Prospectively ECG-triggered high-pitch spiral acquisition for cardiac CT angiography in clinical routine: initial results

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Purpose

Radiation dose due to cardiac CT has become of increasing concern in clinical practice (1). Multiple technological advances have allowed for reduction of radiation exposure from coronary CT angiography (CTA) (2-3). Latest generation of DSCT scanners has introduced a prospectively ECG-triggered helical data acquisition with very high pitch values. This technique enables acquisition of the entire volumetric data set of the heart within a fraction of a single cardiac cycle (4,5).

This study was done to describe initial results of prospectively ECG-triggered high-pitch mode coronary CTA in clinical routine practice with respect to image quality and radiation exposure.
Methods and Materials

Patients

In this IRB approved retrospective study 42 contrast enhanced prospectively ECG-triggered high-pitch mode cardiac CTAs in 34 consecutive patients were analyzed. Study patients were all referred for cardiac CTA. Patients' characteristics are listed in Figure 1.

- 11 female, 23 male
- mean age: 56 ± 15 years
- mean BMI: 27 (range 20 - 39)

Patients referred for evaluation of abnormalities of the ascending aorta (n=2) or coronary bypass grafts (n=2) were also included. A heart rate of 60 bpm or lower and a sinus rhythm was aspired. If necessary, patients' heart rate was controlled with intravenous (iv) beta blocker (metoprolol 5-20 mg) immediately before the scan. Patients with a heart rate > 60 bpm or patients who had an occasional isolated premature ventricular contraction (PVC) prior to the scan, were not excluded from the use of a high pitch mode. Patients with completely irregular rhythms or heart rate higher than 100 bpm were excluded. 33/34 patients received 0.6 mg nitroglycerine sublingually prior to coronary CTA.

MDCT scan protocol

Coronary CTA was performed on a second-generation DSCT (Definition FLASH, Siemens Medical Solutions, Forchheim, Germany). The scanner technology enables a prospectively ECG-triggered high-pitch (3.4) spiral acquisition (FLASH Spiral Cardio, Siemens Healthcare, Forchheim, Germany). The imaging protocol included

- anterior-posterior and lateral scout images
- a non-contrast scan to assess calcium score
- a timing bolus scan (20 ml of iodinated contrast, injection rate 5-7 ml/s [Iopamidol 370 mg/ml], a 20 ml saline flush
- coronary CTA after administration of appr. 50-70 ml of contrast, injection rate 5-7 ml/s, 40 ml saline flush (Figure 1).

Scan parameters included

- 64 x 0.6 mm collimation
- gantry rotation time of 280 ms
- pitch of 3.4
- tube voltage of 80-120 kV (weight-based nomogram)
• tube current of 312-370 mAs/rotation (scout-based automatic reference
tube current selection - CareDose 4D, Siemens Siemens Medical Solutions,
Forchheim, Germany).

The z-axis coverage depended on the indication of the scan. ECG triggered image
acquisition started at 60% of the RR interval. Axial images were reconstructed with a
slice thickness of 0.75 mm at a reconstruction increment of 0.5 mm.

In 8 patients with elevated regular heart rates (> 60 bpm) or in whom occasional PVCs
were noted, a second CTA was acquired immediately during the same contrast injection
timed for the same point in the cardiac cycle ("double flash protocol") (Figure 1). Total
scan time was longer in these patients and the total contrast volume was increased by
25 to 35 cc compared to single high pitch CTA acquisition ([4 seconds + ~1second scan] x
flow rate). In five patients a delayed scan was performed to ameliorate the evaluation
mediastinal or cardiac masses and aortic abnormalities (Figure 1).

Image Analysis

Image quality and CNR were evaluated on an off-line workstation (Multimodality
Workplace, Siemens, Erlangen, Germany). Subjective image quality was rated by two
independent experienced cardiac imagers. Based on the 18-segment model of the
Society of Cardiovascular Computed Tomography (6) subjective image quality was
assessed for every segment using a four-point scale

1. unevaluable
2. moderate image quality with artifacts, but evaluable concerning the
   presence of stenoses
3. good image quality with minimal artifacts, but fully evaluable coronary vessel
   structures
4. excellent image quality without artifacts.

Examples of each score are given in figure 2. The two readers rated the image quality
independently with a subsequent consent read.

An objective measure of scan quality was then performed as it has been previously
described (7). Circular regions of interest (as large as possible, 2-4 mm²) were drawn in
the lumen of the coronary arteries and the adjacent epicardial fatty tissue to measure the
contrast-to-noise ratio (CNR) in nine locations:

• left main coronary artery (LM)
• proximal and distal left anterior descending artery (LAD)
• proximal first diagonal branch (D1)
• proximal and distal left circumflex coronary artery (LCX)
• first obtuse marginal branch (OM1)
proximal and distal right coronary artery (RCA).

A circular ROI (100 mm$^2$) was placed in the contrast enhanced lumen of the aortic root to measure image noise by determining the standard deviation of CT attenuation (8,9).

CNR was calculated as described previously (7):

\[
\text{contrast-to-noise ratio} = \frac{\text{CT attenuation coronary lumen} - \text{CT attenuation adjacent tissue}}{\text{image noise}}.
\]

Radiation dose

CT Dose Index (CTDIvol) and dose-length product (DLP) were obtained for all scans. Patient’s effective dose (mSv) was estimated using the DLP method with a conversion factor $k=0.014$ for adult and $k=0.048$ for pediatric patients (10-11).

Statistical analysis

The statistical analysis was performed using commercially available software (SPSS, 12.0, Inc., Chicago, IL, USA; Microsoft Excel, Redmond, WA, USA). Continuous data are expressed as mean ± SD. Differences of CNR among different coronary locations were examined using one-way analysis of variance (ANOVA). A two tailed $p$-value < 0.05 was considered statistically significant.

Intraclass correlation coefficient (ICC) was used for interobserver agreement of subjective image quality.
### Table 1: Patients' characteristics, radiation dose and contrast application in 42 cardiac high pitch CTAs of 34 patients

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**Fig. 0:** Patients’ characteristics, radiation dose and contrast application in 42 cardiac high pitch CTAs of 34 patients: A second high-pitch CTA was applied in 8 patients ("double flash protocol"), an additional delayed scan in 5 patients.

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Fig. 0: Subjective image quality; typical examples of each score (1-4) regarding the right coronary artery (RCA). A. Excellent image quality (score 4). B. Good image quality (score 3) with slight blurring artifacts (*). C. Moderate image quality (score 2) due to beam hardening artefacts of pacemaker leads (arrows). D. Severe blurring artifacts (arrowhead) cause non diagnostic image quality (score 1) of the mid portion of the vessel.

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Results

Patient characteristics

Patient characteristics are listed in Figure 1.

• Mean heart rate during the scan was 59 ± 8.5 bpm (range 49 - 96 bpm).
• Mean dose of 11.6 ± 8.1 mg iv metoprolol was administered to 24 (70%) of the patients.
• Mean flow rate of 5.7 ± 1.2 ml/s for a mean dose of 69 ± 18 ml of contrast agent was injected (injections were tailored to body habitus and scan time).

Radiation Dose

• Mean z-axis scan length was 14.8 ± 5.2 cm.
• Mean total DLP to the 34 patients was 181.8 ± 103 mGy cm, corresponding to an estimated effective dose of 2.5 ± 1.4 mSv (range 1.1-6.4).
• Regarding the 42 single prospectively triggered high-pitch CTA acquisitions, mean DLP was 99.5 ± 51.1 mGy-cm corresponding to an estimated effective dose of 1.4 ± 0.7 mSv (range 0.4-3.1).
• Mean effective dose for a single high-pitch CTA exclusively of native coronary arteries (after exclusion of the studies for bypass graft, aortic artery and mediastinal mass evaluation) was 1.1 ± 0.4 mSv (range 0.4-1.9).
• Patients with a BMI < 25 demonstrated a mean effective dose of 1.6 ± 0.6 mSv cm for entire examination and 0.8 ± 0.4 mSv for the contrast-enhanced CTA alone (range 0.4 - 1.7).
• Regarding the 8 patients who underwent the "double flash protocol", mean DLP of the whole examination was 275.6 ± 96.1 mGy cm corresponding to an estimated effective dose of 3.9 ± 1.4 mSv (range 2.1-6.4).

Subjective image analysis

A total of 607 coronary artery segments were analyzed.

• 396 segments (68%) had an image quality score of 4 ("excellent"),
• 121 segments (20 %) a score of 3 ("good"),
• 47 segments (8%) a score of 2 ("moderate"),
• 20 segments (3%) were scored as "unevaluable".

Mean rating score for all patients and segments was 3.5 ("good" to "excellent"). An example is given in Figure 2. Unevaluable segments were observed in n=8 patients.
The predominant reasons given by the observers were extensive motion, noise, and streak artifacts due to extensive calcifications. However, 4 of these 8 patients belonged to the subgroup that was examined by the "double flash protocol". In these patients, all segments were evaluable after taking both scans into account. Nine segments (1.5 %) on 4 patients without "double flash protocol" remained unevaluable. Six of these 9 segments were small distal branches with little clinical relevance in the individual patients. The two radiologists demonstrated a good agreement regarding subjective image quality (ICC-coefficient of 0.82).

**Image noise and contrast-to-noise ratio measurements**

The mean CNR of all measured locations was 19.9 ± 4.6 (Figure 3). CNR was significantly lower in the distal LCX as compared to the proximal LCX ($p < 0.04$) and the LM ($p < 0.03$) as well as in the distal LAD compared to the LM ($p < 0.03$). In the RCA, however, differences of CNR between the proximal and distal vessel were not significant. Concerning the CNR in the proximal and distal segments of the different coronary arteries, no significant differences were obtained.
Table 1 shows the patients’ characteristics, radiation dose, and contrast application in 42 cardiac high-pitch CTAs of 34 patients. A second high-pitch CTA was applied in 8 patients (“double flash protocol”), and an additional delayed scan in 5 patients.

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Fig. 0: Images of excellent image quality using the "flash protocol". Prospective high pitch mode cardiac CTA (pitch 3.4, 65 ml at 7ml/s) of a 44 year-old female with atypical chest pain, an averaged heart rate of 64 bpm and BMI 24. Curved reformations of the right coronary artery (A), left main and circumflex artery (B), left main and left anterior descending artery (C) and volume rendering reformation (D) demonstrate excellent image quality. Effective dose was 0.8 mSv for the CTA alone, 1.1 mSv for the whole cardiac exam.

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**Fig. 0:** Coronary CNR measurements in 34 patients. Mean values and standard deviations (SD). LM: left main coronary artery, LAD: left anterior descending coronary artery, D1: proximal first diagonal branch, LCX: left circumflex coronary artery, OM1: first obtuse marginal branch, RCA: right coronary artery.

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Conclusion

- Prospectively ECG-triggered high-pitch mode coronary CTA is a feasible and promising technique.

- When applied in clinical routine, evaluation of the coronary arteries is possible at good to excellent image quality, with high CNR and low radiation exposure.

- The "double flash protocol" may be a promising technique for patients with heart rates >60 bpm or with occasional PVCs, who might otherwise not receive a diagnosis with a single acquisition in this mode.
References


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