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Coronary CT angiography using low concentrated contrast media injected with high flow rates: Feasible in clinical practice

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ABSTRACT

Purpose: Aim of this study was to test the hypothesis that peak injection pressures and image quality using low concentrated contrast media (CM) (240 mg/mL) injected with high flow rates will be comparable to a standard injection protocol (CM: 300 mg/mL) in coronary computed tomographic angiography (CCTA).
Material and methods: One hundred consecutive patients were scanned on a 2nd generation dual-source CT scanner. Group 1 ($n = 50$) received prewarmed Iopromide 240 mg/mL at an injection rate of 9 mL/s, followed by a saline chaser. Group 2 ($n = 50$) received the standard injection protocol: prewarmed Iopromide 300 mg/mL; flow rate: 7.2 mL/s. For both protocols, the iodine delivery rate (IDR, 2.16 gI/s) and the total iodine load (22.5 gI) were kept identical. Injection pressure (psi) was continuously monitored by a data acquisition program. Contrast enhancement was measured in the thoracic aorta and all proximal and distal coronary segments. Subjective and objective image quality was evaluated between both groups.
Results: No significant differences in peak injection pressures were found between both CM groups (121 ± 5.6 psi vs. 120 ± 5.3 psi, $p = 0.54$). Flow rates of 9 mL/s were safely injected without any complications. No significant differences in contrast-to-noise ratio, signal-to-noise ratio and subjective image quality were found (all $p > 0.05$). No significant differences in attenuation levels were found in the thoracic aorta and all segments of the coronary arteries (all $p > 0.05$).
Conclusion: Usage of low iodine concentration CM and injection with high flow rates is feasible. High flow rates (9 mL/s) of Iopromide 240 were safely injected without complications and should not be considered a drawback in clinical practice. No significant differences in peak pressure and image quality were found. This creates a doorway towards applicability of a broad variety in flow rates and IDRs and subsequently more individually tailored injection protocols.

1. Introduction

Image quality of computed tomographic angiography (CTA) and notably coronary computed tomographic angiography (CCTA) is substantially influenced by the degree of intravascular enhancement. Sufficient vessel attenuation is crucial for proper evaluation of vessel pathology, especially in smaller arteries [1]. Enhancement characteristics are based on scan technique, patient-related factors as well as all major parameters of the injection protocol applied (e.g. contrast media [CM] concentration, flow rate, added saline chaser and CM volume). Amount of iodine within the blood at a dedicated tube voltage is considered to be key determinant of vessel attenuation [2–6]. Lowering tube voltage yields stronger contrast enhancement for a given injection protocol [2,7–9]. Current CM

Abbreviations: CM, contrast media; CTA, computed tomographic angiography; CCTA, coronary computed tomographic angiography; IDR, iodine delivery rate; CAD, coronary artery disease; BPM, beats per minute; I.V., intravenous; HU, Hounsfield units; ROI, region of interest; AA, ascending aorta; DA, descending aorta; LM, left main; LAD, left anterior descending artery; Cx, circumflex artery; RCA, right coronary artery; SD, standard deviation; CNR, contrast-to-noise ratio; SNR, signal-to-noise ratio; IQR, interquartile range.

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application protocols should deal with shorter acquisition times of modern scanner technology and, thus, result in smaller CM boli, which might necessitate sharper bolus geometry (e.g. higher flow rates). A high iodine delivery rate (IDR; expressed as grams of iodine per second) is desirable in order to achieve optimal diagnostic intravascular attenuation for CTA [1]. Previous studies investigated the influence of iodine concentration, injection rates and IDR on diagnostic intravascular attenuation [10–16]. Contradictory statements have been made in the literature with regard to optimal CM protocols for imaging of the coronary tree. In order to enable a comparison between CM with different iodine concentrations, adapted injection parameters ensuring identical and constant IDR are mandatory [11]. In current clinical practice, CM with iodine concentrations between 300 mg/mL and 400 mg/mL are routinely used. Recent experiments in a circulation phantom revealed that comparison of protocols using CM with different iodine concentrations (240–400 mg/mL) did not show significant differences in vascular attenuation between all groups when IDR and total iodine load were standardized and kept constant [17]. In order to achieve the desired IDR, lower concentrated CM have to be injected at higher flow rates, concern might be raised about injecting high flow rates. Nevertheless, the use of lower concentrated CM might be advantageous in terms of lower viscosity and consecutively lower injection pressure. Viscosity of CM has been shown to play an important role in the overall enhancement pattern [1,2,18,19]. Aim of this study was to test the hypothesis that peak injection pressures and overall objective and subjective image quality using low concentrated CM (240 mg/mL) injected with high flow rates will be comparable to a standard injection protocol (CM: 300 mg/mL) in CCTA.

2. Materials and methods

2.1. Study population

A total of one hundred consecutive patients with stable symptoms of chest discomfort and suspected coronary artery disease (CAD), referred for CCTA from the cardiology outpatient department, were retrospectively included in this study within 6 months. For this study, ethics approval and informed consent for the use of (coded) images was waived by the local ethical committee (decision number: METC 13-4-022).

2.2. Injection and scan protocol

Scans were performed using a 2nd generation dual-source CT scanner (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany) with a 128 × 0.6 mm slice collimation; gantry rotation time of 280 ms; tube voltage of 100 kV; tube current varied between 320 and 370 $mAs_{eff.}$ (CareDose 4D™, Siemens Medical Solutions). Image reconstruction was done with individually adapted FOV at 0.75 mm slice thickness with an increment of 0.5 mm using an I26f kernel (SAFIRE, Iterative reconstruction strength 2).

In patients with a stable heart rate <60 beats per minute (bpm), a prospectively ECG-triggered "high pitch" spiral protocol was used ("Flash"-technique; 1 s). In patients with a stable heart rate between 60 and 90 bpm a prospectively triggered "adaptive sequence" protocol was used (prospective sequential data acquisition; 7 s). Patients received an oral dose of 50 mg metoprolol tartrate (Selokeen®; AstraZeneca, Zoetermeer, The Netherlands), two hours before CCTA. When indicated, an additional dose of 5–20 mg metoprolol tartrate was administered intravenously to lower the heart rate to <60 bpm, if possible. A maximum dose of 0.8 mg nitroglycerine (Isordil®, Pohl-Boskamp, Hohenlockstedt, Germany) was given sublingually just prior to CCTA. Heart rate and ECG were monitored during CCTA.

CM was administered through dedicated high flow intravenous (i.v.) injection needles (18 G; BD Nexiva Diffusics® I.V. Catheters, Sandy, UT, USA) in an antecubital vein (length i.v. catheter: 1.25 in., maximum registered flow rate: 15 mL/s). These needles have three tear-drop shaped holes positioned near the catheter tip and a strengthened design that enables use with power injectors set up to 325 psi, and proved to be feasible in both in vitro and in vivo experiments [20]. CM was administered with usage of a standard extension tube (length: 15.7 in.) between i.v. catheter and injection pump.

Prewarmed CM was used for all patients (37 °C [99 °F]; Ultravist; Iopromide, Bayer Healthcare, Berlin, Germany) and was injected in a biphasic injection protocol to ensure adequate opacification of the coronary arteries using a dual-head power injector (Stellant, MEDRAD, Warrendale, PA, USA). A non-enhanced scan was performed to determine the calcium score using the Agatston method [21] as part of the standard screening protocol. Patients with a heartrate >90 bpm or a calcium score >1000 were not included in this study.

Group 1 ($n = 50$) received 94 mL Iopromide 240 at a flow rate of 9 mL/s (IDR: 2.16 gI/s), directly followed by 63 mL saline at the same flow rate. Group 2 ($n = 50$) received a standard contrast bolus injection, using 75 mL Iopromide 300 at a flow rate of 7.2 mL/s (IDR: 2.16 gI/s), directly followed by 50 mL saline (flow rate: 7.2 mL/s). Total injection time was 17.4 s (including saline chaser) for both protocols. In both groups, a test bolus was injected at the level of the ascending aorta to assess optimal start time after administration of the bolus (group 1: 25 mL of CM at a flow rate 9 mL/s, group 2: 20 mL of CM at a flow rate of 7.2 mL/s, followed by 3 s administration of saline at the same flow rates). Total iodine load remained identical for both groups (22.5 gI). Injection pressure (psi) and total amount of CM (mL) were continuously monitored by a data acquisition program (Certegra™ Informatics Solution, Bayer) and read out after each injection.

2.3. Quantitative and qualitative efficacy assessments

The acquired data regarding presence of CAD was independently analyzed by an experienced radiologist and an experienced cardiologist who were both blinded to the injection protocol. In case of disagreement, consensus was reached by jointly reviewing findings. The coronary artery tree was assessed using the source images on a dedicated workstation (SyngoVia®, Siemens). Presence of CAD was determined using axial images and curved multiplanar reformatted images. Any coronary plaque (e.g. calcified, non-calcified or mixed) was considered to be positive for the presence of CAD. Axial thin slices were used for allocating all anatomic sites for measurement of the attenuation in Hounsfield units (HU). Contrast enhancement in HU was measured by two experienced observers in consensus using manually placed regions of interest (ROIs) in the ascending aorta (AA), descending aorta (DA), left main (LM) as well as proximal and distal segments of the left anterior descending artery (LAD), the circumflex artery (Cx) and the right coronary artery (RCA). The ROIs were placed on the vessels, care taken to avoid calcifications, plaques and stenosis (Fig. 1).

Objective image quality was analyzed in consensus and defined by several parameters: attenuation of all designated vessels, image noise (standard deviation (SD) of the attenuation in ROIs), contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR). CNR was defined by the following equation:

$$\mathrm{CNR} = \frac{\text{vessel enhancement AA(HU)} - \text{adjacent muscle enhancement (HU)}}{\text{adjacent muscle enhancement SD (HU)}}$$