Radiation Dose Optimization in Cardiac CT: A Technical Review

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17 May 2014

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• Cardiac CT (mainly CCTA): promising, low-invasive
• Radiation dose: major concern for CCTA, esp. for young female patients.
→ increase from 16- to 64-slice CT
→ ECG-gated helical acquisitions: dose up 40 mSv (Jean-François & Hicham, 2007)
• Differences in dose due to performance of CT scanners, technical dose-sparing tools.

Cardiac CT synchronization techniques

Prospective ECG-triggering

- Synchronization occurs when HR and sequential CT scanning in harmony → x-ray tube in same position for various heart beats
- Trigger x-ray beam and acquire data in certain cardiac phase preferably diastolic phase (70 – 80 % of R-R interval) with min. cardiac motion
- e.g. snapshot of 100 ms in 70 % R-R interval
- Slow and stable HR, low radiation dose

(Courtesy to S. Edyvean)
Cardiac CT synchronization techniques

**Retrospective ECG-gating**

- ECG signals and helical scan data acquired simultaneously.
- Scan data selected for image reconstruction w.r.t. pre-defined cardiac phase with a certain temporal relation to onset of R-waves.
- Better temporal resolution with segmented reconstruction
- Redundancy of data acquisition → phase-selective image reconstruction
- High radiation dose

(Courtesy to S. Edyvean)

Prospectively ECG-triggered high-pitch helical acquisition

- State-of-art dual-source scanner - a pitch of 3.4 to fill in the gaps of raw data acquired by second X-ray tube
- Acquire data very quickly — in ~ an 1-mile-per hour table translation speed
- Not prospective ECG-triggering, not retrospective ECG-gating

(Courtesy to Suhny Abbara)
Dose optimization strategies

Strategy 1: ECG-gated mA modulation

Retrospective ECG-gating
- mA adjusted based on predicted cardiac phases to optimal setting (optimal max. and min. mA)
- → acceptable image quality
  e.g. 350 mA during mid-diastole (60 – 80% of R-R interval) and 200 mA for the remainder
Dose optimization strategies

**Strategy 2: Optimization of kVp**

- **Radiation dose with CT ~ α (∆kVp)^2**, 120 to 100 kV → 31% reduction in dose (Bischoff, Hein & Meyer et al. 2009).

- ↑ Intravascular contrast with ↓ tube voltage (100 kVp or 80 kVp) because iodine resorption α 1/ kVp due to higher degree of P.E. effect and lower degree of Compton scattering (Gutstein, Dey & Cheng et al 2008).

- ↓ kVp → ↑ attenuation of vessel lumen and cardiac chambers if iodinated C.M. used.

- 80 – 100 kVp protocols in myocardial CT perfusion, CCTA (< 70 kg)

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**Pflederer, Rudofsky & Ropers et al (2009)**

- 100 kVp for patients weighing <= 90 kg or with a BMI <= 30 kg/m^2
- 120 kVp for patients weighing > 90 kg or with a BMI > 30 kg/m^2
- Higher kVp (e.g. 135 kVp) for severely obese patients (> 100 kg).
Dose optimization strategies

Strategy 2: Optimization of kVp

Hoe (2013)
• < 100 kg - 100 kVp (Siemens DSCT FLASH)
• < 85 kg - 100 kVp (Siemens DSCT)
• < 25 kg/m² BMI – 100 kVp (GE 64-slice MDCT)
• < 30 kg/m² BMI – 100 kVp (GE 750 HD)
• < 80 kg – 100 kVp, 400 mA
  > 80 kg – 120 kVp, 800 mA (GE 64-slice MDCT)
• < 60 kg – 80 kVp – ↓ dose by 80 %

What body weight or BMI for lower kVp CCTA scan?

Remark: (i) < 70 kg – 100 kVp, 350 mA, 0.35 s
(ii) 120 kVp for post-stenting CCTA (Toshiba Aquilion 64)

Dose optimization strategies

Strategy 3: Optimal scan length

• Absorbed dose $\alpha$ DLP = CTDI_{vol} x scan length

• Optimal scan range: minimum scan length clinically necessary
• With reference to calcium score scan, CCTA scan range from level just above LM to heart base
• Margins of 10 mm sup. and inf. to most cranial and caudal slices allowed
  → account for breath-hold inconsistencies
  → scan manually stopped if desired anatomy covered
• Optimal scan length planning → each breath-hold at same inspiration depth


Dose optimization strategies

Strategy 4: Reconstruction of optimal slice thickness

- Noise α 1 / √ (reconstructed slice thickness)
- ↓ radiation dose (through a reduction in kVp or mA) with ↑ in slice thickness while maintaining same image noise.
- 3-mm thick image has 73% less noise than 1-mm thick image (Halliburton, Abbara, Chen, Gentry, Mahesh, Raff, Shaw & Hausleiter, 2011).
- Images reconstructed with greatest possible slice thickness for given cardiovascular CT indications (e.g. 0.5 mm slices for evaluating coronary artery stenosis, 3.0 mm for calcium scoring or evaluating larger blood vessels such as aorta and PA).

Strategy 5: Helical scanning with higher pitch

- Latest generation of dual-source CT technology: ECG-triggered helical scanning at very high pitch values (High helical pitch “flash” acquisition)
- Interleaving data measured from 2 detector systems separated by ~ 90 degrees, pitch → 3.4
- Near complete elimination of overlap in cone beam → ↓ amount of redundant data collected
Dose optimization strategies

Strategy 6: Filters and breast shields (Rajiah, Halliburton & Flamm, 2012)

- Filters placed beneath the x-ray tube selectively attenuate low-energy x-rays not contributing to image formation
- Flat and cardiac bow-tie filters used with small SFOV → ↓ radiation exposure to lungs

(Courtesy to S. Edyvean)


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Dose optimization strategies

Strategy 6: Filters and breast shields (Rajiah, Halliburton & Flamm, 2012)

Bismuth-impregnated latex shield
- placed between x-ray beam and breasts (i.e. in AP projection)
→ specifically ↓ radiation dose by over 25 %

(Courtesy to M. Gure)

Dose optimization strategies

Strategy 7: Organ-based dose modulation

• mA modulation avoiding direct X-ray in radiosensitive organs

(Dual et al, 2011)

Pok Oi Hospital
Dose optimization strategies

Strategy 8: Adaptive collimation

Over-ranging in MDCT
- generally ↑ with collimation
- unnoticed exposure to breasts

Adaptive collimation
- elimination of radiation exposure unnecessary for image reconstruction

Strategy 9: Iterative reconstruction

Filtered back-projection (FBP)
- fast, images prone to high noise in low dose situations
- clinical situations in which image quality tends to be less acceptable include:
  1. CT scans in large patients,
  2. images with small voxels, such as the targeted FOV used for cardiac CT,
  3. images through the bony pelvis.
Dose optimization strategies

Strategy 9: Iterative reconstruction

Iterative reconstruction algorithm

- Assumes initial $\mu_{x,y,z}$ for all voxels to predict projection data.
- Predicted projection data compared with actual, measured projection data.
- Voxel attenuations modified and compared with measured data until the error between estimated and measured projection data acceptable.
- Significant computational power and additional time
- Improves noise properties

(Leipsic, Labounty & Heilbron 2010)

Dose optimization strategies

Strategy 9: Iterative reconstruction of images

- IR performed from raw (projection) data or image (slice) data or both

(i) IRIS (Iterative Reconstruction in Image Space) (Siemens)
   - IR from image data only
(ii) Veo (Model-based Iterative Reconstruction) (GE)
   - IR from raw data only
(iii) ASIR (Adaptive Statistical Iterative Reconstruction) (GE)
   - SAFIRE (Sinogram Affirmed Iterative Reconstruction) (Siemens)
   - iDose4 (Philips)
   - AIDR (Adaptive Iterative Dose Reduction) (Toshiba)
   - IR from both raw data and image data
Dose optimization strategies

Strategy 10: Garnet gemstone-based detector

Garnet gemstone-based scintillator (CT750 HD)
• configured to emit fluorescence when irradiated with x-rays
• decay time of 30 ns, 100 times faster than conventional scintillators (e.g. GOS, Bismuth Germinate (Bi4Ge3012) and Cadmium Tungstate (CdWO4))
• afterglow level only 25% of those of conventional scintillator materials
• spatial resolution: 18.2 lp/cm
→ high-definition imaging at up to 230-μm resolution and delineation of stents
• enhances S/N
→ improves low contrast resolution
→ optimizes mA and radiation dose without significant loss of image quality (Yanagawa, Tomiyama & Honda et al., 2010)


Dose optimization strategies

Strategy 11: Patient preparation

• Proper patient preparation
  (i) Careful explanation of procedure
  • warm sensation to pelvis during CM injection
  • breathing instructions (esp. for 16- or 64- MDCT)
(ii) Administration of oral (50 mg + 50 mg) / IV (5 mg + 5 mg) beta-blockers
(iii) TNG (1 puff SL just prior to CCTA scan)

• High HR, arrhythmia and breathing artefacts
  → degrade image quality

• Proper HR control
  → prospectively ECG-triggered axial sequential scanning if HR < 60 & stable.
**Dose optimization strategies**

**Strategy 11: Patient preparation**

Breath hold practice

- Patients instructed to take comfortable breath in – about 75% of full inspiration
- Scan performed in end inspiration – not Valsalva
- Place hand under costal margin to monitor if patient really holding breath
- Count – 1 sec, 2 sec, 3 sec, 4 sec, etc. for each second

**Strategy 12: Monitoring and recording dose information**

Two primary purposes:
1. documenting individual dose burden
2. quality control

Recording dose descriptors in:
1. A DICOM image with radiation information in a PACS
2. A paper-based logbook
3. ePR or RIS
4. A dedicated database or local registry

- periodic review of radiation doses
- local data compared with international standards and other references (e.g. Diagnostic Reference Levels)
Conclusion

1. Cardiac imaging - demanding application of MDCT
   - improving with technological advances
   - better temporal resolution

2. Prospective ECG-triggering, retrospective ECG-gating & scan parameters
   → optimize cardiac imaging protocols & radiation dose

3. Recommended radiation dose optimization strategies applied
   → clinical indications
   → characteristics of patient
   → hardware and software constraints on CT scanner

   ▶ lowest possible dose with diagnostic image quality

4. Radiation dose recording & monitoring → ↑ dose awareness of radiographers
THANK YOU