Step-and-Shoot: A New Low Radiation Coronary Computed Tomography Angiography Technology: Our Initial Experience with 125 Consecutive Asymptomatic Patients

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ABSTRACT: **Background:** Coronary CT angiography is an accurate imaging modality; however, its main drawback is the radiation dose. A new technology, the "step and shoot," which reduces the radiation up to one-eighth, is now available.

Objectives: To assess our initial experience using the "step-and-shoot" technology for various vascular pathologies.

Methods: During a 10 month period 125 consecutive asymptomatic patients (111 men and 14 women aged 25–82, average age 54.9 years) with various clinical indications that were appropriate for step-and-shoot CCTA (regular heart rate < 65 beats/minute and body weight < 115 kg) were scanned with a 64-slice multidetector computed tomography Brilliance scanner (Philips, USA). The preparation protocol for the scan was the same as for regular coronary CTA. All examinations were interpreted by at least one experienced radiologist and one experienced interventional cardiologist. The quality of the examinations was graded from 1 (excellent imaging quality of all coronary segments) to 4 (poor quality, not diagnostic). There were 99 patients without a history of coronary intervention, 13 after coronary stent deployment (19 stents) and 3 after coronary artery bypass graft.

Results: Coronary interpretation was obtained in 122 examinations (97.6%). The imaging quality obtained was as follows: 103 patients scored 1 (82.4%), 15 scored 2 (12%), 4 scored 3 (3.2%) and 3 scored 4 (2.4%). The grades were unrelated to cardiac history or type of previous examinations. Poor image quality occurred because of sudden heart rate acceleration during the scan (one patient), movement and respiration (one patient), and arrhythmia and poor scan timing (in one). Two patients were referred to percutaneous coronary intervention based on the CCTA findings, which correlated perfectly.

Conclusions: Step-and-shoot CCTA is a reliable technique and CCTA algorithm comparable to regular CCTA. This technique requires the lowest radiation dose, as compared to other coronary imaging modalities, that can be used for all CCTA indications based on the inclusion criteria of low (> 65 bpm) and stable heart rate.

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KEY WORDS: computed tomography, coronary artery, step and shoot, low dose radiation, angiography

Cardiac imaging with 64-slice multidetector computed tomography is a non-invasive diagnostic tool with well-established data confirming its accuracy in various clinical indications in the cardiac vasculature [1-5]. However, radiation exposure is a critical issue that limits its use. Reducing the radiation dose is possible by various dose-modulation techniques (mAs, Kv, collimation and pitch), limited field of view, new techniques such as dual-source computed tomography angiography, and prospectively gated algorithms like "step-and-shoot" where the acquisition is limited to only a small part of the cardiac cycle. These result in a 70–90% reduction almost without compromise in the quality of the diagnostic image [6-19].

The aim of this study was to evaluate the use of the step-and-shoot sequence in 125 consecutive asymptomatic patients with various coronary findings, including stents and coronary artery bypass graft.

PATIENTS AND METHODS

During a 10 month period (May 2008 to February 2009), a retrospective study was undertaken to evaluate the accuracy of assessing coronary CTA using the step-and-shoot algorithm. The study group consisted of 125 consecutive patients (111 men and 14 women; mean age 54.9 years, age range 25–82) who were suitable for the S&S protocol and underwent CT of the coronary arteries at the same imaging center.

CCTA = coronary computed tomography angiography
S&S = step-and-shoot

All participants were asymptomatic prior to the examination and most of them were self-referred. Patients were included if they had at least one risk factor for atherosclerotic coronary disease (e.g., family history of symptomatic coronary atherosclerosis, hypercholesterolemia, smoking history, diabetes mellitus, hypertension, peripheral vascular disease) or had a previous coronary intervention like percutaneous coronary intervention or CABG. Three patients underwent CABG and 13 patients had previous angiographic intervention with stent deployment (total of 19 stents) and were referred for non-invasive angiographic follow-up. Exclusion criteria were allergy to iodine, impaired renal function (creatinine levels above the normal range or creatinine clearance < 60 ml/min), body weight < 115 kg, irregular heart rate, and heart rate > 65 bpm after ingestion of oral beta-blockers (metoprolol 50 mg or propranolol 20 mg 3 hours before the examination in all patients who were not already taking this class of medication). Patients signed an informed consent form before the examination, having received a full explanation of the procedure and the new protocol.

The patients suitable for the step-and-shoot were informed that only if the heart rate remains constant below 65 bpm will the S&S algorithm be used; otherwise, the standard CCTA protocol will be performed. They were also informed that if the S&S sequence fails, regular CCTA will not be automatically performed. The decision whether to continue with CCTA was decided per patient and was based on medical history, calcium score, and location of pathologies along the coronary tree as depicted in the S&S. All patients underwent a detailed medical investigation by an internist prior to the CT examination. To facilitate adequate breath hold, the patients were connected to an oxygen mask and asked to hyperventilate.

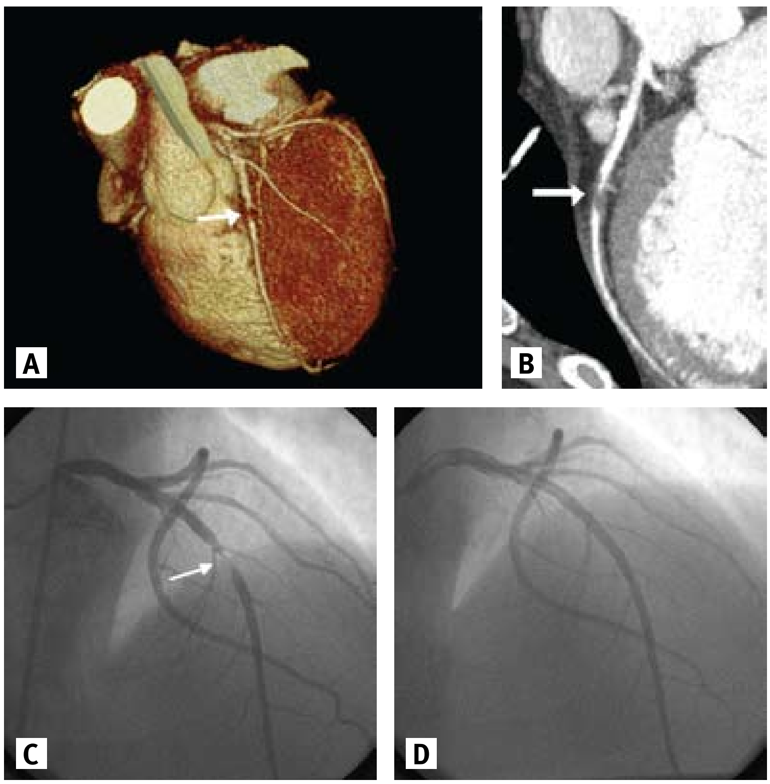
All examinations were performed with the 64-slice Brilliance CT scanner (Philips, Cleveland, OH, USA) with dedicated cardiac reconstruction software and electrocardiography triggering equipped with the step-and-shoot protocol. Patients were scanned in the supine position twice, first without contrast medium to calculate the calcium score and to scan the lungs, and then with contrast medium. Intravenous non-ionic contrast agent (Ultravist 370, Schering AG, Germany), 85–90 ml, was injected at a rate of 4–5 ml/sec followed by saline flush to the antecubital vein using a dual-head automatic injector (Stellant, Medrad, PA, USA).

The second scan volume was determined from the carina to the diaphragmatic surface of the heart. Scan parameters were as follows: 120 kVp (same as for regular CCTA), 150 mAs (versus 800 mAs in the regular CCTA), 0.4 sec rotation speed, slice width 0.62 mm and collimation of 64 x 0.625. In the S&S algorithm, pitch and slices overlap is not needed. Images were reconstructed in 75% cardiac phase automatically cycled using a prospective ECG-gated reconstruction algorithm with 1 mm sections with reconstruction of 0.4 mm.

All images were transferred to an Extended Brilliance workspace V3.5 (Philips Medical System, The Netherlands) for review by two experienced CT radiologists and an experienced interventional cardiologist, all with experience of over 3000 CCTA interpretations. The images were first analyzed in their original two-dimensional format in the standard mediastinal windows (400W/40C), lung windows (1700W/-500C), bone windows (2500W/500C), and liver windows (200W/100C) for the detection of extracoronary findings followed by calcium score analysis using the dedicated program in the workstation. Thereafter, the multiplanar reconstructions were analyzed and compared with the images after contrast medium injection by various imaging reconstructions in different planes [Figures 1-3].

The image quality was analyzed separately by at least two observers and was matched afterwards. If both observers did

Figure 1. Step-and-shoot cardiac CTA and cardiac catheterization in an asymptomatic 50 year old man. **[A]** Volume rendering image in left anterior oblique view demonstrates the heart. Short stenosis of mid-left anterior descending artery (LAD) is evident (arrow). **[B]** Curved multiplanar reconstruction (MPR) image of the LAD demonstrates the severe stenosis caused by a soft plaque (arrow). **[C]** Catheterization of the left main artery verifies the severe short stenosis of the mid-LAD (arrow). **[D]** Completion angiography of the same vessel after successful angioplasty using a stent



CABG = coronary artery bypass graft

Figure 2. Curved MPR of the right coronary artery in an asymptomatic patient, demonstrating patent stent without stenoses along the vessel

Figure 3. Volume rendering image of asymptomatic patient after CABG. Patent left internal mammary LAD (arrow) with patent anastomosis, and patent venous bypass graft to the first diagonal artery (arrowhead)

Table 1. Scores for image quality evaluation in observer study

Score	Definition	No. of patients (%)
1	No motion artifacts for all coronary artery segments: all assessable for diagnosis	103 (82.4%)
2	Minor and moderate artifacts in one or more segments assessable for diagnosis	15 (12%)
3	Severe motion artifacts limiting the diagnosis in at least one segment	4 (3.2%)
4	At least one coronary segment image had no diagnostic quality	3 (2.4%)

not agree on the image findings the third team physician also viewed the images and the decision was reached by all three. The image quality of the coronary arteries was scored from 1 to 4 [Table 1] and was based on quality score according to Joemai et al. [20]. A score of 1 designated a high quality examination where all the coronary segments were assessable for diagnosis. A score of 2 was given for examinations with minor and moderate motion artifacts in at least one coronary segment that were still assessable for diagnosis. A score of 3 was given for examinations with severe motion artifacts in one or more segments causing diagnostic limitations (like stenosis grading).

Radiation exposure was systematically recorded for each patient by the effective mAs and dose-length product measured in mGy cm. The average effective dose was calculated by multiplying the DLP value by a factor of 0.017 mSv/mGyv cm. For reproductive women (under the age of 50) the ED was multiplied by 1.3.

Institutional Review Board approval was not required because patients were examined according to departmental practice and approved equipment.

DLP = dose-length product
ED = effective dose

RESULTS

There were no contrast adverse events in patients who were discharged home 30 minutes after the scan and removal of the intravenous line. All patients underwent cardiac and extracoronary consultations after the procedures and were referred for further investigations if needed. Two patients were referred for coronary angiogram based on the S&S findings. The non-invasive findings completely matched the invasive angiography and both patients were successfully treated with stent implantation [Figure 1].

Technical success, i.e., obtaining high quality CCTA adequate for a detailed and accurate report based on two independent reviewers was obtained in 122 patients (97.6%). Complete correlation between the two observers was observed in all examinations [Table 1]. A score of 1 was noted in 103 patients (82.4%), of whom 12 were after coronary stent deployment (up to 4 stents in one patient). In all but one patient, good imaging quality enabling accurate interpretation was noted [Figure 2]. In addition, three patients in this group underwent CABG [Figure 3].

A grade of 2 was assigned to 15 patients (12%): 14 without coronary intervention history and one after percutaneous cardiac intervention with stent. A score of 3 was assigned to four patients (3.2%), mostly because of suboptimal scan timing and higher body weight. In all patients, the suboptimal imaging quality did not change the patient's cardiac workup since the suboptimal locations and findings were either too peripheral or mild for additional examinations.

In three patients the image quality was of grade 4, as detected during the scan and the subsequent interpretation. The sequence failure in one patient occurred because of sudden heart rate acceleration during the scan, in another because of respiration and movement during the scan, and poor scan timing and cardiac arrhythmia in the third patient. One patient (the one who moved) agreed to repeat the S&S algorithm; which was successfully obtained (and an occluded distal right coronary artery stent was detected), one patient with normal calcium score refused to continue with regular CCTA; and the third underwent regular CCTA (normal examination).

The average radiation exposure calculated as ED was 3.4 mSv, ranging from 2.05 to 4.5 mSv (in post-CABG patients where the scanned field is larger). The radiation exposure in the S&S algorithm is equal to a reduction of 70% compared to the regular CCTA – a reduction that derived from the algorithm that enables X-ray scanning only during a certain section of the cardiac cycle [13,14,17-20].

DISCUSSION

The introduction of 64-slice cardiac CT allows scanning with very high resolution in most patients. Scan times are on the order of several seconds (usually 5–12 seconds); thus even patients with severe pulmonary disease and congestive heart failure can hold their breath for the required length of time. The number of slices signifies high spatial and temporal resolution and the 64-slice scanners are capable of performing 64 slices per rotation at less than 0.4–0.7 mm resolution. Such high resolution allows visualization with extremely high accuracy and detail.

Coronary CTA is considered an accurate non-invasive imaging modality with established high sensitivity and specificity [1,2,4]. The indications for use of this modality, although this study focused only on the imaging quality and not on the appropriateness criteria, include diagnosis or exclusion of various coronary pathologies [21] and more recent indications such as open heart reoperations [22]. Although not indicated, extracoronary findings that are frequently detected are sometimes even more important than the coronary disease itself [23]. However, the main drawback of the examination is the high radiation dose, which ranges between 10 and 14 mSv on the 64-slice MDCT scanners. The radiation levels are derived from the need to scan small structures, to overlap the 4 to 5 slices and to use high kilo voltage for penetrating the surrounding structures, to differ between the small coronaries and their surroundings, and to assess the atheromatous plaque structure [6].

In order to reduce the radiation dose various options were developed, such as tube voltage reduction from 120 to 100 and even 80 kVp [16,24]; tube current modulation, namely, lowering radiation by 40 to 80% during 60–80% of the cardiac cycle, where the heart movement is higher and the image quality is inferior [6]; scan length to the minimum necessary; dual energy scanning; and newer scanners with more slices. The new MDCT with 256 and 320 detectors enables scanning of the entire heart in one rotation during one beat, which means less exposure time and obviates slices overlapping [25].

The conventional CCTA protocols are retrospective gating algorithms that cover the entire cardiac cycle during the scan. The continuous scan, using a low helical pitch, enables selective reconstruction of the data at any time point (phase) in the cardiac cycle and produces cine images of the cardiac movement.

Prospective cardiac gating was the primary acquisition technique in the early days of cardiac CT and was mainly used for calcium scoring. It is well known that at low heart rates it is generally sufficient to reconstruct the entire coronary tree in a single mid-diastolic phase and to obtain diagnostic image quality [11]. New prospective electrocardiograph triggering algorithms, or step-and-shoot mode, are based on the ability to scan only at predefined times during the cardiac phase when the heart is minimally moving (phase 75–80 mid-diastole). In this protocol, only during one-seventh of the cardiac cycle the X-ray is operative and the heart is scanned; in the remaining cycle the X-ray current is off. The partial radiation enables radiation dose reduction by 70% from 10–14 mSv to 1–4 mSv on the 64-slice MDCT [12-14,16-19]. The reconstruction is made from the same cardiac phase; the faster the heart rate, the smaller the S&S sampling and the image quality decreases, thus lower than 65 bpm is mandatory for the S&S. Body weight is also a factor: with higher weight, more radiation is needed to penetrate; with a body weight above 115 kg, the image quality in this algorithm is dramatically reduced. Recent studies have shown that S&S offers diagnostic image quality of the coronary tree with a dramatic reduction in radiation down to ED 1–4 mSv [12,13]. Our data support the diagnostic accuracy of the S&S in various conditions including stent imaging and CABG. It is important to simulate the scan prior to the real scan in order to detect patients suitable for this algorithm. Furthermore, the examination can be repeated and the radiation dose is lower compared to conventional CCTA.

Our study has a few limitations: first, there is almost no correlation to the gold standard coronary angiography. Second, the image quality was subjectively determined, even though it was based on experience of thousands of CCTA examination interpretations. Third, there was no comparison to a control group of regular CCTA; fourth, the study group was relatively small although it was in the range of other such comparative studies [18,22]. Further studies are needed to quantify its sensitivity, specificity and predictive values, Moreover, the new scanners with 256 and 320 rows [25], which have faster rotation speed, will reduce the ED levels to even lower than 1 mSv.

MDCT = multidetector computed tomography

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