Eur Radiol (2011) 21:205–212
DOI 10.1007/s00330-010-1907-3

VASCULAR-INTERVENTIONAL

High-pitch dual-source CT angiography of the aortic valve-aortic root complex without ECG-synchronization

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Received: 17 March 2010 / Revised: 14 June 2010 / Accepted: 19 July 2010 / Published online: 31 July 2010

Abstract
Purpose To compare image quality and radiation dose of high-pitch computed tomography angiography(CTA) of the aortic valve-aortic root complex with and without prospective ECG-gating compared to a retrospectively ECG-gated standard-pitch acquisition.
Materials and Methods 120 patients(mean age 68± 13 years) were examined using a 128-slice dual-source CT system using prospectively ECG-gated high-pitch (group A; n=40), non-ECG-gated high-pitch(group B; n= 40) or retrospectively ECG-gated standard-pitch(C; n=40) acquisition techniques. Image quality of the aortic root, valve and ascending aorta including the coronary ostia was assessed by two independent readers. Image noise was measured, radiation dose estimates were calculated.
Results Interobserver agreement was good(κ=0.64–0.78). Image quality was diagnostic in 38/40 patients(group A), 37/40(B) and 38/40(C) with no significant difference in number of patients with diagnostic image quality among all groups (p=0.56). Significantly more patients showed excellent image quality in group A compared to groups B and C(each, p<0.01). Average image noise was significantly different between all groups(p<0.05). Mean radiation dose estimates in groups A and B(each; 2.4±0.3 mSv) were significantly lower compared to group C(17.5±4.4 mSv; p<0.01).
Conclusion High-pitch dual-source CTA provides diagnostic image quality of the aortic valve-aortic root complex even without ECG-gating at 86% less radiation dose when compared to a standard-pitch ECG-gated acquisition.

Keywords Dual-source computed tomography · DSCT · High pitch · Radiation dose · Aortic valve

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Introduction

Accurate knowledge of the anatomy of the aortic valve-aortic root complex as well as precisely locating the coronary ostia is critical for a number of interventional and surgical cardiovascular procedures, including cannulation or catheterization of the coronary arteries, aortic graft repair or root replacement, and implantation of aortic valves using minimal invasive surgical or interventional techniques [1]. In addition, detailed visualization of the anatomy is mandatory for demonstrating the extent of aortic disease involving the aortic root, such as type A aortic dissection or annulo-aortic ectasia and aortic aneurysms.

When performing computed tomography angiography (CTA) of the structures of the aortic valve-aortic root complex (i.e. aortic valve, aortic root, ascending aorta and coronary ostia), the application of either retrospective or prospective ECG-gating is considered mandatory in order to avoid artifacts caused by cardiac motion [2]. In case of non-diagnostic image quality, retrospectively ECG-gated acquisitions allow for alternate data reconstructions out of any other time point of the cardiac cycle. However the downside of retrospectively ECG-gated acquisitions is a relatively high radiation dose exposure compared to prospectively ECG-gated acquisitions, which, however, only allow for data reconstructions out of a predefined time point of the cardiac cycle [3].

In ECG-gated CTA of the aortic valve-aortic root complex, a low helical pitch factor is usually required to ensure gapless volume coverage. However, decreasing the pitch factor leads to a proportional increase of radiation dose [4]. In single-source CT systems, the pitch factor is limited to a maximum of approximately 1.5 to provide gapless volume coverage. The recently introduced second generation dual-source CT (DSCT) system—owing to the geometry of the two detector elements—is equipped with a high-pitch data acquisition mode with pitch values of up to 3.4 [5]. By filling the gaps left behind by the first detector-system with data acquired by the second detector, this high-pitch mode reduces the duration of a CT data acquisition of the entire chest to below 1 s [6] and allows for CT angiographies of the thoracic aorta at radiation dose values around 1 mSv [7]. An additional feature of this CT system is its improved gantry rotation time of 0.28 s, which leads to a high temporal resolution of 75 ms for each acquired slice. Because of this fast volume coverage and high temporal resolution, it might be feasible to assess the aortic valve-aortic root complex in diagnostic image quality even without the application of ECG-gating. However, this has not been investigated so far.

The purpose of our study was to compare the image quality and radiation dose estimates of high-pitch dual-source CTA of the aortic valve-aortic root complex both with and without prospective ECG-gating to a retrospectively ECG-gated standard-pitch spiral data acquisition protocol.

Materials and methods

Study population

One hundred and twenty consecutive patients (age 68± 13 years [mean ± standard deviation], range 32–92; 24 female, 96 male) were included in this study. Indications for CTA of the thoracic aorta included postoperative follow-up after vascular surgery (*n*=33), follow-up of endovascular aortic aneurysm repair (*n*=29), evaluation of suspected aortic dissection (*n*=38), and preoperative evaluation prior to aortic surgery (*n*=20). All 120 patients (Table 1) were randomly assigned to three different groups without regard to indications or patient characteristics.

- *Group A (n=40): prospectively ECG-gated high-pitch dual-source CTA.*
- *Group B (n=40): non ECG-gated high-pitch dual-source CTA.*
- *Group C (n=40): retrospectively ECG-gated standard-pitch dual-source CTA.*

General exclusion criteria for CTA were renal insufficiency, defined as a serum creatinine level above 150 µmol/L, and known hypersensitivity to iodine-containing contrast agents. Patients with elevated or irregular heart rate (HR) were not excluded from this study. No additional premedication for HR control or vasodilatation was added to the patients' baseline medication prior to all examinations. IRB approval was obtained. Written informed consent was waived because all CTA studies were clinically indicated.

CT data acquisition and post-processing

All examinations were performed on a second-generation, 128-slice DSCT system (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany). In each patient, 100 mL of Iopromide (Ultravist 300, 300 mg/mL, Bayer Schering Pharma, Berlin, Germany) were injected at a flow rate of 5 mL/s followed by a 60 mL bolus of saline solution at the same flow rate. The amount of contrast agent was not tailored to the patients' body mass index (BMI). The tube voltage was kept constant at 120 kV in all examinations. Bolus tracking in the ascending aorta was performed with a signal attenuation threshold of 100 Hounsfield Units (HU). A cranio-caudal direction for CT data acquisition was chosen in all protocols. For detailed CT parameters see Table 2. All prospectively ECG-gated CT acquisitions in group A were timed to achieve data acquisition at 60% of the RR-interval at an indicated level 2 cm below the tracheal bifurcation. All retrospectively ECG-gated CT acquisitions in group C were performed using ECG-based tube current modulation for radiation dose reduction [8]: At mean heart rates below 60 bpm, full tube current was applied from 60 to 70%, at heart rates between 61 and 70 bpm from 50 to 80%, and at heart rates above 70 from 30 to 80% of the RR-interval.

All images were reconstructed to a slice thickness of 2 mm and a reconstruction increment of 1.6 mm, using a medium smooth tissue convolution kernel (B30). The HR

Table 1 Patient demographics

	Total	Group A	Group B	Group C
Number of patients	120	40	40	40
Mean Age [years] (range)	68±13 (32–92)	67±13 (41–92)	69±13 (32–85)	67±13 (41–83)
Gender (female/male)	24 / 96	6 / 34	9 / 31	9 / 31
Mean Heart Rate	70±16 (45–135)	71±17 (39–114)	71±20 (45–135)	70±15 (50–111)
Body Mass Index (kg/m2)	25.7±3.3 (18.0–35.6)	25.2±2.9 (19.5–30.8)	26.3±3.5 (19.9–32.4)	25.2±3.9 (18.0–35.6)

immediately prior to the start of CT acquisition of all patients was noted. All images were anonymised and transferred to an external workstation (Multi-Modality Workplace, Siemens Healthcare, Forchheim, Germany) for further image analysis.

Analysis of image quality

Image quality of the aortic valve cusps and commissures, the aortic annulus, the aortic root (defined as the portion ranging from the aortic annulus to the sino-tubular junction), the sinuses of Valsalva, the sino-tubular junction, the ascending aorta and the left and right coronary ostium (including the proximal 5 mm of the left and right coronary artery, Fig. 1) was assessed by two independent and blinded readers (R1, 5 years of experience in thoracic CTA image interpretation; R2, 3 years of experience) using a semi-quantitative three-point grading scale:

- Score 1, ***excellent image quality*** without any motion or stair step artifacts;
- Score 2, ***moderate image quality***, minor blurring but still diagnostic;
- Score 3, ***non-diagnostic image quality***, severe blurring or doubling of the outline of anatomical structures.

Imaging examples for all image quality scores are provided in Figs. 2 and 3. Disagreements in data analysis were resolved by selecting the worst image quality score from both readers.

Image noise

The image noise was determined as the standard deviation of the attenuation value in a region-of-interest (ROI) that was placed in the ascending aorta. These measurements were made in each data set by both readers.

Estimation of radiation dose

The effective radiation dose delivered at thoracic CTA was calculated applying a method proposed by the *European Working Group for Guidelines on Quality Criteria for CT* [9] using the dose-length-product (DLP) and a conversion coefficient (k) of 0.017 mSv / [mGy · cm] [10]. The DLP was

Table 2 Image quality scores

Location	Image quality score[a]	Group A	Group B	Group C
Aortic valve	1	98% (39/40)	58% (23/40)	75% (30/40)
	2	2% (1/40)	40% (16/40)	25% (10/40)
	3	0% (0/40)	2% (1/40)	0% (0/40)
Aortic root	1	93% (37/40)	75% (30/40)	73% (29/40)
	2	7% (3/40)	25% (10/40)	27% (11/40)
	3	0% (0/40)	0% (0/40)	0% (0/40)
Ascending aorta	1	95% (38/40)	95% (38/40)	95% (38/40)
	2	5% (2/40)	5% (2/40)	5% (2/40)
	3	0% (0/40)	0% (0/40)	0% (0/40)
Right coronary ostium	1	80% (32/40)	65% (26/40)	53% (21/40)
	2	18% (7/40)	28% (11/40)	45% (18/40)
	3	2% (1/40)	7% (3/40)	2% (1/40)
Left coronary ostium	1	93% (37/40)	90% (36/40)	70% (29/40)
	2	5% (2/40)	10% (4/40)	30% (11/40)
	3	2% (1/40)	0% (0/40)	0% (0/40)

[a] Image quality scores of the aortic valve, aortic root, ascending aorta and both coronary ostia. Disagreements in data analysis were resolved by selecting the worst image quality score from both readers. Score 1 = excellent image quality; Score 2 = moderate image quality; Score 3 = non-diagnostic image quality

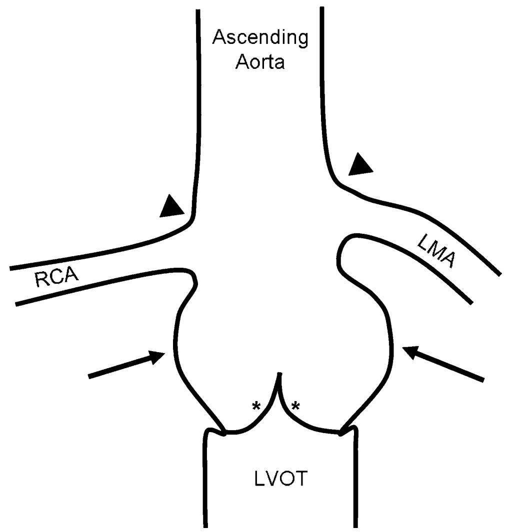

Fig. 1 Schematic presentation of the aortic valve-aortic root complex that was investigated in this study with three different CT protocols. *Asterisks* aortic cusps; *Arrows* Sinuses of Valsalva; *Arrowheads* Sinotubular junction; *LVOT* left ventricular outflow tract; *RCA* right coronary artery; *LMA* left main artery

obtained from an electronic protocol that summarized the individual radiation exposure parameters of each CT data acquisition.

Statistical analyses

All statistical analyses were performed using commercially available software (SPSS, release 17; Chicago, USA). Continuous variables were expressed as means ± standard deviation and categorical variables were expressed as frequencies or percentages.

Inter-observer agreement concerning the image quality of all assessed regions was evaluated using Cohen's Kappa statistics for all groups. A κ value greater than 0.81 was interpreted as excellent interobserver agreement, values of 0.61–0.80 were interpreted as good, values of 0.41–0.60 as moderate, values of 0.21–0.40 as fair and values less than 0.20 as poor agreement.

Statistical testing among the three groups was performed with a Kruskal–Wallis one-way analysis of variance. Pairwise comparison between groups was performed by using the Mann-Whitney paired-sample test. A p-value of <0.05 was considered statistically significant.

Results

Patient demographics

Patient characteristics are summarized in Table 1. No significant differences were found for age (p=0.61), gender

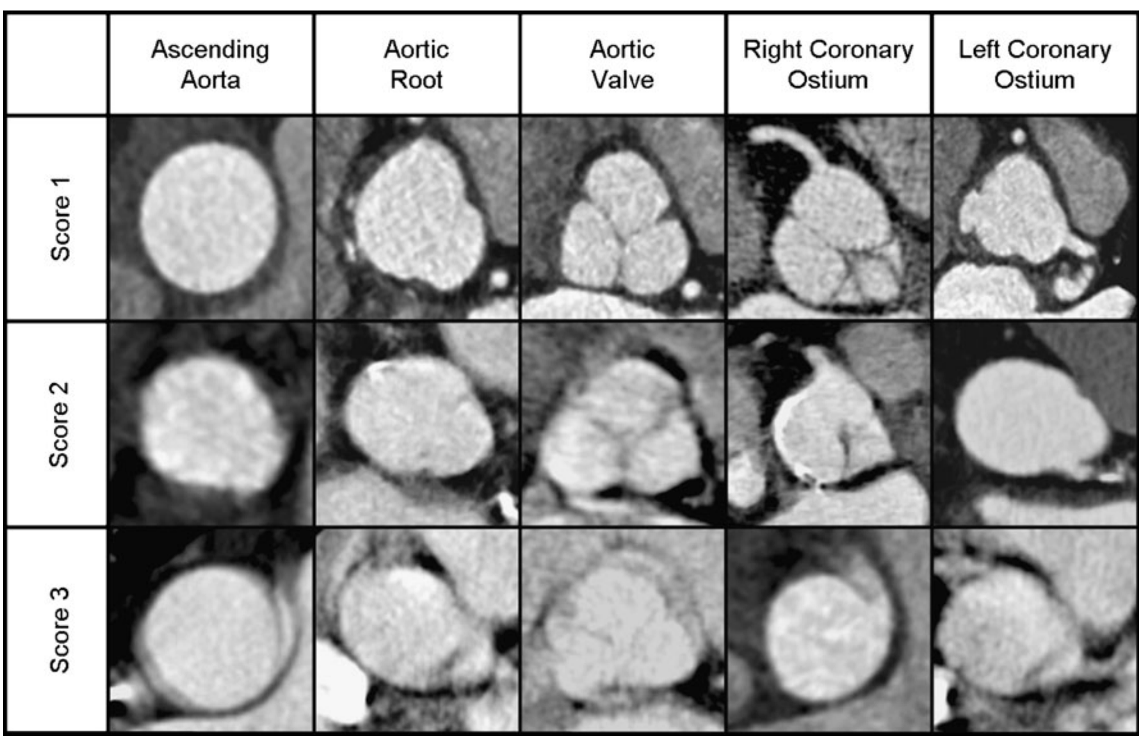

Fig. 2 CT examples for the assessment of image quality scores of the ascending aorta, the aortic root, the aortic valve as well as the right and left coronary ostium. *Score 1* = excellent image quality; *Score 2* = moderate image quality; *Score 3* = non-diagnostic image quality

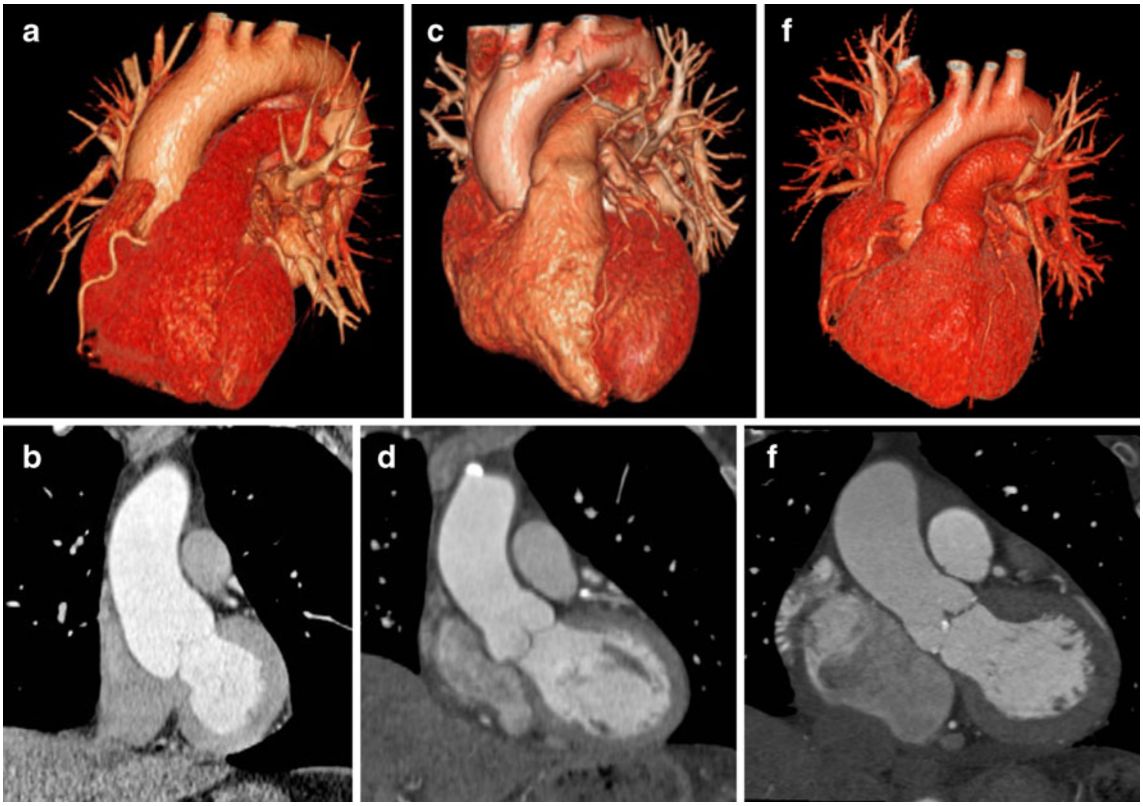

Fig. 3 Volume renderings and corresponding double-oblique coronal reformations of the aortic root in three representative patients undergoing ECG-gated high-pitch (**a**,**b**; *left*), non-gated high-pitch (**c**,**d**; *centre*), and retrospectively ECG-gated standard-pitch spiral CTA (**e**,**f**; *right*) of the chest. Note the higher image mottle, however, the diagnostic image quality of the data acquired in the high-pitch mode

(p=0.21), HR (p=0.97), and body mass index (p=0.29) comparing the three groups.

Imaging findings

Ectasia or aneurysm of the ascending aorta (n=19), type A aortic dissection (n=32), pulmonary artery aneurysm (n=2), replaced aortic valves (n=14), replaced aortic root after type A dissection (n=48) and normal structures of the aortic valve-aortic root complex (n=5) were the imaging findings.

Interobserver agreement

All interobserver agreements for image quality assessment of all structures of the aortic valve-aortic root complex, including the right and left coronary ostium were good (aortic valve: κ=0.67; aortic root; κ=0.72; left coronary ostium κ=0.65; right coronary ostium κ=0.64; ascending aorta κ=0.78). No systematic difference between the two observers' results was found during data analysis.

Image quality

Image quality results are summarized in Table 2. In group A, excellent image quality of all evaluated anatomical structures was present in 80% (32/40) of the patients while diagnostic image quality was found in 98% (39/40) of the patients.

One of the patients (2%) of group A was graded non-diagnostic due to motion artifacts of both coronary ostia. In group B, excellent image quality of all evaluated anatomical structures was present in 58% (23/40) of the patients while diagnostic image quality was found in 91% (36/40) of the patients. In group B, non-diagnostic image quality was found at the right coronary ostium in 7% (3/40) of the patients and at the aortic valve in 2% (1/40) of the patients. In group C, excellent image quality of all evaluated anatomical structures was present in 53% (21/40) of the patients while diagnostic image quality was found in 98% (39/40) of the patients. In group C, non-diagnostic image quality was present in the right coronary ostium in 2% (1/40) of the patients.

There was no significant difference in the number of patients with non-diagnostic image quality between all groups ($p=0.56$), while there were significantly more patients with excellent image quality in group A compared to groups B and C (each; $p>0.01$). No difference in numbers of patients showing excellent image quality was found between groups B and C ($p=0.88$). No stair step artifacts were observed in all groups and patients.

Image noise

The interobserver agreement for measuring the image noise in the ascending aorta ($\kappa=0.81$) was excellent. Thus, the mean of both observers' measurements was used for further statistical calculations. Mean image noise was 32.3±6.3 HU (range 21.7–48.4 HU) in group A, 36.8±8.9 HU (range 21.4–57.5 HU) in group B and 22.1±5.9 HU (range 13.1–36 HU) in group C. Significant differences were found between groups A and B ($p<0.05$), A and C ($p<0.001$) and B and C ($p<0.001$).

CTA acquisition parameters and estimation of radiation dose

CTA acquisition parameters and radiation dose estimates are summarized in Table 3. There was no significant difference in anatomical length covered by CTA among all groups ($p=0.31$). The duration of CT data acquisition was significantly shorter in groups A and B when compared to group C ($p<0.01$), while there was no significant difference in duration of CT data acquisition between groups A and B ($p=0.91$). The DLP and the effective radiation dose estimates were not statistically different between groups A and B (each; $p=0.73$), but were significantly lower in groups A and B when compared to group C (each; $p<0.01$).

Discussion

The purpose of this study was to evaluate image quality and radiation dose estimates of high-pitch CTA of the aortic valve-aortic root complex using a second generation 128-slice dual-source CT system by comparing prospectively ECG-gated high-pitch, non ECG-gated high-pitch and retrospectively ECG-gated standard-pitch acquisition techniques. We found a similar number of patients showing diagnostic image quality when comparing amongst all groups, however the radiation dose estimates were significantly lower when performing high-pitch CTA.

The recently introduced second generation of DSCT systems is able to perform high-pitch data acquisitions with pitch values of up to 3.4, allowing for an accelerated data acquisition of the entire chest in below 1 s [6] still ensuring gapless volume coverage. Additionally, the gantry rotation time had been reduced to 0.28 s, leading to a temporal resolution of 75 ms. Therefore, high-pitch CT enables the acquisition of all axial image planes that comprise the aortic valve-aortic root complex in 250–300 ms, corresponding to an anatomical length of 9.6 cm–11.6 cm in the z-axis, hence capturing the region of interest during a fraction of a single heart beat [11]. Compared to conventional prospectively ECG-gated CTA, stair-step motion artifacts may therefore be eliminated [3].

However, using the high-pitch acquisition mode, the axial source images are not acquired during the same time point of the cardiac cycle but are delayed "slice-by-slice" along with the cranio-caudal progression of the CT data acquisition towards the apex of the heart. Therefore the disadvantage of prospectively ECG-gated high-pitch CTA compared to retrospectively ECG-gated CTA is the limitation to a single cardiac phase. In case of non-diagnostic image quality, no additional phases of the cardiac cycle may be reconstructed. In patients with known or suspected coronary artery disease, this is of importance because additional evaluations of the coronary arteries prior to aortic root or valve operations may become necessary. Furthermore, the high-pitch mode does not permit a functional cardiac analysis of the entire cardiac cycle (i.e., for evaluation of ventricular function or valves).

Our study demonstrates that high-pitch CTA using a 128-slice DSCT system allows for the assessment of the aortic valve-aortic root complex with diagnostic image quality with or without ECG-gating even in patients with

Table 3 CTA acquisition parameters, image noise values and radiation dose estimates

	Group A	Group B	Group C
CT data acquisition time [sec] (range)	1.1±0.2 (0.8–1.3)	1.2±0.2 (0.8–1.4)	9.2±3.3 (5.5–14.9)
CT data acquisition length [mm] (range)	345.4±73.07 (318–371)	351.4±69.26 (309–379)	338±53 (274–394)
DLP[a] [mGy x cm] (range)	142±15 (123–171)	141±20 (112–171)	1030±256 (587–1503)
Image Noise Values [HU] (range)	32.3±6.3 (21.7–48.4)	36.8±8.9 (21.4–57.5)	22.1±5.9 (13.1–36)
Radiation dose estimate [mSv] (range)	2.4±0.3 (2.1–2.9)	2.4±0.3 (1.9–2.9)	17.5±4.4 (10.0–25.6)

[a] *DLP* Dose Length Product

heart rates >100 bpm. This might be an advantage in chest pain examinations in the emergency room, where the possibly time-consuming application of the ECG electrodes could be obviated. In chest pain examinations however, the additional assessment of the coronary arteries in diagnostic image quality is considered mandatory [12–14]. Two recent studies by Götti et al. have shown, that a depiction of the coronary arteries in diagnostic image quality using high-pitch DSCT is feasible only in patients with an average heart rate less than 63 beats / min and a heart rate variability of less than 1.2 beats / min [15]. Additionally, the patency of coronary bypass grafts can be assessed with decreasing image quality at high heart rates in high-pitch prospectively ECG-gated thoracic 128-slice DSCT angiography at a low radiation dose [16]. For chest pain assessment, the application of a triple-phase contrast injection protocol in combination with prospectively ECG-gated high-pitch DSCT timed at 50–60% of the cardiac cycle has also been investigated recently [17].

Besides achieving diagnostic image quality of the aortic root in high-pitch CTA, we found that this mode is associated with a low mean radiation dose exposure of 2.4 mSv for thoracic CTA while maintaining the benefit of high spatial and temporal resolution, which is mandatory for the visualization of the aortic root, valve, the ascending aorta and the coronary ostia. By reducing the acquisition of overlapping projection data, the high-pitch mode leads to substantially lower radiation dose values than those commonly obtained in standard-pitch CTA of the thoracic aorta, which have been described to range from about 5.4 mSV [18] to 18.6 mSv [19]. Furthermore, radiation exposure is significantly lower compared to single-source 64-slice CT coronary angiography and acute chest pain CT protocols with reported values of up to 21 mSv [20–22]. In our study, we have found higher image noise values when using the high-pitch mode compared to the standard pitch mode, however a reduction of image noise in high-pitch mode has been observed when applying prospective ECG-gating.

Limitations

Our study has some limitations. We used a qualitative image quality scoring system that may be influenced by a subjectivity bias. On the other hand, our image quality kappa value of 0.68 corresponds to a good inter-observer agreement. Moreover, we have used retrospective ECG-gating in protocol C instead of prospective ECG-gating (i.e., step-and-shoot technique). This is a limitation because recently, prospective ECG-gating has replaced former retrospectively ECG-gated protocols for the standard CT evaluation of the aortic root—aortic valve complex.

Conclusion

High-pitch dual-source CTA of the chest—either with or without prospective ECG-gating—provides a diagnostic image quality of the aortic valve-aortic complex, along with the coronary ostia that is similar to that of a retrospectively ECG-gated standard-pitch spiral data acquisition mode, but is associated with a 86% lower radiation dose.

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