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High-pitch prospective ECG-triggered helical coronary computed tomography angiography in clinical practice: image quality and radiation dose

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Abstract High-pitch prospective ECG-triggered helical (PTH) protocols for coronary computed tomography angiography (CCTA) have demonstrated adequate image quality (IQ) in small-scaled studies and highly selected patients. Clinical applicability in a general clinical population is uncertain. This study evaluated the implementation of a PTH protocol in a routine clinical cohort, focusing on IQ and radiation dose. The local scientific board approved the retrospective analysis and all patients signed an informed consent statement for usage of their data. In consecutive patients suspected of coronary artery disease CCTA was performed using a dual source 128-slice scanner. All patients with a regular heart rate <65 bpm underwent a PTH CCTA. IQ for each coronary segment was graded (1 = absence of artifacts to 4 = non-evaluable). In 664 (80.4 %) of 826 included patients [mean age ± standard deviation (SD) 57 ± 11, 65 % female, mean body mass index (BMI) ± SD 27 ± 9 kg m^{-2}] PTH CCTA was acquired whereas in 162 (19.6 %) a non-PTH sequence was used. Reasons for not performing a PTH protocol were persistent high heart rate (41.6 %) or heart rate irregularity (58.4 %). Mean ± SD heart rates for PTH and non-PTH CCTA were 55 ± 5 and 65 ± 9 bpm, respectively, $p < 0.001$. In the PTH group 92 % of the segments were of diagnostic quality (score 1–3), versus 87 % in the non-PTH group ($p = 0.055$). Per patient, mean IQ score was 1.19 and 1.21 respectively (lower is better; $p = 0.012$). Effective dose (including topogram, test bolus, and coronary calcium score), as calculated with a conversion factor of 0.014 mSv mGy^{-1} cm^{-1} was 1.6 ± 0.6 and 4.7 ± 2.6 mSv for the PTH and the non-PTH group respectively, ($p < 0.001$). Performing high-pitch PTH sequences on a routine basis is feasible in the majority of patients with high IQ and significant reduction in radiation dose.

Keywords Cardiac computed tomography · CCTA · Coronary computed tomography angiography · High-pitch · Flash · Image quality · Radiation dose

Introduction

Cardiac computed tomography (CT) imaging has evolved rapidly in the past decade. In the evaluation of coronary artery disease (CAD) there is evidence that coronary computed tomography angiography (CCTA) is a robust technique to evaluate the presence or absence of CAD, particularly in patients with chest pain and a low to intermediate cardiovascular risk profile [1–3]. Broad endorsement of CCTA is advocated by national societies as a CAD rule out technique resulting in an exponential growth of the number of performed CCTA studies worldwide [4–6]. Notwithstanding its value in clinical practice, radiation exposure of CCTA is of concern. Next to appropriate

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patient selection, much effort has been invested to employ strategies to reduce radiation dose. Among these are tube current modulation throughout the cardiac cycle [7], prospective gating sequences [8, 9], tube voltage reduction in non-obese patients [10], and utilization of iterative reconstruction algorithms to optimize IQ [11, 12]. Although these measures have proven to be successful, registries have revealed that reported mean effective dose remains as high as 12 mSv [13]. Therefore, continuing efforts are warranted to further limit radiation dose, especially in daily clinical practice. Recent advances in CT technology have demonstrated the feasibility to conduct sub-millisievert CCTA protocols using prospectively ECG-triggered helical (PTH) acquisition without appreciably compromising IQ [14, 15]. These studies, however, have been conducted at highly specialized imaging centers on small number of carefully selected patients in terms of body weight and sufficiently low heart rate. The applicability of such advanced protocols in routine clinical practice is currently unclear. The present study was conducted to evaluate the feasibility of PTH CCTA imaging in clinical practice in a large general population of patients, suspected of CAD, who were referred to CCTA.

Materials and methods

Patients

The study was conducted at the Medical Center Alkmaar (MCA), a community and teaching hospital in The Netherlands. The local scientific board approved the retrospective analysis and all patients signed an informed consent statement for usage of their data. From December 2011 until January 2013, consecutive patients with a clinical indication for CCTA without a history of CAD, predominantly on an outpatient basis, were included. Patients were retrospectively evaluated. Pregnant and lactating patients were not eligible for CCTA and patients in atrial fibrillation or with an eGFR <30 ml min^{-1} were excluded. In clinical patients an acute coronary syndrome had to be excluded prior to the exam. Patient characteristics, a full cardiovascular risk profile, and a Duke Clinical Score for prediction of significant CAD in patients with chest pain were recorded [16, 17].

CCTA acquisition

CCTA was performed after at least 4 h of fasting. Medication was continued, with the exception of metformin (in case of an estimated glomerular filtration rate (eGFR) < 60 ml min^{-1}) and sildenafil. To prevent contrast induced nephropathy, patients with an eGFR between 30 and 60 ml min^{-1} received volume expansive therapy. In cases of a heart rate >60 bpm 100 mg atenolol was given orally 1 h prior to CCTA. If heart rate during inspiration remained >65 bpm, up to 30 mg metoprolol was administered intravenously in incremental doses of 5 mg. Two doses of 0.4 mg nitroglycerine were given sublingually.

In all patients with a regular heart rate <65 bpm a high-pitch PTH CCTA with a narrow exposure window was performed [18, 19]. In patients with a heart rate >65 bpm or irregularity an alternative optimal CCTA acquisition protocol (non-PTH) was chosen on an individual basis according to heart rate and/or rhythm. Body mass index (BMI) was not used for protocol selection. Alternative protocols varied from a prospective ECG-triggered axial (PTA) with narrow (60–76 or 31–56 %), or wide window (31–76 %), to a retrospective ECG-gated helical (RGH) scan protocol with tube current modulation.

Coronary calcium scoring (CCS) and CCTA were acquired with a Somatom Definition Flash CT scanner (Siemens® Medical Systems, Erlangen, Germany). All patients underwent CCS and an Agatston score was calculated [20]. CCS was obtained using a tube voltage of 120 kV, with 3 mm slice thickness, in high-pitch (3.4) PTH or PTA mode in best diastolic phase, which was automatically determined by the software algorithm, with automatic tube current selection. The dataset was filtered using a B35f medium reconstruction kernel. Areas with Hounsfield units >130 were considered to contain calcium, and were manually assigned to coronary arteries.

A 10–15 ml test bolus containing non-ionic low-osmolar iodinated radiocontrast (Ultravist 370®, Bayer, Germany) was injected, followed by a flush of 40 ml saline, both at a flow rate of 6 ml s^{-1}. The time point of maximal contrast enhancement in the ascending aorta at the level of the pulmonary trunk was recorded and an additional delay of 5 s was added to define the optimal time point for acquisition of coronary artery data. A dual head injector then injected 48–75 ml contrast depending on kV used for the PTH acquisition and 75 ml in case of PTA or RGH acquisition, followed by 45 ml 30/70 % contrast/saline solution at a flow rate of 6 ml s^{-1}. The tube voltage (80, 100, or 120 kV) and tube current were determined automatically by the scanning system based on body habitus [21]. The X-ray beam collimation was 64 × 0.6 mm. Both detectors acquired with a flying focal spot, resulting in 128 × 0.6 mm acquired slices per detector-tube assembly with gantry rotation of 280 ms resulting in a temporal resolution of 75 ms. The images were reconstructed with a slice thickness of 0.6 mm with increment of 0.3 mm for PTH acquisitions and increment of 0.4 mm for PTA acquisitions. A B26f (medium) kernel plus an Advanced Smoothing Algorithm (ASA) image filter was primarily used. When appropriate, an I46f kernel (sharp) was used to

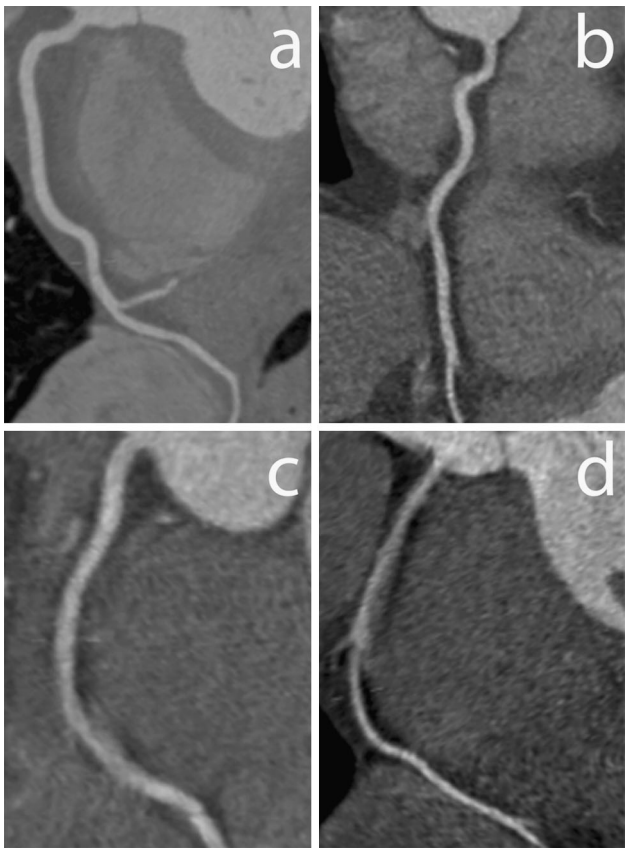

Fig. 1 Examples of representative PTH scans (*curved* maximum intensity projections; MIPs), demonstrating the four-point imaging quality scale (**a** absence of any artifacts; **b** minor artifacts, but fully evaluable; **c** severe artifacts (mid-RCA) but evaluable concerning the presence of stenosis, **d** non-evaluable (severe artifacts proximal and mid RCA)

decrease blooming artifacts, in conjunction with an iterative reconstruction algorithm and ASA. The iterative reconstruction, performed by Siemens' Sinogram Affirmed Iterative Reconstruction (SAFIRE) software, additionally led to noise reduction.

CCTA interpretation

Two physicians, both accredited by the Society of Computed Cardiovascular Tomography (SCCT) read all scans. Each coronary segment was scored for the presence of plaques. Structures >1 mm^2 within and/or adjacent to the coronary artery lumen, which could be clearly distinguished from the vessel lumen, were determined as a coronary plaque [22].

Two independent observers (KB and SR with respectively four and 3 years of experience in cardiac imaging), blinded to clinical data evaluated IQ. Discrepancies were resolved by consensus. Both CAD and IQ were evaluated on a patient, vessel, and segment basis using the 18-segment model of the SCCT [23]. A four-point scale for IQ was used (1 = absence of any artifacts, 2 = slight artifacts, but fully evaluable, 3 = artifacts, but evaluable concerning the presence of stenosis, 4 = non-evaluable) [15]. Figure 1 demonstrates examples of each category. Mean image score was calculated by dividing the sum of the segment scores by the total number of present segments.

Estimation of radiation dose

The effective dose of the scan was estimated by multiplying the dose length product (DLP), provided by the Siemens software, with 0.014 mSv × (mGy × cm)$^{-1}$ as described previously [13]. The Siemens software calculates separate DLPs for each acquired topogram, CCS, test bolus sequence, and CCTA. The sum was used to estimate the effective dose for each patient.

Statistics

Statistical Package for Social Sciences version 21 (IBM®, SPSS, Chicago, USA) was used for descriptive statistics. Between groups, differences in means were tested for significance with two sided, two sample t tests or Mann–Whitney U tests, when appropriate. $p \leq 0.05$ was considered significant. Pearson Chi square test was used for dichotomous variables.

Results

Baseline characteristics

A total of 840 scans were performed in 826 consecutive patients. In 14 of these patients (1.7 %) CCTA was repeated because the initial scans were considered non-diagnostic for various reasons. In all patient based analyses, the 14 replaced CCTAs were excluded. In the segment based analyses all scans were used. Baseline characteristics are shown in Table 1. There were more females in the non-PTH group as compared to the PTH group ($p = 0.004$). Although BMI did not differ between groups ($p = 0.087$), patients in the non-PTH group had a higher body weight than those in the PTH group ($p = 0.015$). In addition, diabetes ($p < 0.001$) and hypertension ($p = 0.029$) were more prevalent in the non-PTH group, as was beta-blocker usage ($p = 0.002$).

CT-data

The CT-data are shown in Table 2. A total of 664 out of 826 (80.4 %) scans was performed in PTH mode, of which

Table 1 Patient characteristics

	Entire group (n = 826)	PTH group (n = 664)	Non-PTH group (n = 162)	*p* value
Age (years, mean ± SD)	57 ± 11	57 ± 11	57 ± 12	0.526
Female (%)	540 (65)	418 (63)	122 (75)	0.004
Length (cm, mean ± SD)	172 ± 10	172 ± 10	170 ± 9	0.041
Weight (kg, mean ± SD)	79 ± 15	78 ± 15	82 ± 16	0.015
BMI (kg m^{-2}, mean ± SD)	27 ± 9	27 ± 9	28 ± 5	0.087
Patients >100 kg (%)	74 (9)	51 (8)	23 (14)	0.014
Cardiovascular risk factors (%)				
Diabetes	55 (7)	33 (5)	30 (19)	<0.001
Smoking	166 (20)	132 (20)	34 (21)	0.827
Family history of premature CAD	428 (52)	353 (53)	75 (46)	0.231
Hypercholesterolemia	157 (19)	130 (20)	27 (17)	0.623
Hypertension	177 (21)	130 (20)	47 (29)	0.029
Duke score (mean ± SD)	27 ± 21	27 ± 21	26 ± 22	0.772
ECG abnormalities (%)	95 (12)	70 (11)	25 (15)	0.099
Relevant prior medication (%)				
Aspirin	279 (34)	222 (33)	57 (35)	0.713
Beta-blockade	350 (42)	263 (40)	87 (54)	0.002
Statin	286 (35)	227 (34)	59 (36)	0.647
ACE-inhibitor	195 (24)	150 (23)	45 (28)	0.182
Coronary artery disease				
Calcium score (mean ± SD)	85 ± 320	87 ± 338	78 ± 228	0.773
CAD (%)	392 (47)	318 (48)	74 (46)	0.600
Invasive coronary angiography (%)	80 (10) 10	53 (8)	17 (10)	0.403

14 PTH scans were performed with a heart rate of >65 bpm, due to sudden increase of heart rate during the scan. 154 out of 826 scans (18.6 %) were performed in PTA mode and 8 out of 826 (1.0 %) in RGH mode. Eighty-eight out of 154 PTA scans (57.1 %) were performed with a narrow window and 66 out of 154 PTA scans (42.9 %) were performed using a wide window acquisition protocol. In 64 (41.6 %) patients the reason for performing a non-PTH acquisition was a heart rate above 65 bpm, the others (n = 90) due to insufficient heart rate stability. Of the 14 repeated scans, 13 were initially performed in PTH mode and one in PTA mode. Seven scans were repeated in PTA mode, six again in PTH mode, and one in RGH mode. Four scans (two PTH, one PTA and another RGH) again produced at least one non-diagnostic segment. Reasons for a non-diagnostic scan were mainly suboptimal triggering due heart rate variability, contrast timing inaccuracies, and stair-step artifacts. Oral beta-blockers were administered more frequently to patients in the non-PTH group as compared to the PTH group ($p < 0.001$), in order to decrease the heart rate during CT acquisition. Doses of additionally administered beta-blockers were also higher in the non-PTH group ($p < 0.001$). Nevertheless, in this group heart rates remained significantly higher during the scan (Table 2, $p < 0.001$).

Detection of coronary artery disease

In total 436 (52.8 %) patients displayed a calcium score of zero. Of all patients 392 (47.5 %) were diagnosed with CAD (Table 1). Eighty (9.7 %) patients subsequently underwent invasive coronary angiography. In the group of patients with at least one non-evaluable segment (n = 77), 33 (42.9 %) were diagnosed with CAD on the basis of the evaluable segments. Forty patients (51.9 %) were considered to have no CAD based on the calcium score and evaluable segments.

Radiation dose

The effective radiation dose estimates are listed in Table 2 and subdivided in the dose used for the topogram, CCS, test bolus, and CCTA respectively. The mean overall DLP was 157 ± 126 mGy cm^{-1} with an estimated mean effective radiation dose of 2.2 ± 1.8 mSv. Patients in the PTH group received a total dose of 1.6 ± 0.6 mSv on average, whereas patients in the non-PTH group received 4.7 ± 2.6 mSv ($p < 0.001$). There was a significant difference in mean radiation dose between the narrow and the wide PTA protocol (4.2 ± 2.5 vs. 5.3 ± 2.6 mSv, $p = 0.005$). The eight RGH scans showed an average radiation dose of 6.1 ± 1.9 mSv.

Table 2 CCTA parameters per patient

	Entire group (n = 826)	PTH group (n = 664)	Non-PTH group (n = 162)	*p* value
Pre medication (%)				
Oral beta-blockade	520 (63)	388 (58)	132 (81)	<0.001
Intravenous beta-blockade	376 (46)	266 (40)	110 (68)	<0.001
Nitroglycerine s.l.	809 (98)	653 (98)	156 (96)	0.100
Heart rate during scan (bpm, mean ± SD)	57 ± 7	55 ± 5	65 ± 9	<0.001
Effective dose (mSv, mean ± SD)				
Topogram	0.11 ± 0.04	0.12 ± 0.04	0.10 ± 0.05	0.056
Coronary calcium score	0.34 ± 0.21	0.32 ± 0.13	0.40 ± 0.40	0.158
Test bolus	0.17 ± 0.17	0.17 ± 0.10	0.18 ± 0.32	0.206
CCTA	1.35 ± 1.58	0.87 ± 0.56	3.33 ± 2.58	<0.001
Total	2.20 ± 1.77	1.59 ± 0.62	4.74 ± 2.56	<0.001

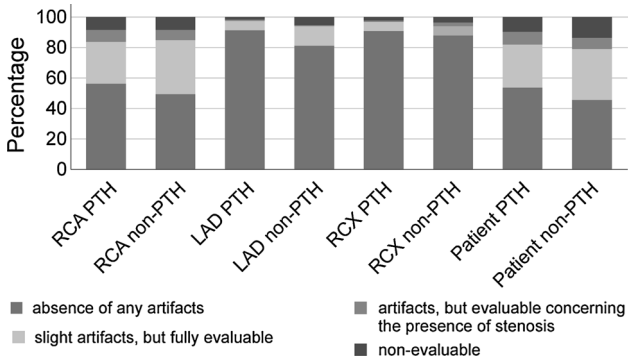

Fig. 2 Image quality per coronary vessel on high-pitch PTH scans versus non-PTH scans (as percentage of total amount of analyzed coronary vessels of the specified type, on all 840 performed scans)

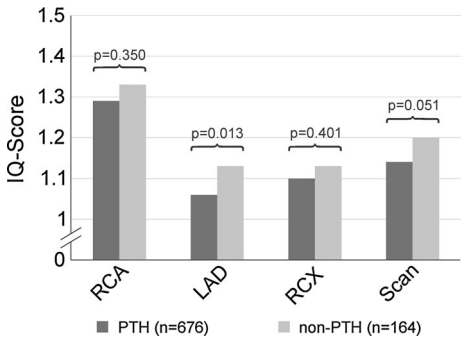

Fig. 3 Mean image quality score (IQ score) per vessel and per performed scan (n = 840)

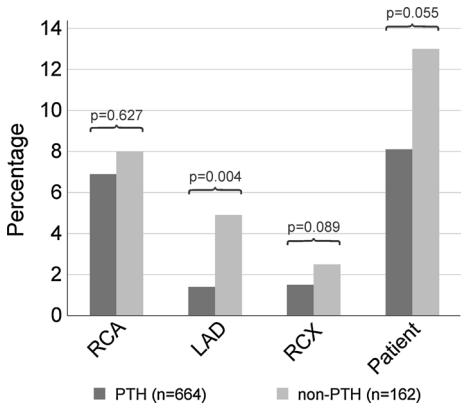

Fig. 4 Percentage of non-diagnostic scans (at least 1 non-evaluable segment) in the PTH versus the non-PTH group per coronary vessel and per patient (3 vessels combined, n = 826)

Image quality per segment

In total 12,652 coronary segments were present in a total of 840 scans (including the 14 replaced scans), of which 868 (6.9 %) were considered too small for analysis (<1 mm). An optimal IQ score was assigned to 10,577 (83.6 %) segments, whereas 807 (6.4 %) showed minor and 163 (1.3 %) severe artifacts. The remaining 237 (1.9 %) segments were deemed non-evaluable. Differences between the PTH group and the non-PTH group are depicted in Figs. 2 and 3. Non-evaluable segments were predominantly (44 %), but not exclusively, located in the RCA. In total 87 (10.4 %) out of 840 scans demonstrated at least one non-evaluable segment, 65 (9.6 % of 676 scans) of which were scanned by PTH CCTA and 22 (13.4 % of 164 scans) by non-PTH CCTA. In 44 out of 87 (50.6 %) of these scans only one segment was non-diagnostic.

Image Quality per vessel and patient

The overall mean IQ score was 1.12 ± 0.27 in the PTH group versus 1.19 ± 0.30 in the non-PTH group, ($p = 0.012$). In total 75 (9.1 %) out of 826 patients demonstrated at least 1 non-evaluable segment, of which 54 (8.1 % of 664 scans) were in the PTH group and 21 (13.0 % of 162 scans) were in the non-PTH group

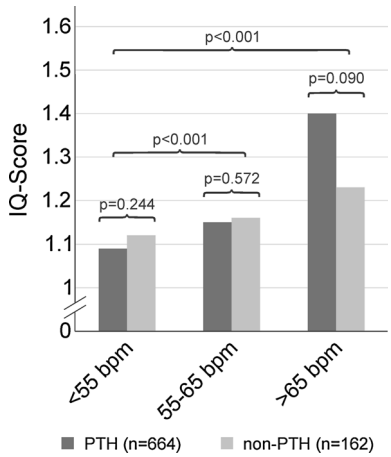

Fig. 5 Mean image quality score (IQ score) of the PTH group versus the non-PTH group stratified by heart rate range (n = 826)

($p = 0.055$). The data for each coronary artery are depicted in Fig. 4. In the LAD 1.4 % of the patients scanned with a PTH protocol versus 4.9 % scanned with a non-PTH protocol produced at least one non-diagnostic segment ($p = 0.004$).

Body weight and heart rate

Of the patients weighing over 100 kilograms (kg; n = 74), six out of 51 demonstrated at least one non-diagnostic segment in the PTH group (11.8 %) versus two out of 23 in the non-PTH group (8.7 %, $p = 0.880$). Mean IQ score was significantly better for patients weighing less than 100 kg in the PTH group compared to patients weighing over 100 kg, (1.12 ± 0.27 vs 1.17 ± 0.31, $p = 0.014$). In the non-PTH group this difference was not present (1.19 ± 0.32 vs 1.14 ± 0.22, $p = 0.266$).

In a group of patients with a heart rate of <55 bpm, the mean IQ score was significantly better (1.08 ± 0.2 vs. 1.15 ± 0.3, $p < 0.001$) compared to a group of patients with a heart rate between 55 and 65 bpm, or an group of patients with a heart rate of >65 bpm (1.08 ± 0.2 vs. 1.26 ± 0.41, $p < 0.001$). The latter is more pronounced in the PTH versus the non-PTH scans (Fig. 5).

Discussion

Few clinical trials have evaluated IQ and radiation dose of high-pitch PTH CCTAs in a large general population. This study, describing a consecutive series of 826 patients, illustrates the feasibility of performing a PTH CCTA in the majority of a large population of patients (80.4 %), demonstrating high IQ and a low radiation dose of 1.6 ± 0.6 mSv.

PTH sequences enable data acquisition within a single heartbeat by continuous and fast movement of the table and dual source acquisition. The technique prevents misalignment artifacts or stair-step artifacts known to prospective sequences with a lower pitch. The second advantage is a reduction in radiation dose since the acquisition is completed in a single sweep; redundant radiation dose as the detector enters and leaves the 180° arc, required for image reconstruction, is prevented [15].

Patient selection

Optimal selection of patients for PTH acquisitions is extremely important and definitive selection criteria remain subject for debate. Proof of concept studies demonstrated feasibility in patients with a regular heart rate <60 bpm and a body weight <100 kg (or BMI <30 kg m^{-2}) [14, 15, 24]. Alkadhi et al. [25] even showed comparable IQ and diagnostic interpretability in a randomized trial between a PTH protocol and a PTA protocol in patients with a regular heart rate <70 bpm. In this study only 14 patients had a heart rate >65 bpm in the PTH group, the mean overall IQ in these patients was significantly worse (IQ score 1.40 vs. 1.15, $p < 0.001$). Neefjes et al. [26] described a randomized trial comparing several scanning techniques on IQ and radiation dose. They conclude that PTH is only for the selected few with a heart rate <55 bpm, because of degrading IQ above this heart rate. The present study is in line with the observations of Neefjes et al. since an improved IQ was detected in patients with a heart rate <55 (Fig. 5). However, significant differences between the PTH and the non-PTH group were not observed at any heart rate. Interestingly, two recent studies demonstrated high quality images in PTH performed in the 20–30 % R–R phase in patients with higher heart rates, with equivalent IQ compared to PTH in diastole in patients with lower heart rates [27, 28].

Body weight is a second determinant of IQ. In the present study, selection criteria for PTH did not include BMI. The mean BMI in this study was 27 kg m^{-2} overall, with 76 (9.2 %) patients weighing >100 kg and 463 (56.1 %) had a BMI >25 kg m^{-2}. Body weight differed significantly between both groups whereas BMI did not. In patients scanned with a PTH protocol a better mean IQ was observed in those weighing <100 kg. In patients with a body weight of >100 kg, still 90 % of the scans were of diagnostic image quality.

This study confirms the possibility of performing a PTH in the majority of patients (80.5 %) when applying a proper, 1-h, preparation protocol and a 65 bpm cut off. We showed a diagnostic scan in 92 % of patients scanned with a PTH protocol.

Image quality

Naturally the comparable IQ of PTH and non-PTH really implies an underestimation of the IQ in the non-PTH group, since heart rate and body weight differed between both groups. The high percentage of diagnostic scans however demonstrates the usefulness of the technique. In total 2 % of all segments were considered non-evaluable in 87 (10.4 %) scans and 77 (9.2 %) patients. However in 51 % of the non-diagnostic scans only one segment was judged non-evaluable. Compared to the primary studies by Achenbach et al. [14, 15], where in a very selected population hardly any non-diagnostic segment is found, our results actually reflect daily clinical practice in community and teaching hospitals. Other studies by Alkadhi et al. and Srichai describe similar amounts of non-diagnostic segments using PTH protocols [25, 29].

Radiation dose

Worldwide radiation exposure to low levels of ionizing radiation from medical imaging procedures increases, mainly by the use of computed tomography [30] and the concern for radiation induced malignancies is growing [31, 32]. Large epidemiological studies have estimated that lifetime excess relative risk of developing cancer for radiation levels <50 mSv could be up to 2 % [33–36]. Women especially are at risk, since the organ dose of the female breast can go up to 50–80 mSv [31], using standard helical protocols. Since the cardiac CT scans are usually performed in low to intermediate risk patients, it is generally felt that radiation dose is large issue. Lately though detection of coronary artery disease in women has been of particular interest, since cardiovascular disease has become the number one cause of mortality, mortality rates perhaps seem to be climbing [37] and diagnostic procedures are known to be less accurate [38]. In the present study 65 % of the patients were female, which is considerably more than the usual cardiac population, which may illustrate an increasing interest in improving the (early) detection of CAD in this group.

The actual radiation dose resulting from CCTA has declined drastically in the past decades, from 15 to 20 mSv reported in the late nineties to recent studies reporting mean effective radiation doses of 0.7–0.9 mSv in selected patients weighing <100 kg using PTH protocols [14]. We report a higher mean radiation dose of 1.6 mSv in our PTH group. This value includes the CCS and the radiation dose of the test bolus acquisition as well as the topogram. The mean effective radiation dose for the CCTA alone was 0.87 ± 0.56 mSv. The differences in radiation dose between the both groups with respect to the CCS and the test bolus can be explained by the higher body weight of the patients in the non-PTH group.

As in most publications, the conversion factor (k-factor) that was used for the conversion of the DLP to the effective dose in mSv was 0.014 mSv mGy^{-1} cm^{-1} in the present study, which favors the comparability with previous publications on the subject. Based on the adjusted tissue weighting factors in ICRP publication 103 (2007), the k-factor and hence, the effective dose, are likely to be higher for CCTAs [39]. A more appropriate k-factor of 0.028 mSv mGy^{-1} cm^{-1} has been determined by the group of Gosling et al. [40], and should be used for comparison of radiation doses with other imaging modalities.

Performing CCS is subject of debate. The large multicenter CONFIRM study data did not demonstrate additional prognostic value of performing CCS on top of CCTA but still it is widely performed [41]. Future protocols could perhaps be done without performing CCS hereby reducing radiation dose even further. Furthermore, recent studies have been published describing the possibility to obtain a CCS from CTA images providing an option to replace the traditional CCS without increasing radiation [42, 43].

Study limitations

Although our data successfully demonstrated the ability of high-pitch PTH protocols to produce CCTA scans with diagnostic IQ in approximately 90 % of the scans and reduce effective radiation dose by 65 % compared to a non-PTH sequence, our study has several limitations. First, patients were non-randomized as protocol selection was performed on a per patient basis only by looking at heart rate and rhythm. Naturally, patients with a persistent higher heart rate after beta blockade and/or arrhythmia were scanned using a PTA or even a RGH protocol. Furthermore, assessment of IQ remains subjective and effective radiation doses were estimated and not measured. Also we did not study diagnostic accuracy concerning the detection of obstructive CAD by means of CCTA, since no systematic invasive coronary angiography was performed in our clinical patient cohort. However, several recent studies demonstrated the diagnostic strength of PTH scanning protocols that are generally believed to be comparable with other scanning sequences such as non-PTH protocols [18, 24, 25].

In conclusion, performing high-pitch PTH scans on a routine basis is feasible in the majority of patients with high IQ and significant reduction in radiation dose.

Conflict of interest None.

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