceeded the Malaysian and further evaluation is important to ensure the dose optimisation for patients.

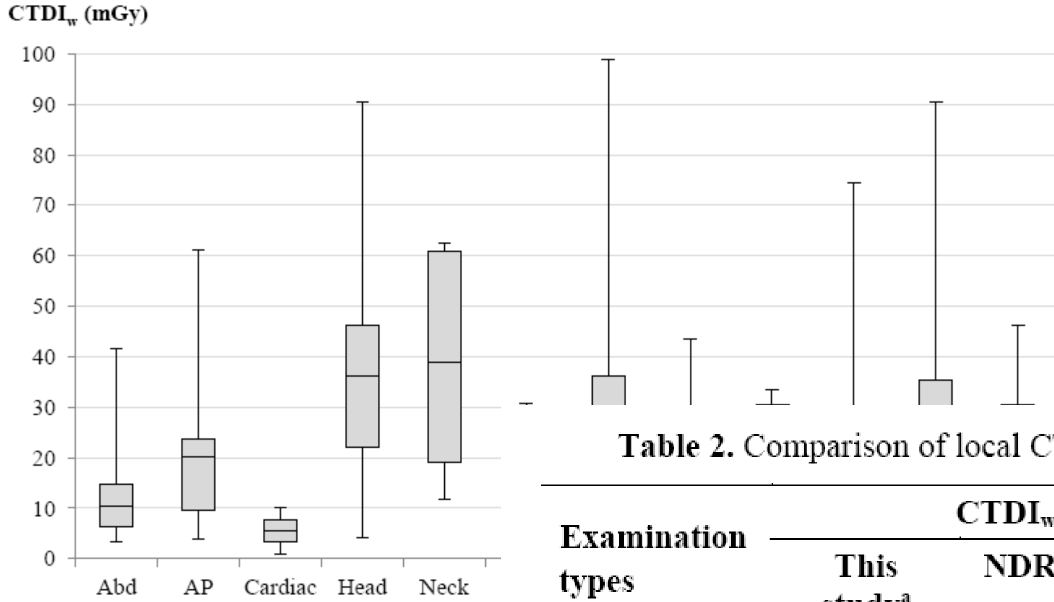


Figure 1. CTDI$_w$ (mGy) d

Table 2. Comparison of local CT dose data in AMDI with the reference values of NDRL.

Examination types	CTDI$_w$ (mGy)			DLP (mGy.cm)		
	This study[a]	NDRL[b]	% difference	This study[a]	NDRL[b]	% difference
Abdomen	12.6	12.8	1.56	466	450	3.56
Brain / Head	49.5	46.8	5.77	995	1050	5.23
Cardiac	21.0	11.8	77.9	295	870	66.1
Pelvis	29.4	39.1	24.8	632	730	13.4
Spine	21.0	16.3	28.8	578	390	48.2
Thorax	33.8	21.3	58.7	642	420	52.9

[a] Local dose data in this study were set at the level of third quartile value for CTDI$_w$ and DLP.

[b] NDRL values are based on reference standard established by MOH Malaysia [3].

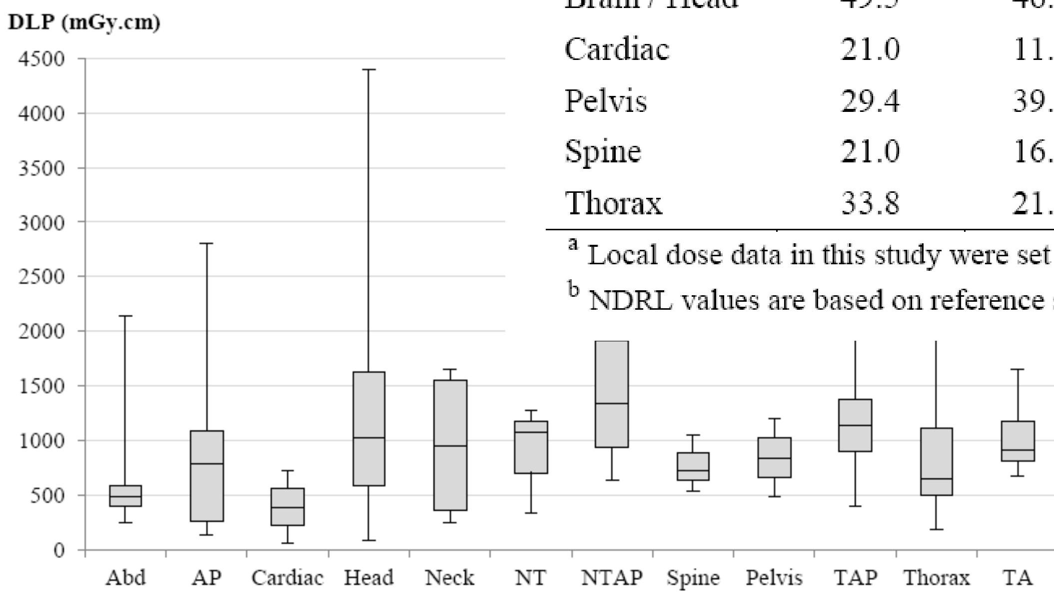
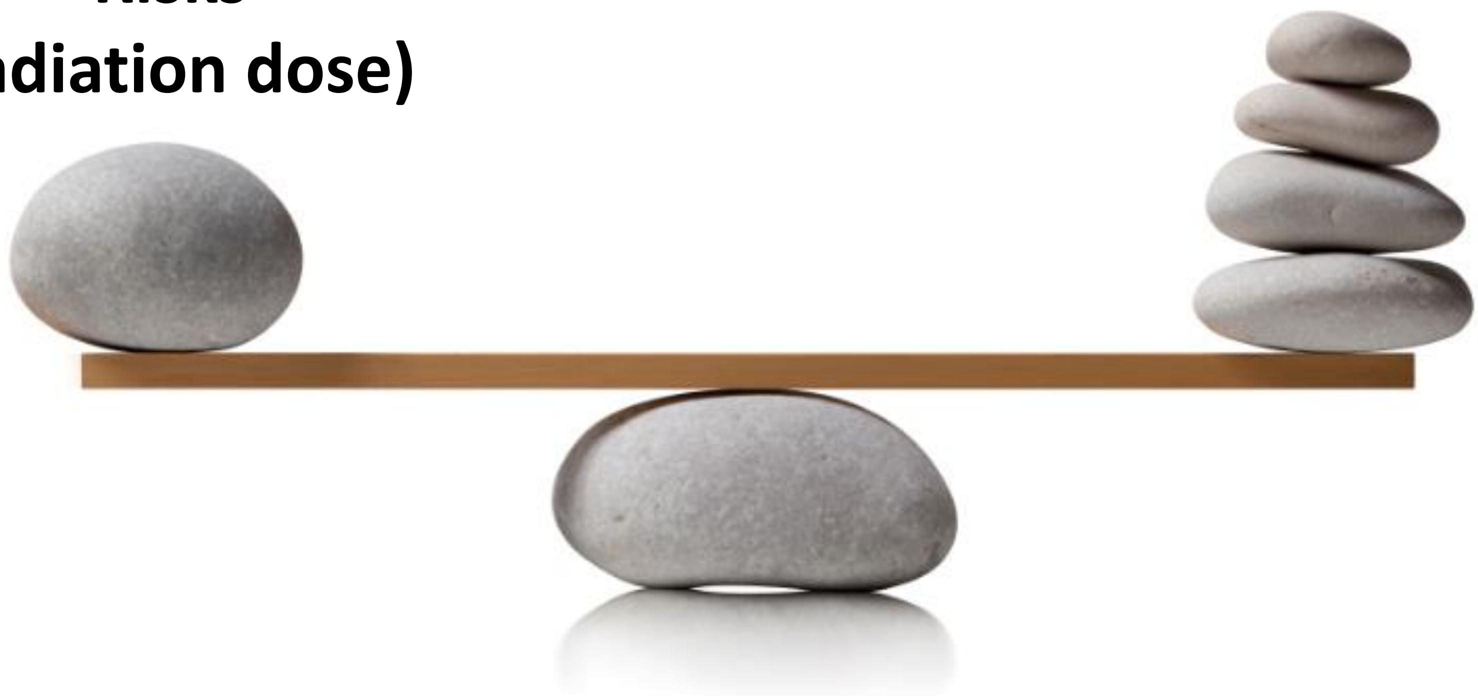


Figure 2. Dose-length product (DLP) distribution for each CT procedure.

Take home notes!

Benefits
(image quality)

Risks
(radiation dose)



Thank you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