CT pediatry: influence of new technologies on patient dose

N Buls
Department of Radiology
VUB – B.E.F.Y.

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

BVS, Brussel, 20 juni 2008

Content

Technical evolution in CT

- Influence on clinical outcome pediatrics

CT dosimetry

- Standards for pediatric CT
- Pediatric dose surveys

Dose optimisation strategies

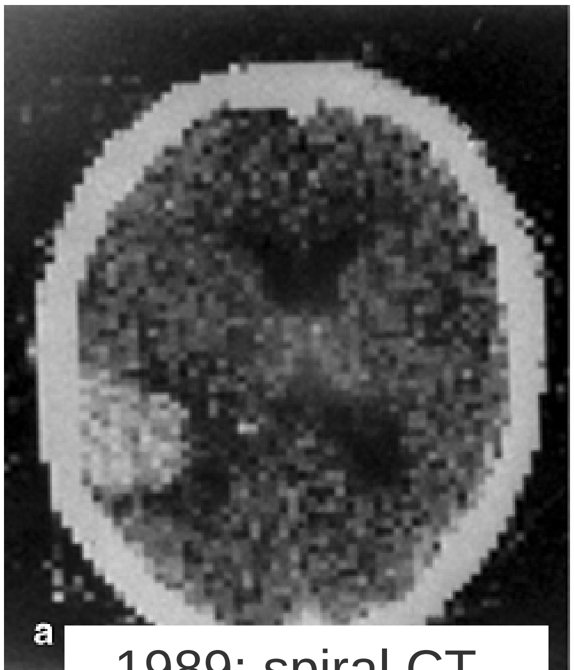
Advanced applications MSCT and RP tools

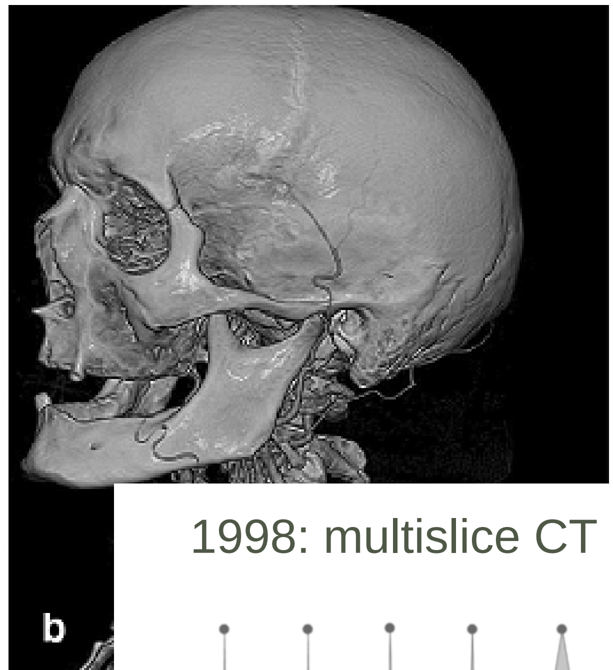
Technical evolution

Technical evolution
From slice imaging to isotropic voxels

1 slice – 5 min

complete volume scan – few sec

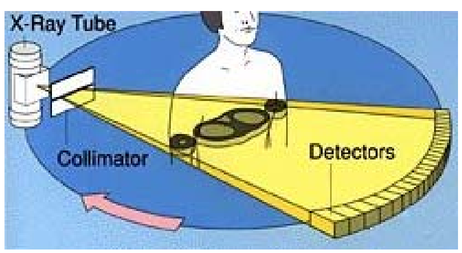




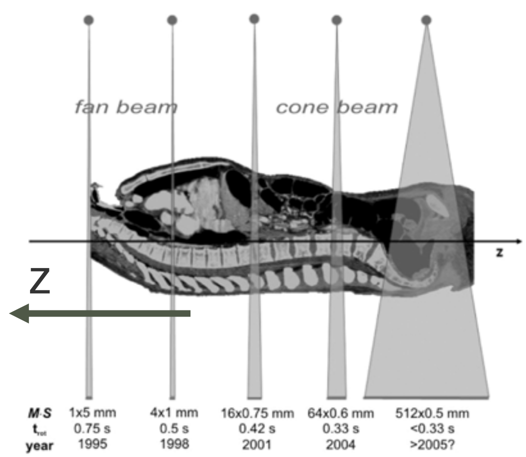
Kalender W,

Eur Radiol (2005)

1989: spiral CT



1998: multislice CT (MSCT)



RSNA 2007:

Toshiba: 320 rows
Philips: 128 rows
Siemens: 64 x 2 rows

Universitair Ziekenhuis Brus

Vrije Universiteit Brussel

MSCT improves clinical outcome

MSCT has potential of imaging faster, imaging larger volumes, imaging same volume at better geometrical resolution

1. Faster

allows examinations where motion artefacts previously contraindicated its use

young children, severe pain, reduced i.v. contrast, general anaesthesia with intubation (CT $\leftrightarrow$ MR)

MSCT reduces sedation rate in pediatric CT

Pappas et al, *Radiology* 2000

MSCT improves clinical outcome

2. Larger volumes
allows to survey large volume in short time

e.g. malignant lymphoma staging neck and entire trunk in children

Donnely et al, *AJR* (2000)

3. Image quality
improved isotropic resolution allows organ evaluation in different planes

children have smaller organs and less fat, multi-phase imaging, 3D post-processing

Impact of MSCT on clinical management

"MSCT improves all areas of pediatric CT imaging"

Yekeler E. *EJR*, 2004

"The benefit of MSCT in pediatric patients is very high"

EU MSCT guidelines, 2004

Due to this clear clinical benefit we can expect:

increasing number of CT exminations / exposure

increasing dose per examination ….
- larger volumes / more phases
- increased resolution
- advanced applications

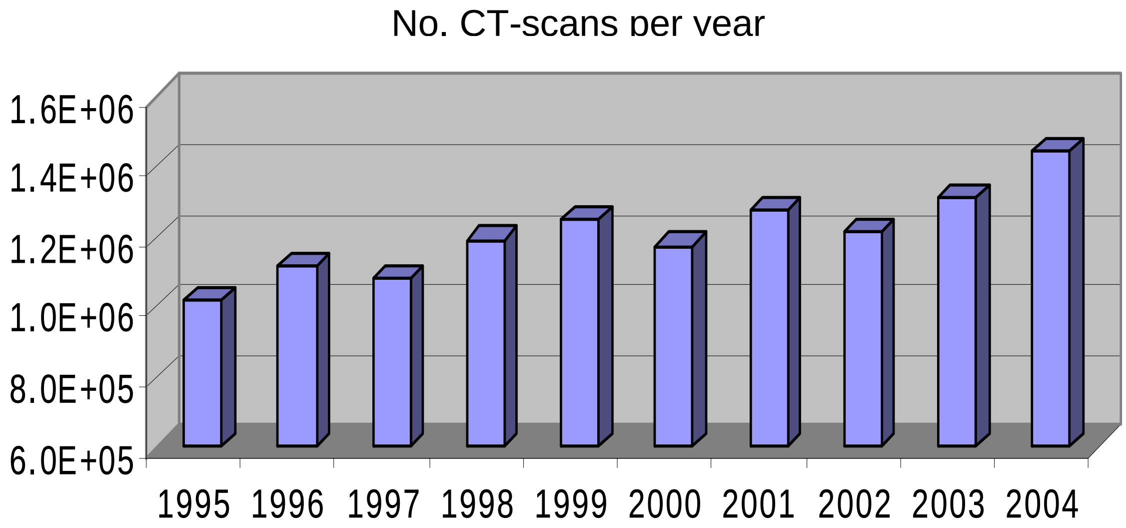
Impact of MSCT on clinical management

U.S.

Today, 62 million scans per year, compared to 3 million in 1980s

Brenner D. et al (2007), *NEJM* 357

.be



Universitair Ziekenhuis Br....

Vrije Universiteit Brussel

Impact of MSCT on clinical management

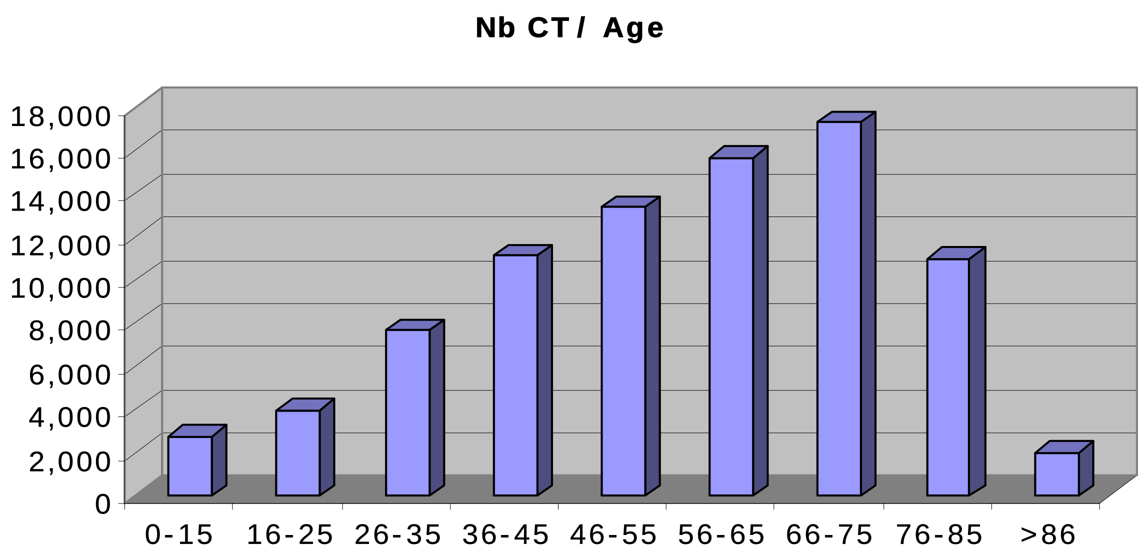
U.S.

CT-scans in **children** have increased from 4% to 11% of all CT examinations

- 1/3 before age 10
- 1/6 before age 5

Brenner D. et al (2001), *AJR* 176:289-296.

.be



Data from 2003.

70% > 45 yr

~3% < 15 yr

CT dosimetry

Universitair Ziekenhuis Brussel

Vrije Universiteit Brussel

CT dose indices

Dose from one tube rotation

- weighted CT dose index (CTDI$_w$)

- volume weighted CT dose index (CTDI$_v$

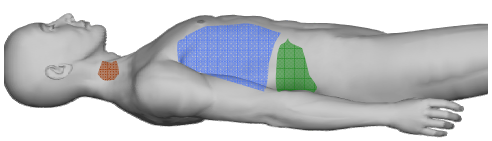
Dose from one scan sequence

- dose-length product (DLP)

Basis for DRL's
and
scan parameter
optimisation

In addition

- organ dose / effective dose (E)



Universitair Ziekenhuis Brussel

Vrije Universiteit Brussel

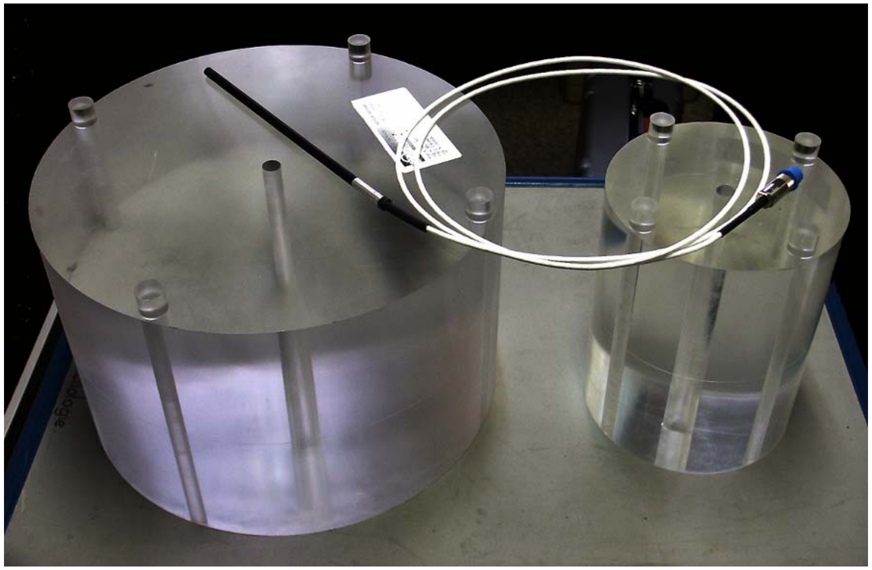
CT dose indices

CTDI = the integral along a line parallel to the axis of rotation (*z*) of the dose profile, *D(z)* for a single slice, divided by total detector acquisition width (*N*x*T*)

$$ {}_{n}CTDI_{100,x} = \frac{1}{N \times T} \cdot \int_{-50mm}^{+50mm} D(z) \cdot dz $$

fixed integration length of 100 mm (-50 to +50 mm)

Phantom standards 32 cm and 16 cm diameter



Body adult

Head adult
Body child

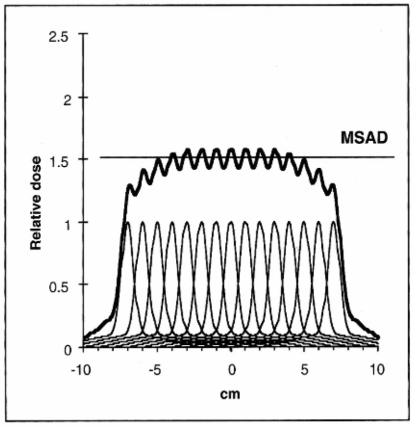
Universitair Ziekenhuis Brussel

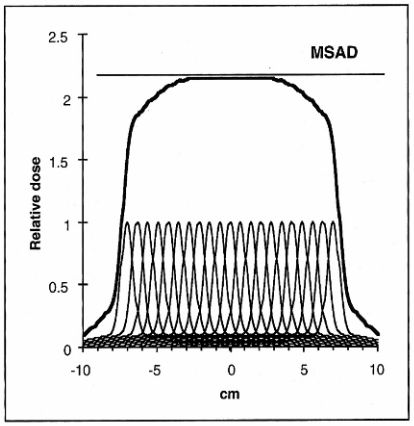
Vrije Universiteit Brussel

CT dose indices

How is the volume scanned?

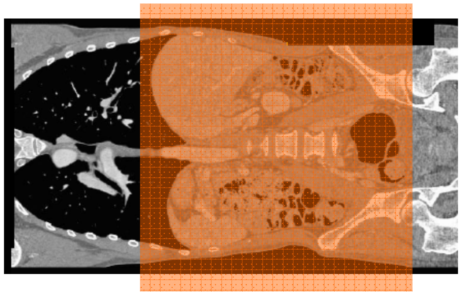
$$CTDI_{VOL} = \frac{CTDI_w}{pitch}$$





What is the length of the sequence?

$$DLP = CTDI_{VOL} \times L$$



DLP includes all technical scan parameters and scanner characteristics.

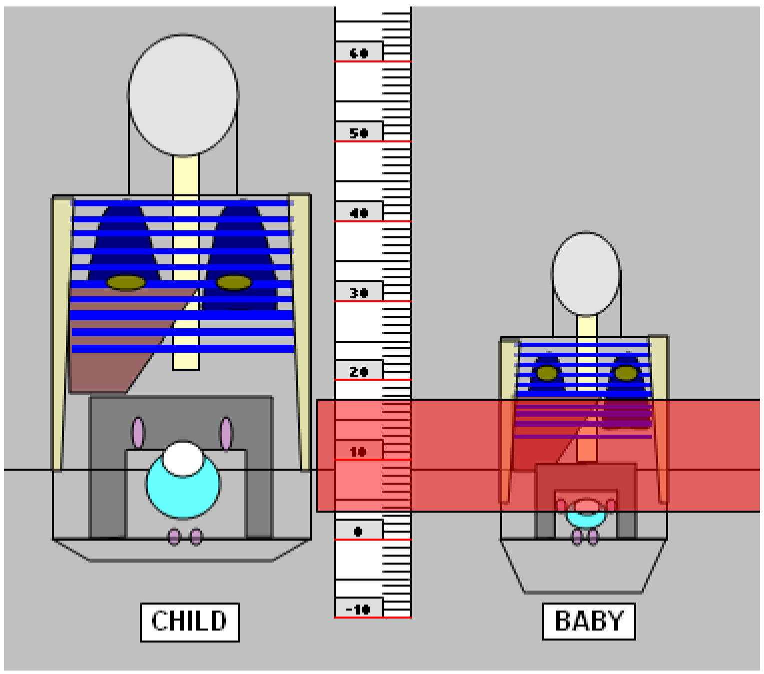
$CTDI_{vol}$ and DLP indicated on scanner console.

IEC (2003) standard 60601-2-44

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

CT dose indices
Organ dose

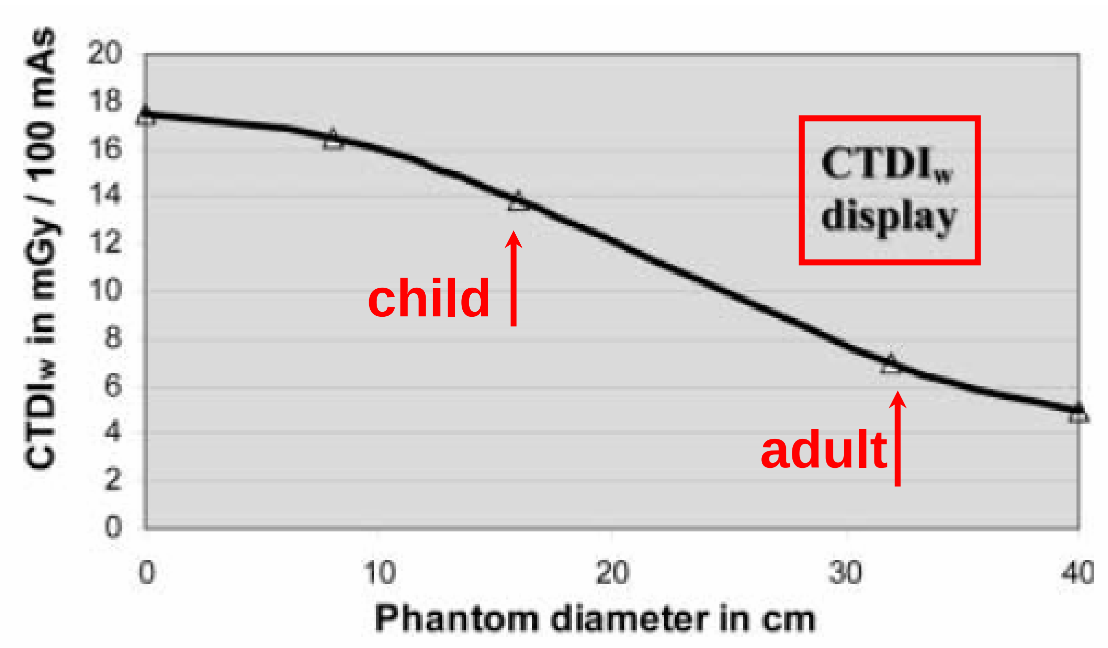
Organ dose calculations from $CTDI_{VOL}$ by MC simulation



- Windose
- NRPB, report SR250
- ImPACT
- GSF, bericht 30/91
- CT-Expo, *Nagel*

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Considerations for pediatrics
Influence of diameter on CTDI



Suess et al, Pediatr Radiol (2002)

Displayed CTDI on console does not reflect actual dose in paediatric patients

Shrimpton P, NRPB W-67 (2003)

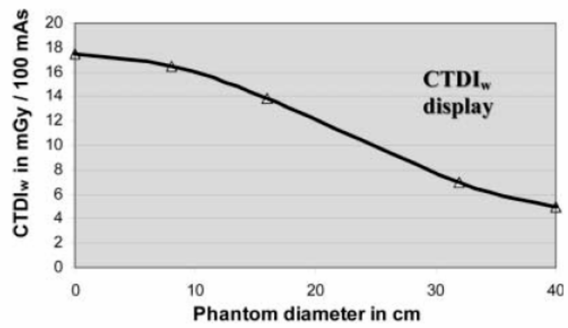
Paediatric dose is much higher than adult dose: 16cm ≈ CTDI x 2 ≈ DLP x 2

Siegel M, Radiology (2004)

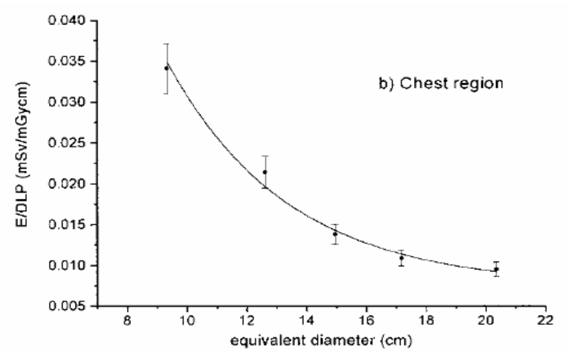
Universitair Ziekenhuis Brussel

Vrije Universiteit Brussel

CT dose indices
Increased radiation risk for children

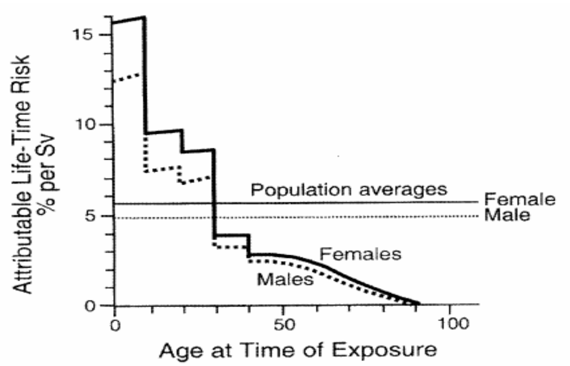


Increased
CTDI and DLP



Increased
E/DLP

from Shrimpton, NRPB-PE/1 (2004)



Increased
radiosensitivity

CT potentially poses significantly greater risk to children

Donnelly L, AJR (2001)

Brenner D, AJR (2001)

Scanning children with adult protocols

In CT, the technical limitation of the x-ray tube/generator determines the maximum amount of exposure, not the detector.

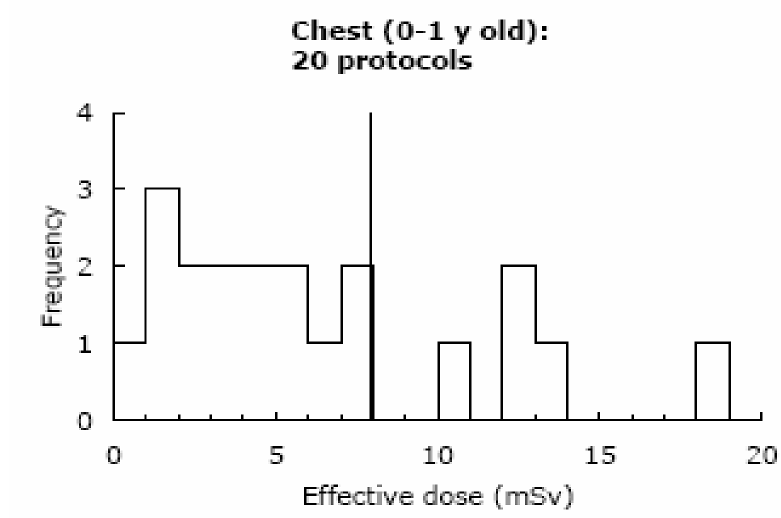
all patients can be scanned with the same technical settings (kV, mAs)

"it is not unusual that radiologists apply adult protocols for children" Paterson et al, AJR (2001)

Dose surveys
Suggest potential for dose reduction

NRPB-W67 (2003)
UK review CT doses

- sample of 126 scanners
- adults and children
- ~25% UK scanners
- DRLs



EU guidelines for MSCT (2004)
Bongartz G et al.

- field survey
- UK, CH, NL
- 4 indications
- chest (0-1 y old)

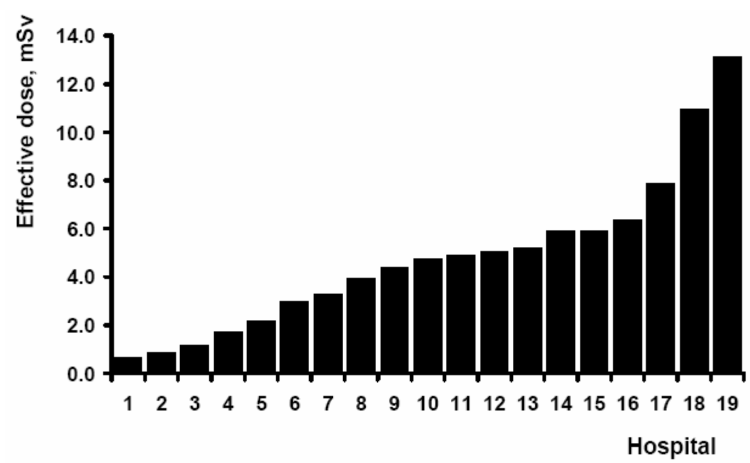


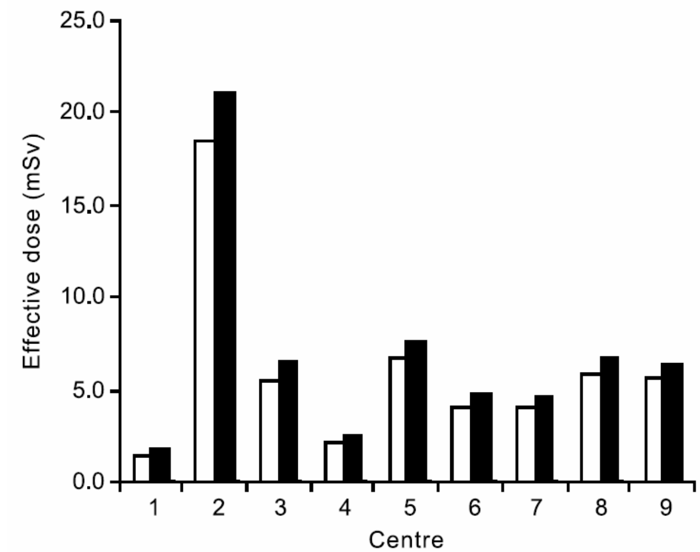
Figure 15. Histogram showing the effective dose at 19 departments.

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Dose surveys
Suggest potential for dose reduction

McLean et al, *Australian Radiol* (2003)

- Australia
- 9 centers
- chest (7 y old)



Pages et al, *Br J Radiol* (2003)

- Belgium, regional
- 7 centers
- abdomen (1 y old)

CT unit	DLP (mGycm)	DRL (mGycm)	E (mSv)
1-year-old			
A	217		4.6
B	171	4 > 330	3.9
C	576		15.5

same scanner

Universitair Ziekenhuis Brussel

Vrije Universiteit Brussel

Surveys
Suggest potential for dose reduction

Results from CT pediatric surveys show

substantial dose variations for same age group

no common trend in parameter selection

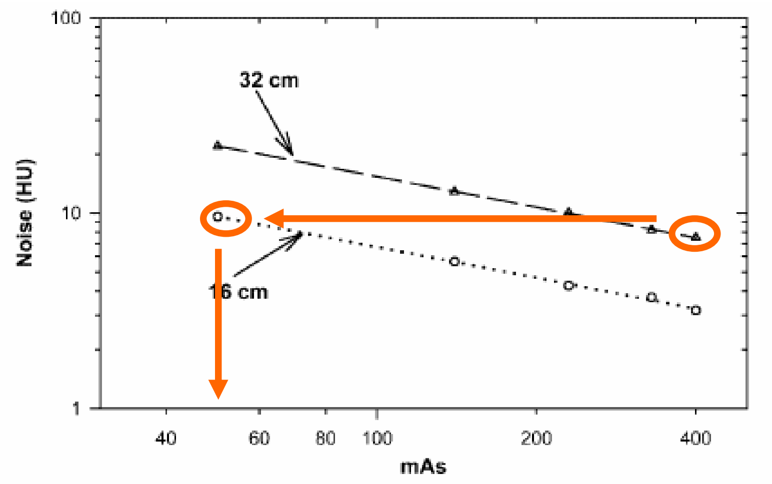
suggest realistic potential for dose reduction

Dose optimisation strategies

Dose optimisation
Adapting tube current

Halve value thickness of tissue in CT is approximately 4 cm

Patient diameter – 4 cm → intensity at detector x 2



Huda W, Pediatr Radiol (2002) 32:709-713

Dose optimisation
Adapting tube current

Recommendations to user:
"adapt tube current (mAs) manually to patient size"

- manually….hmmmm…
- what is the size of this patient?
- how much mAs is required?
- mA or mAs? tube rotation?
- mAs scanner A mAs ≠ mAs scanner B
- standardized guidelines?

TABLE 1 Suggested Tube Current (mA) by Weight of Pediatric Patients for Single-Detector Helical CT

Weight		mA	
lb	Kg	Chest	Abdomen or Pelvis
10–19	4.5–8.9	40	60
20–39	9.0–17.9	50	70
40–59	18.0–26.9	60	80
60–79	27.0–35.9	70	100
80–99	36.0–45.0	80	120
100–150	45.1–70.0	100–120	140–150
>150	>70	≥140	≥170

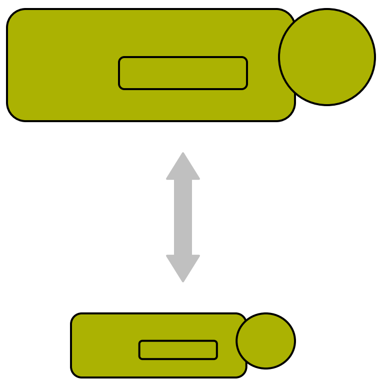
Brenner D et al, *AJR* (2001)
Donnelly L, *AJR* (2001)
Lucaya J et al, *AJR* (2000)

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Dose optimisation
Adapting tube current to size: TCM and AEC

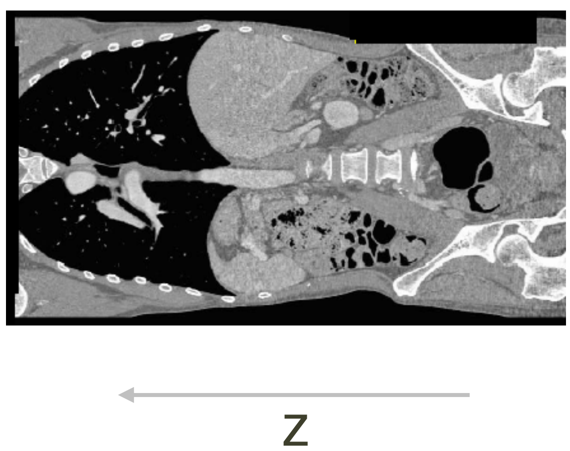
TCM

According patient overall size

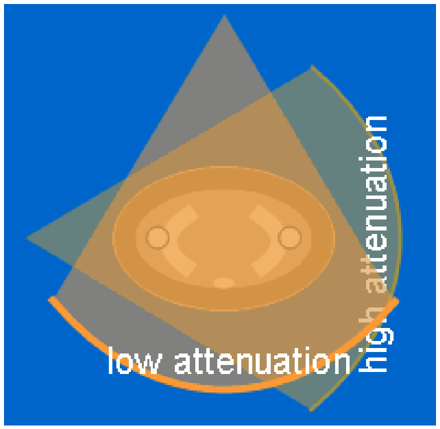


AEC

For each axial slice position (along z-axis)

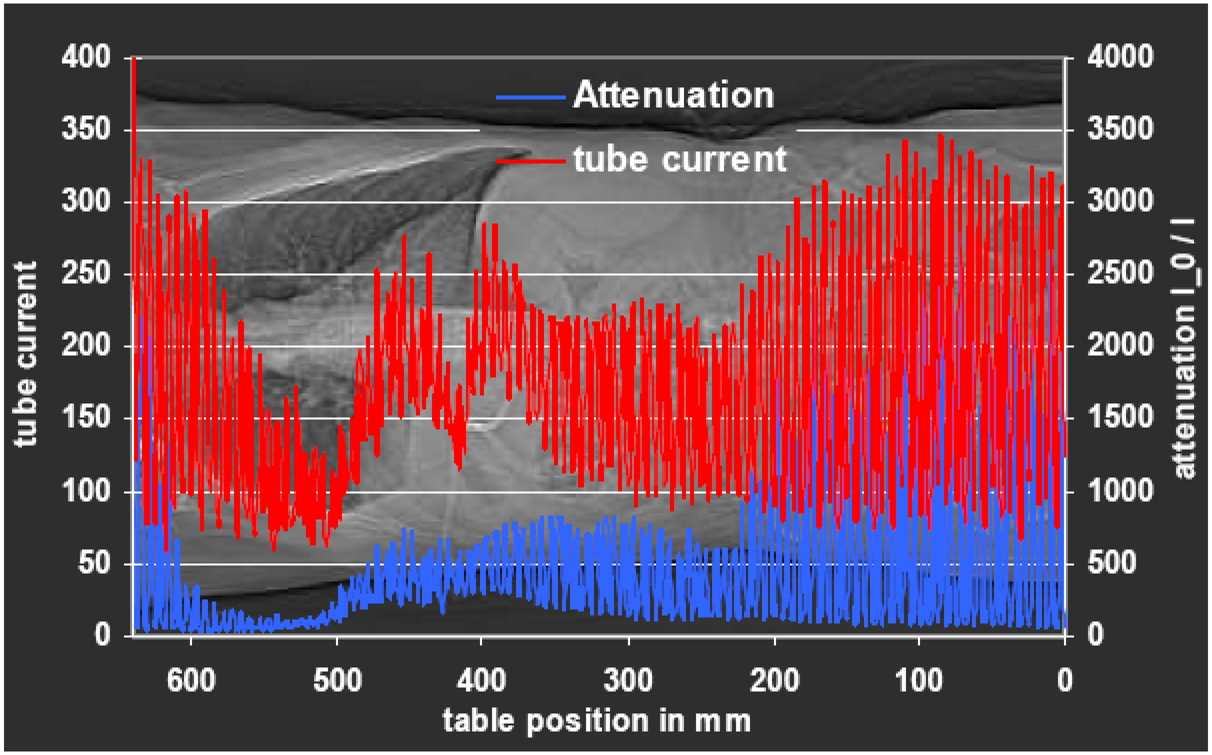


Angular (alpha)



Goal: constant IQ, dose optimised, reduces tube load, less artefacts

Dose optimisation
Adapting tube current to size: AEC and TCM

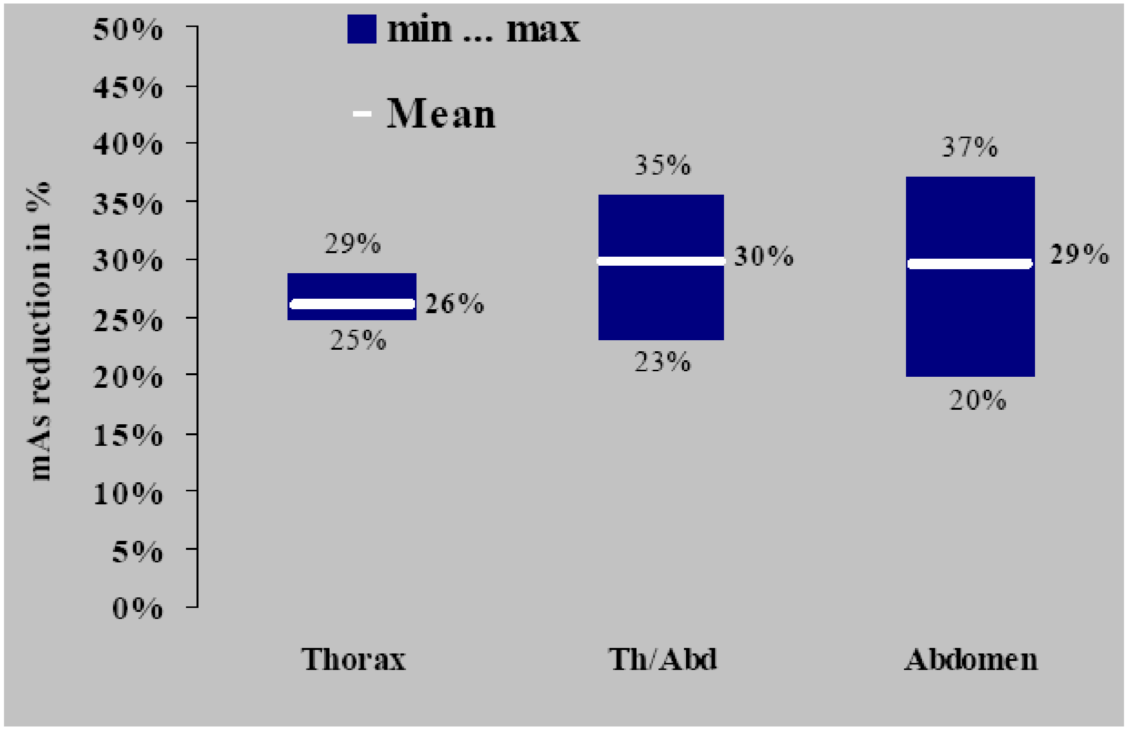


AEC

Courtesy of
U.Baum, University Hospital Erlangen

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Dose optimisation
Adapting tube current to size: AEC and TCM



"20-25% dose reduction can be achieved with AEC compared to fixed mA"

Greess et al, *Eur Radiol* (2002)

Nowadays, ATM and AEC is standard on most high-end CT scanners

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Dose optimisation
Spectral optimisation

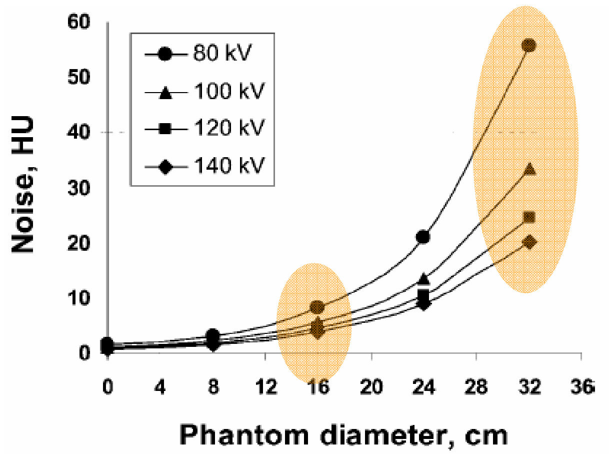
Subsecond scanning requires high tube output and thus high kV (120 – 130 kV).

$$tube\ \ output \propto mA \cdot kV^{2.5}$$

Nagel H, CTB publications (2002)

In pediatric applications smaller volumes are scanned and tube load parameters can be reduced.

Image noise increases but the effect is minimal in smaller phantoms



Siegel et al, *Radiology* (2004)

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Dose optimisation
Spectral optimisation

Lower kV can be applied routinely for contrast studies and soft tissue imaging

Using 80 kV instead of 120 kV can reduce dose by 50% - 70 % for constant CNR

Suess et al, *Pediatr Radiol* (2002)

Tube voltages of around 60 kV should be made available for scanning small children

Buchenau et al, *ECR* (2008)

Changing kV requires effort!

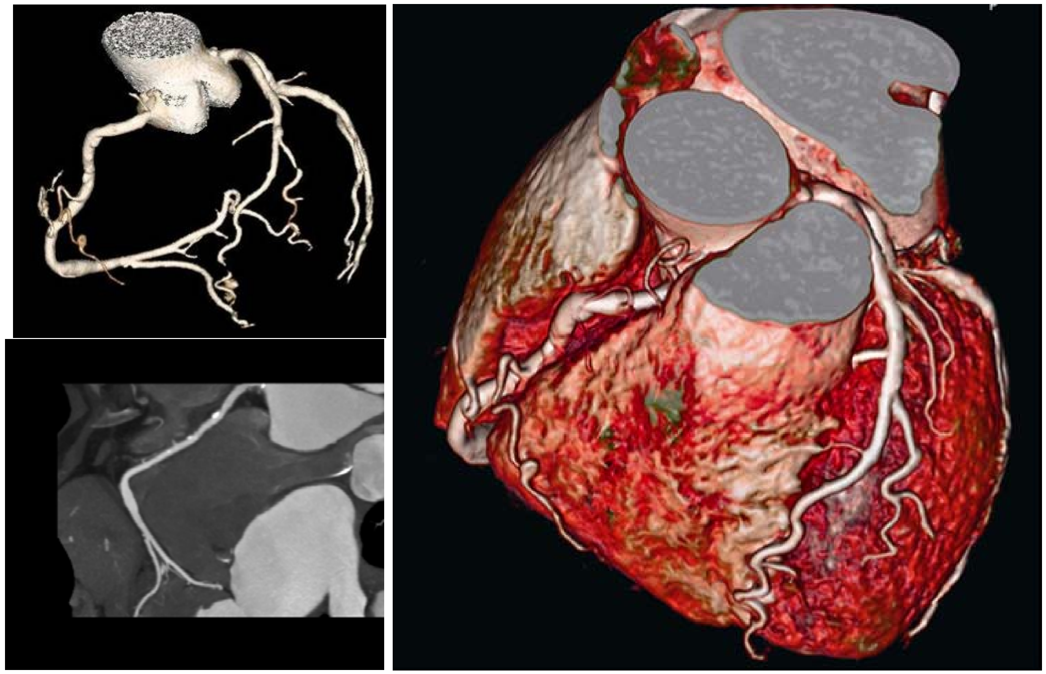
- beam hardening artefacts Cody et al, *AJR* (2004)
- CT (HU) numbers change
- radiologists have to adapt to different image impression

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Advanced applications and RP tools

Advanced applications…
Cardiovascular imaging: typical high dose

Non-invasive viewing of coronary arteries
Visualisation, analysis of stenoses and plaques



Also applied for children!

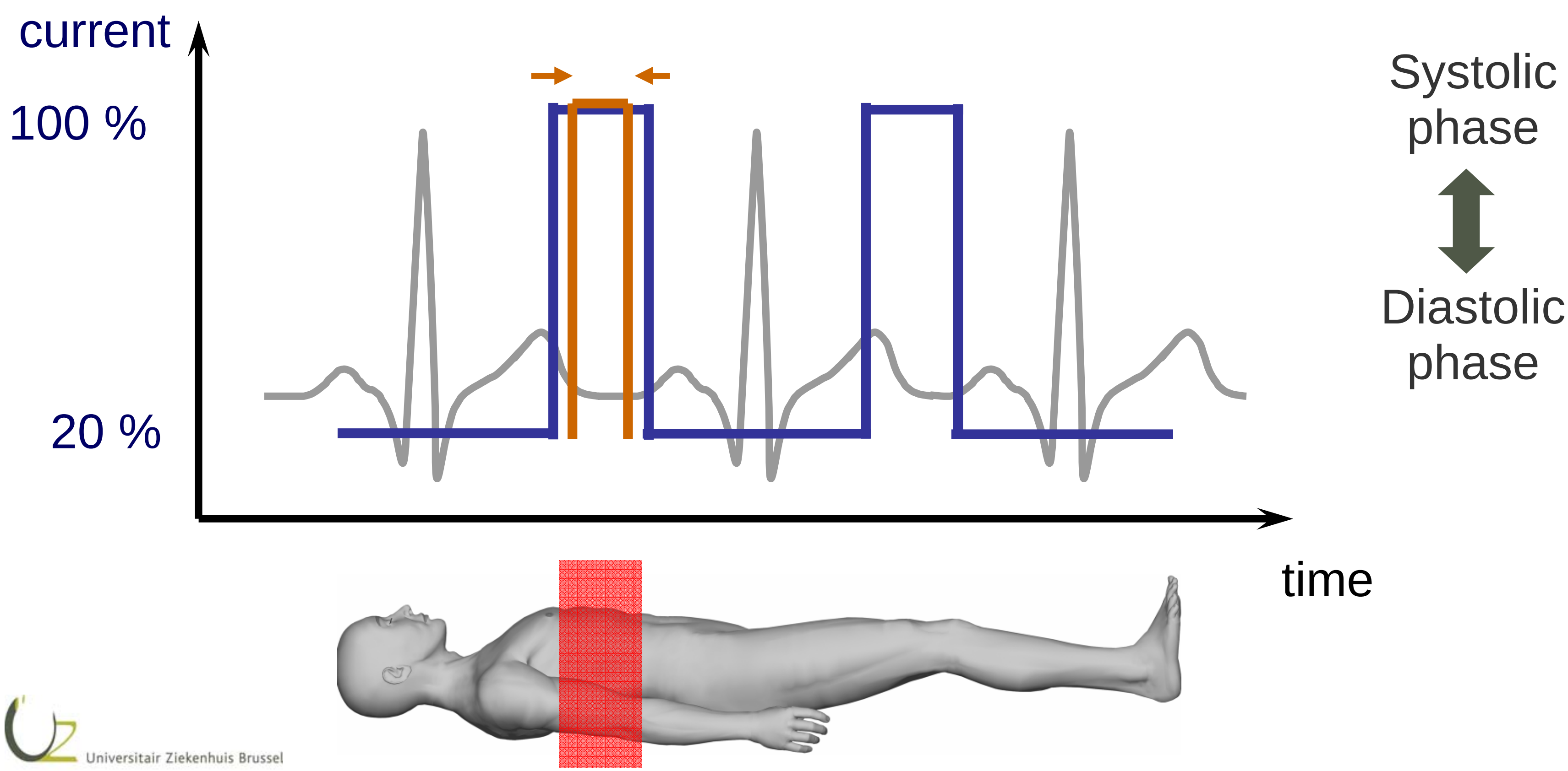
congenital heart disease (age: 1 day – 15 yr)

Herzog et al, *AJR* (2008)

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Advanced dose optimisation strategies
ECG triggered tube current modulation

Acquisition and reconstruction only during selected phase of cardiac cycle

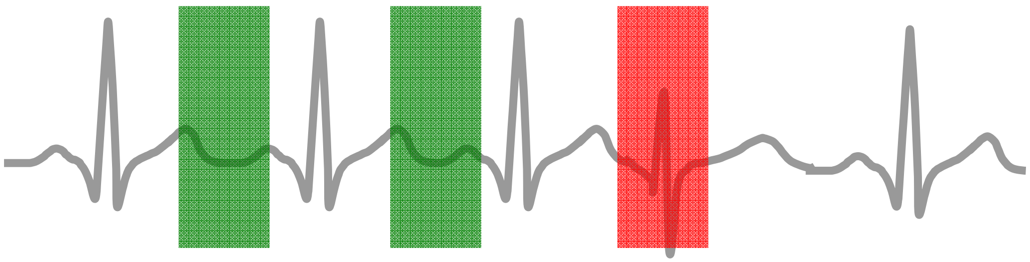


Advanced dose optimisation strategies
ECG triggered tube current modulation

Early papers w/o ECG modulation describe patient doses in the range of 10 – 20 mSv.

Recent studies w ECG modulation show typical dose reductions of ~50%.

Recent studies show applicability of ECG modulation in daily practice.



Universitair Ziekenhuis Brussel

Vrije Universiteit Brussel

Advanced dose optimisation strategies
ECG triggered tube current modulation

Herzog et al, *AJR* , May 2008

TABLE 2: Radiation Exposure for 80- to 120-kVp Scans: 64-MDCT with Automatic Tube Current Modulation (ATCM) in Comparison with Reference Values Estimated from Actual 64-MDCT mAs Values

Measure of Radiation Exposure	64-MDCT with ATCM			
	80 kVp (n = 17)	100 kVp (n = 9)	120 kVp (n = 12)	Mean
Tube current–time product (mAs)				
Actual value	24.8 ± 3.9	65.1 ± 45.9	76.7 ± 48	54.1 ± 44
Reference value[a]	72.3 ± 7.9	144.4 ± 70.3	174.2 ± 84.9	128 ± 77.5
Difference (%)	65.7	54.9	56.0	57.8
p	< 0.05	< 0.05	< 0.05	< 0.05
$CTDI_{vol}$ (mGy)				
Actual value	0.5 ± 0.1	2.2 ± 1.8	5.3 ± 3.2	2.8 ± 3.1
Reference valuea	1.5 ± 0.2	4.7 ± 2.4	12.2 ± 5.7	6.4 ± 6
Difference (%)	66.6	53.2	56.6	56.3
Dose–length product (mGy × cm)				
Actual value	8.5 ± 2.9	59.4 ± 50.9	156.8 ± 123.5	77.1 ± 103.7
Reference valuea	24.6 ± 8	128.1 ± 70.3	346.1 ± 220.2	171 ± 200.2
Difference (%)	65.4	53.6	54.7	54.9
Radiation dose equivalent (E) (mSv)				
Actual value	1.0 ± 0.2	1.9 ± 1.5	4.4 ± 2.1	2.5 ± 2.1
Reference value[a]	2.9 ± 0.7	4.5 ± 2.4	10.6 ± 3.7	6.3 ± 4.4
Difference (%)	65.5	57.8	58.5	60.3

[a]Values for 64-MDCT without ATCM were estimated from prevailing actual 64-MDCT mAs values.

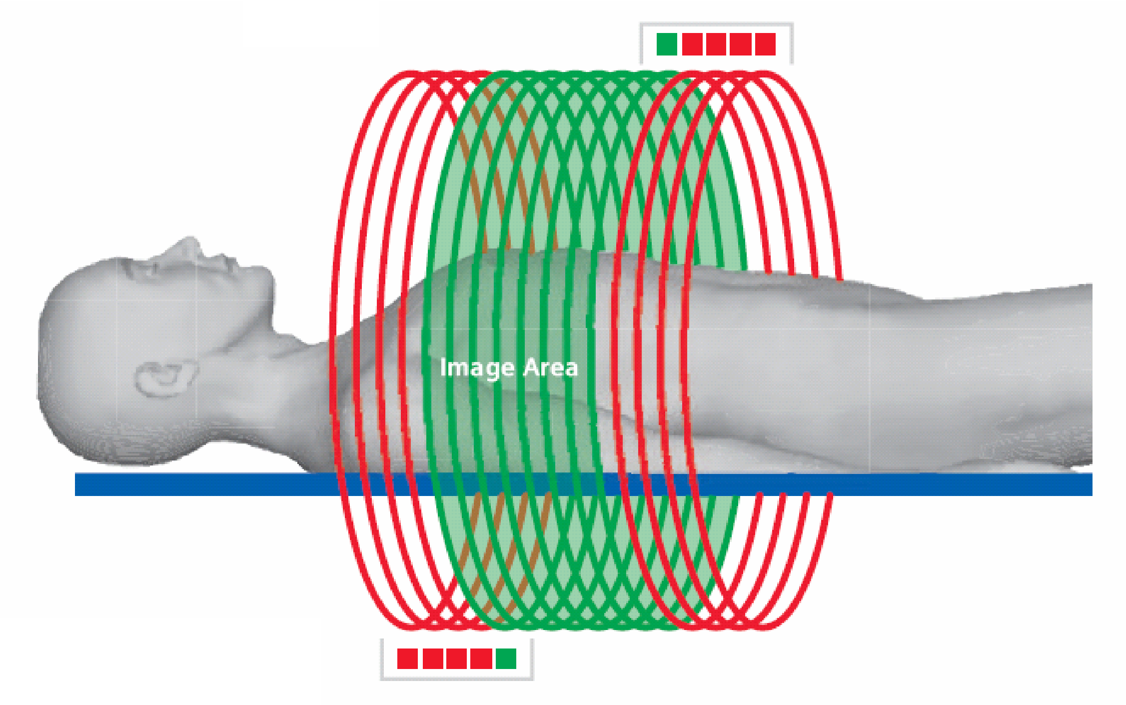
Universitair Z

Vrije Universi

Advanced dose optimisation strategies
Adaptive overscanning collimation

All helical MSCT require overscanning

tissue exposure beyond boundaries of imaged volume

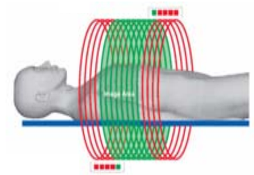


X-ray tube penumbra

Reconstruction prerequisite

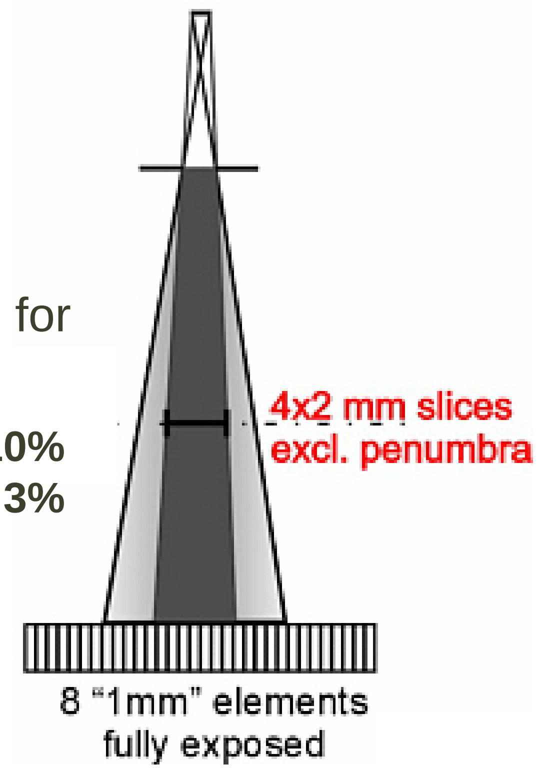
Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Advanced dose optimisation strategies
Adaptive overscanning collimation



How much extra dose?

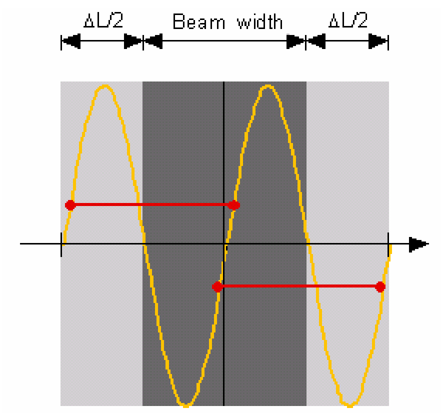
Penumbra



Effect diminishes for larger *z* :

4-slice ~ 10%
64-slice ~ 3%

Reconstruction

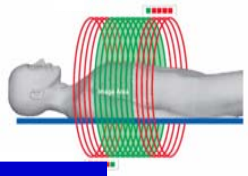


Tzedakis et al, *Med Phys* (Apr 2007)

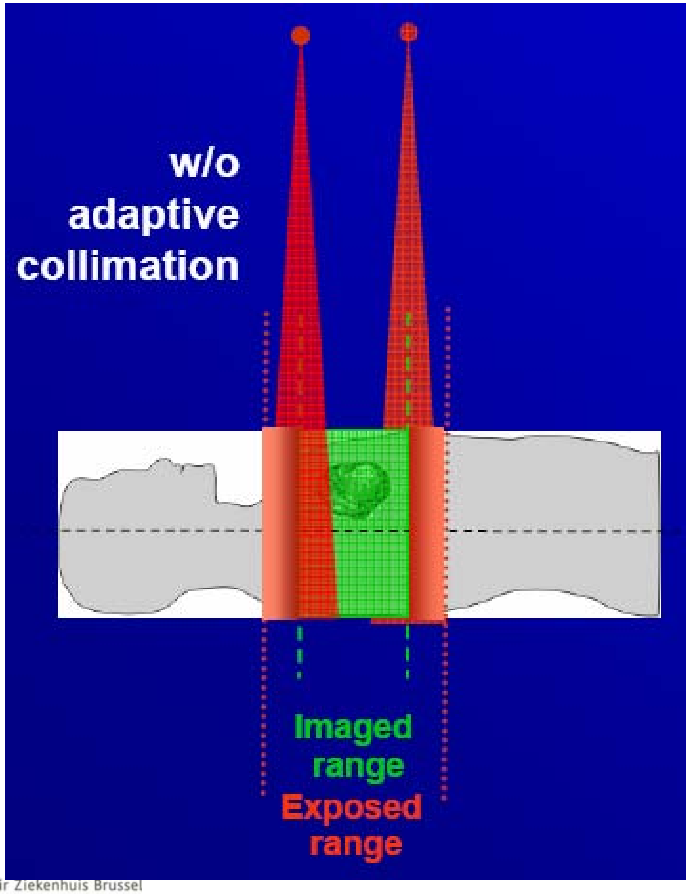
Children 0 – 15 yrs

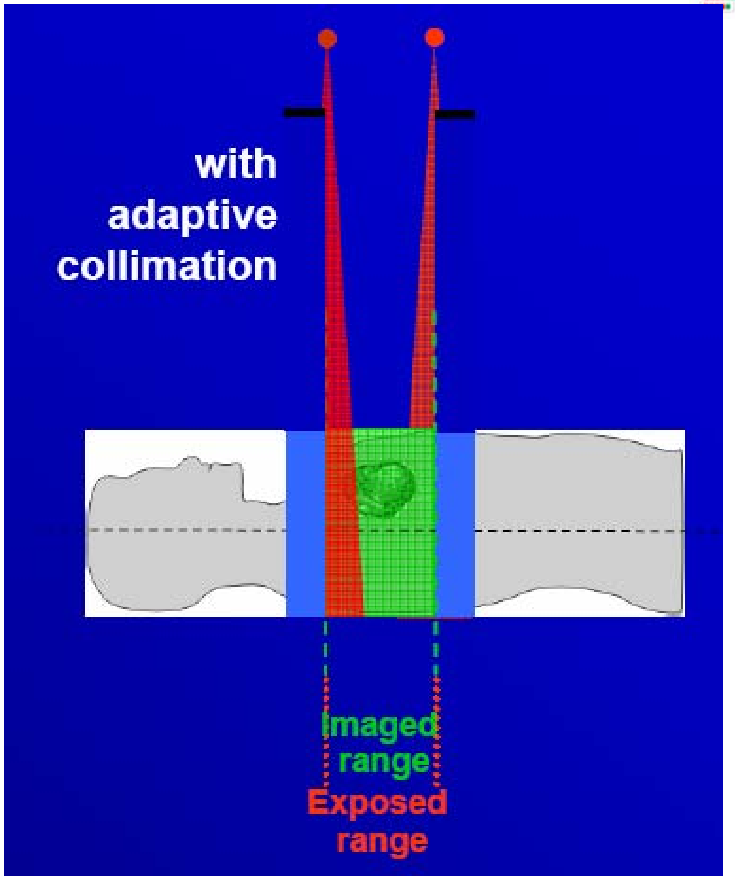
Normalized E:
Helical versus axial (26% to 70%)!

Advanced dose optimisation strategies
Adaptive overscanning collimation



Kalender,RSNA 2008





Universitair Ziekenhuis Brussel

Vrije Universiteit Brussel

Advanced applications
CT colonography – virtual colonoscopy

Non-invasive method for the evaluation of the colon lumen

Also reported for children!

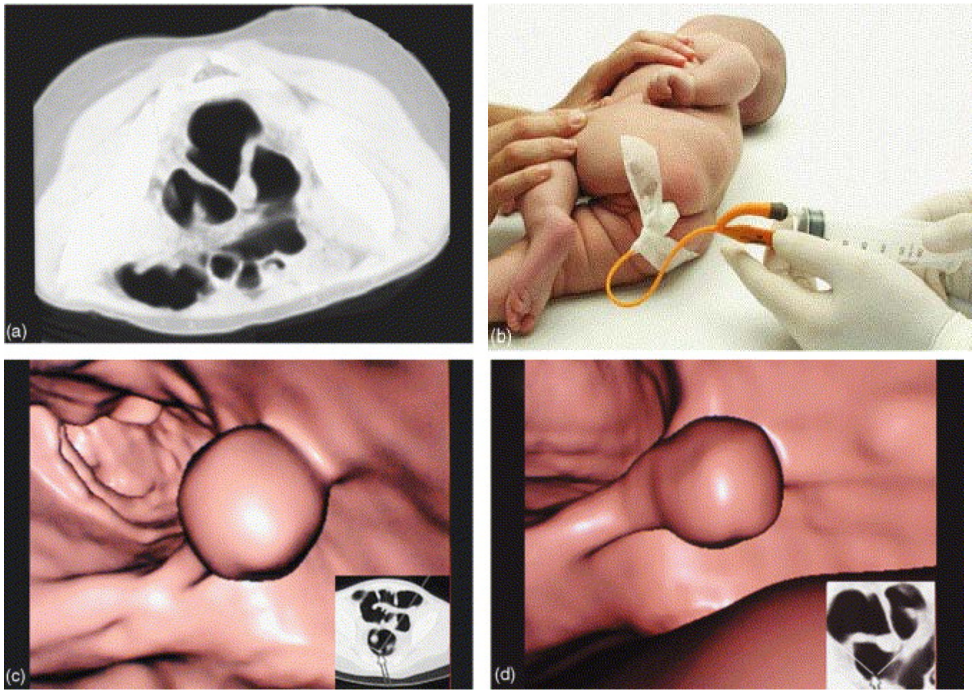
Capuñay et al, *Eur J Radiol* (2005)

Study group:

- 100 childr, age 30d – 16yr
- Low dose protocol (90 kV)

Major advantage over conventional colonoscopy:

- no anesthesia or sedatives
- no complications



Pedunculated polyp in sigmoid colon

Universitair Ziekenhuis Brussel

Vrije Universiteit Brussel

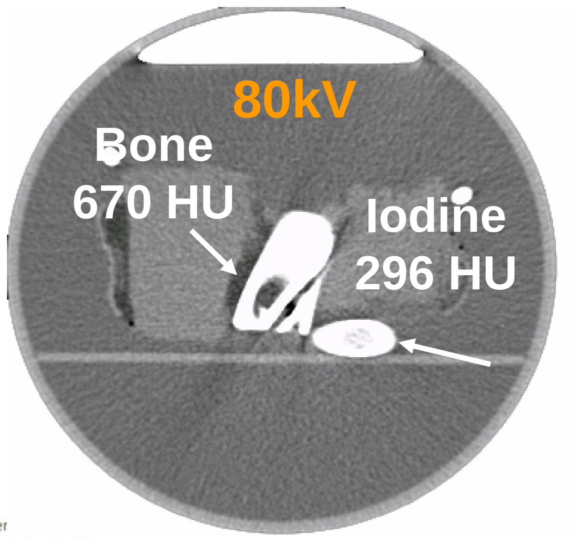
Advanced applications
Dual Energy CT scanning

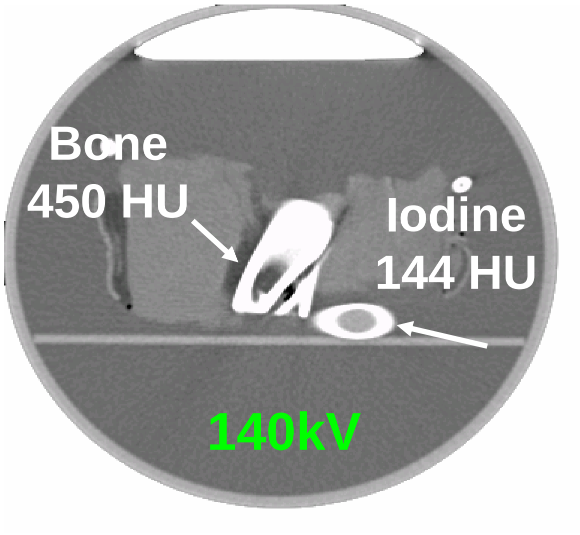
New?

Kelcz F et al, *Med Phys* (1979)

Noise considerations in dual energy CT scanning

Elemental composition of tissues/materials

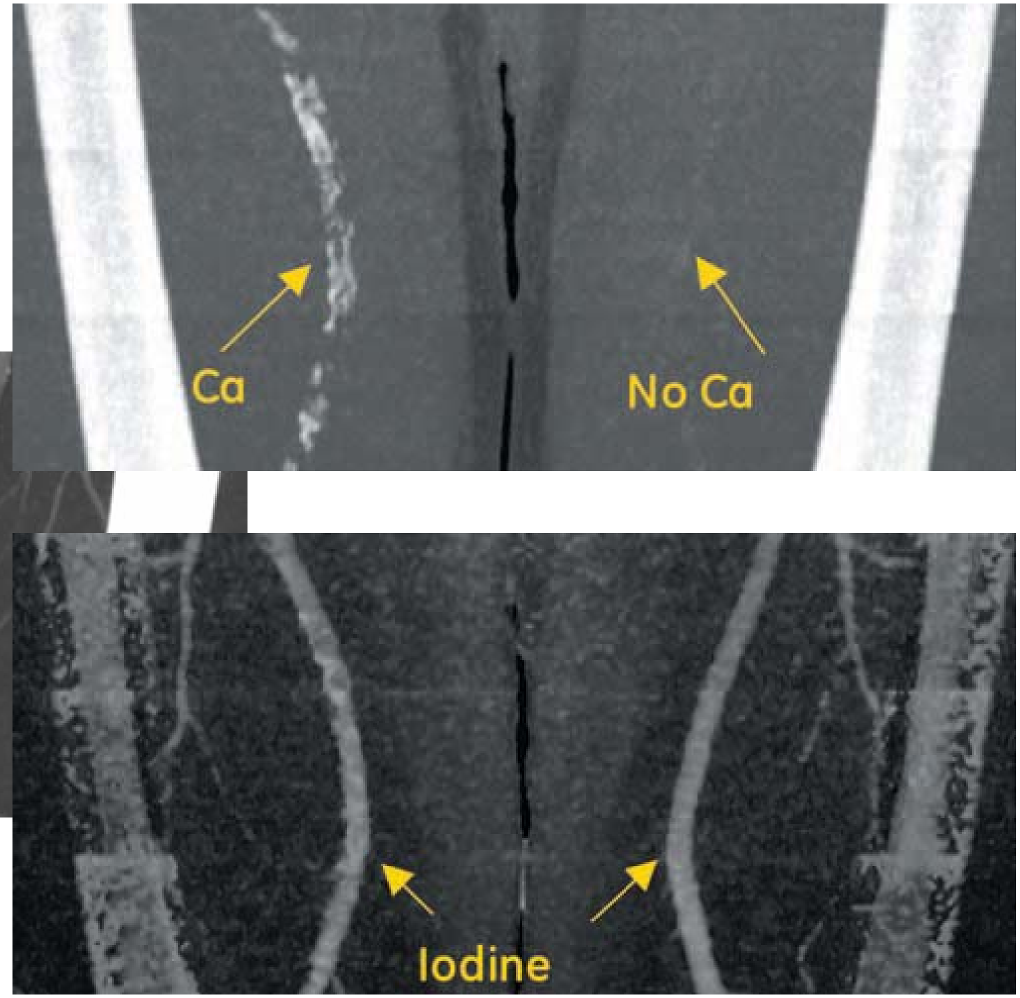




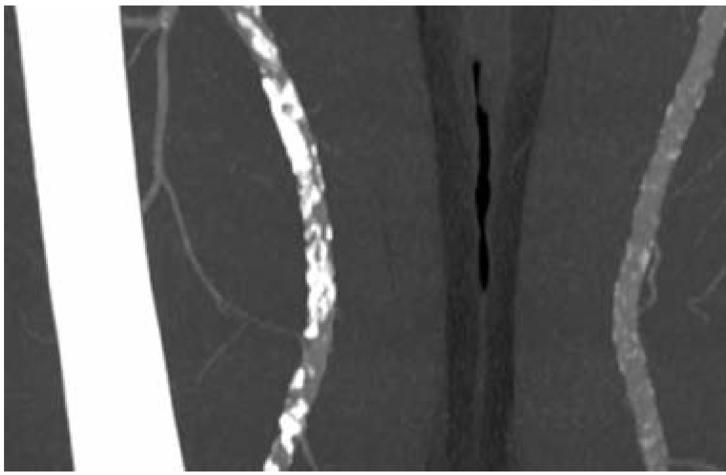
Universitair Zieken
Vrije Universiteit Brussel

Advanced applications
Dual Energy CT scanning

Arterial calcification



CT angiogram



Fishman E, *Appl Radiol* 2006

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Conclusions

The benefit of MSCT in pediatric imaging is very high

examinations will probably further increase

Currently, strong development going on….

Shift from HU slice imaging to advanced, functional applications (perfusion, DE, cardiac)

Pediatric CT imaging requires carefull scan parameter selection

studies report doses up to 20 mSv per scan

surveys show substantial variations between centers

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel

Conclusions

Recent years (~2001) RP received a lot of attention

recent reports show decreased doses

efforts from manufacturers side include

- AEC and TCM
- dedicated paediatric scan protocols
- advanced techniques (cardiac, helical, etc)

Legislation

- special attention children and CT
- paediatric DRLs become available for MSCT
- local dose audits

Conclusions

There is still a lot of work

Operating AEC efficiently is not straightforward

AEC systems require understanding of newer concepts

AEC systems should be included in scanner QC

CT dosimetry in children is not a trivial task

Scan protocol optimisation and advanced applications

Thank you for your attention

If you require a copy of this presentation
email Nico.Buls@uzbrussel.be

Universitair Ziekenhuis Brussel
Vrije Universiteit Brussel