Visualization of the coronary arteries in atrial fibrillation with ultra-high-end CT imaging.

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Aims and objectives

Incidence of atrial fibrillation (AF) is approximately 5% of the population over 65 years [1]. Frequently, coronary artery disease (CAD) is not only associated with this age group, but can also be - besides many others - one of the underlying causes in the pathogenesis of AF [2].

Detection of significant CAD is feasible with high sensitivity and high negative-predictive value when using multi-detector CT in patients with regular sinus rhythm. However, reliable visualization of the coronary arteries remains challenging in patients with AF despite improvements in pro- or retrospective ECG gated single-source CT (SSCT) and dual-source CT (DSCT) technology [3-8]. Main reasons for reduced image quality are dynamic changes in the heart rate during scan acquisition resulting in data misregistration and motion artifacts [9].

Generally, 3D CT images of the cardiac cavities are used for anatomic guidance during radiofrequency catheter ablation procedures of ectopic electrical foci at the transition of the pulmonary veins to the left atrium [10, 11]. Thus, the purpose of this pilot-study was to evaluate the visualization of the coronary arteries simultaneously with the left atrium and the pulmonary veins in patients suffering from AF by using an ultra-high-end CT equipment.
Methods and materials

Patients

32 consecutive patients (14 females, 18 males) with paroxysmal or permanent AF (heart rates varying between 34 and 125 beats per minute) were enrolled into the study. The patients were referred to CT imaging to depict the pulmonary veins and the left atrium before undergoing pulmonary vein isolation. Except of nitro-glycerine spray applied sublingually at the beginning of the CT exam, the patients did not receive other drugs (i.e. beta-blockers) for regulation of the heart rhythm.

CT imaging: Data acquisition

CT scans were performed on an ultra-high-end platform (Revolution CT®, GE Healthcare, Waukesha/USA) - Figure 1. These acquisition parameters were applied: 80 up to 120kV (dependent on patient's body weight and clinical task), noise index 32.0, SmartmA 50 to 545mA, coverage 160mm, slice thickness 0.625mm, ASiR-V 70%. ECG auto-gating was used to synchronize and start an one-beat acquisition of a 3D dataset with the use of WCCA mode (wide cone cardiac axial). The WCCA mode covers a variable acquisition window within one RR cycle with regard to the actual heart rhythm (window variable in time; laying near the systolic phase in tachycardia and near the diastolic phase in patients with normal rhythm). An amount of 40 to 50ml contrast agent (iomeprol, 400mg iodine/ml) was applied intravenously with the use of a power injector. The bolus geometry was mono-phasic at a flow rate of 4.0 to 5.0 ml/s, followed by a saline flush of 50ml. The contrast bolus was monitored with the "smart prep" tool for synchronizing data acquisition with the bolus arrival in the ascending aorta (threshold of 120 HU). Plain cardiac scans for coronary calcium scoring were not operated.

CT imaging: Post-processing

Image post-processing was performed by two observers (radiologists experienced 14 resp. 8 years in cardiovascular CT imaging) on a client-server workstation (AW 6.4, GE Healthcare, Waukesha/USA) with the use of the "CardIQ Xpress Reveal 2.0" software tool [12].

- For displaying the left atrium and the pulmonary veins, two reconstruction approaches were exerted: Firstly, the "2D Cardiac Review" tool to depict the left atrium by means of coronal MPR images (slice thickness 3 mm), and secondly, the "Heart VR" tool for 3D visualization of the pulmonary vein anatomy (after having removed the bony and arterial structures).
- For analysing the coronary arteries, two post-processing protocols were applied: Firstly, the "Tree VR" tool for a 3D survey of the coronary arterial tree, and secondly, the "Auto Coronary Analysis" tool for the detailed
vessel assessment (automatic centreline detection with manual editing of the vessel trace possible, manual display and selection of the most diagnostic views of the coronary branches). In selected cases of AF induced arrhythmias, the correction tool "snap-shot freeze" (SSF) was applied to reduce blurring and motion-artifacts of the coronary vessels.

**Image evaluation**

The 15-segment coronary model of the American Heart Association (AHA) was applied to describe the coronary anatomy. A 5-point grading scale was used for assessing image quality and artifacts (1 = excellent, 2 = good, 3 = fair, 4 = poor, and 5 = non-assessable). Graduation of vessel quality and artifacts was determined on a per-segment-based analysis by the observers in consensus reading. A total of 480 coronary segments were analysed (per-segment evaluation).
Fig. 1: Cardiac imaging with the use of the Revolution CT scanner. Scans were performed in patients suffering from atrial fibrillation before undergoing radiofrequency catheter ablation.

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Results

472 (98,3%) of the 480 coronary artery segments were visualized in excellent or good image quality (grades 1 and 2) - Figure 2, including 4 segments reliably judged as being aplastic. 8 coronary segments (1,7%) were depicted in moderate quality (grade 3). Not any of the assessable 476 coronary segments (a total of 480 segments minus 4 aplastic segments) was either missed or assessed with insufficient quality (grades 4 and 5) in CT imaging.

The motion correction tool SSF was applied in 17 of the 32 patients (53%), all of them with AF-related arrhythmias during the CT scan.

13 of the 14 lesions (92,9%) in 5 patients with known coronary artery disease (CAD) were correctly detected - Figure 3. Additionally, 4 significant stenoses (> 50%) of the coronary arteries were found in 3 other patients - Figure 4.

Radiation dose varied between 0.5 and 1.1mSv.
Fig. 2: CT imaging of a patient (male, 43 years, BMI 24) with long-term, permanent atrial fibrillation. Revolution CT scanner, WCCA protocol, median of the scan interval in the late-systole (438msec), total dose of 1,07mSy. a) ECG record with heart rate varying between 32 and 75 bpm during the CT scan. b) VR display of the left atrium and the pulmonary veins (posterior view). c) CT angiography of the right coronary artery (RCA). Normal finding, grade 1 image quality. d) CT angiography of the left artery descending (LAD). Normal finding, grade 1 image quality. e) CT angiography of the left circumflex artery (LCx). Normal finding, grade 1 image quality.

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Fig. 3: CT imaging in a patient (male, 76 years, BMI 33) with permanent atrial fibrillation and known coronary artery disease. Revolution CT scanner, WCCA protocol, median of the scan interval in the mid-systole (338msec), total dose of 1,04mSy. a) ECG record displays tachyarrhythmia (mean 91 bpm) with a heart rate varying between 85 and 136 bpm. b) VR display of the left atrium and the pulmonary veins (posterior view). c) CT angiography of the right coronary artery (RCA). Ectatic vessel with luminal irregularities and severe calcifications. Grade 2 image quality. d) CT angiography of the left artery descending (LAD). Significant calcifications, but no stenosis present. Grade 2 image quality. e) CT angiography of the left circumflex artery (LCx). Vessel showing also severe calcifications. Grade 2 image quality.

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Fig. 4: CT imaging results in a patient (female, 72 years, BMI 26) with known atrial fibrillation and incidental finding of a stenosis of the left artery descending (LAD). Revolution CT scanner, WCCA protocol, median scan interval in the end-diastole (75%), total dose of 0.60mSy. a) ECG record shows a heart rate between 51 and 71 bpm during the CT scan. b) VR image of the heart (view from anterior-superior) displays a 3D survey of the coronary artery tree. c) CT angiography of the right coronary artery (RCA). Some calcified plaques and wall irregularities are present. Grade 1 image quality. d) CT angiography of the left artery descending (LAD) reveals a high-grade stenosis (> 70%) in the proximal third (AHA segment 6) caused by a mixed plaque. Significant irregularities are also present in the mid vessel third (segment 7). Grade 2 image quality. e) The LAD stenosis is confirmed in selective catheter angiography. f) CT angiography of the left circumflex artery (LCx). Large vessel with some non-significant wall calcifications in the distal part (segment 13). Grade 1 image quality.

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Conclusion

The presence of CAD is not uncommon in patients suffering from AF. In the presence of arrhythmias, different strategies have been developed to overcome the limitations of cardiac CT imaging in detecting and staging CAD:

- Adaptive ECG gating (e.g. percent delay from the first R wave, fixed offset delay from the second R wave) allows SSCT and DSCT scanners to reject premature heart beats to avoid or reduce scan misregistration [13, 14].
- Prospectively ECG-triggered sequential CTA was superior to the retrospectively ECG-gated helical CTA with respect to image quality and radiation exposure, when comparing the DSCT acquisition modes in patients with AF [8, 14].
- In DSCT imaging, the end-systolic phase (absolute delay of 250 to 300 msec after the R wave) was found to deliver the highest image quality of the coronary vessels in AF patients; therefore the prospective acquisition technique [5, 14, 15] as well as the reconstruction time in retrospective scanning [4, 7] should focus on the systolic interval (including a 150-msec window).
- In the so-called "double flash mode" of DSCT imaging, one trigger is set at 60%, and another at 30% of the R-R interval within two prospectively acquired cardiac cycles [16].

In literature, most of the CT imaging studies in patients suffering from AF were performed with DSCT scanners of the first [3, 5-7, 14, 15] or second generation [8, 16]. Image quality of the coronary images was mostly diagnostic in the DSCT studies allowing to rule out significant coronary stenoses [3, 7, 14]. But the number of assessable segments was less in AF patients than in non-AF patients [3]. One advantage of the cardiac DSCT technology over the conventional SSCT approach is its high temporal resolution of 83 msec yielding in an improved image quality [3, 5]. Remarkably, mean dose requirements were in ranges between 4 and 12 mSv in the DSCT studies [3, 7, 8, 15].

To our best knowledge, only three studies have been published currently concerning SSCT scanners with mono-phasic coverage of the whole heart in AF patients [17-19]. 320-row scanners were utilized for coronary imaging in the end-diastolic interval. Image quality of the AF group was comparable to patients with normal sinus rhythm, and detection of CAD was feasible [18, 19]. However, effective radiation doses were 1.8-fold higher in the AF group [18], and exceeded the mean value of 3mSv [19].

In our study, diagnostic image quality of grade 1 and 2 was obtained in all patients despite the presence of AF related arrhythmias. Irradiation exposure was below or near 1mSv. We suggest several hardware and software innovations for yielding excellent imaging
results at low exposure doses and for overcoming cone beam artifacts, scatter and beam hardening artifacts:

- Firstly, an increased sensitivity of the detector material with a reduced X-ray need at the scintillator entry site.
- Secondly, improvements of the in-plane resolution (0.23mm) as well as the resolution in Z-direction due to orthogonal alignment of the scintillator elements.
- Thirdly, the temporal resolution of 140ms (enabled by gantry rotation speed), and the intelligent snap-shot freeze tool for heart motion correction (24ms temporal resolution at any heart rate).
- And finally, the new software generation of iterative reconstruction technology (ASiR-V) which allows for dose reduction up to 70%.

In conclusion, anatomy of the coronary arteries can be assessed reliably and uncompromised in a one-beat, motion-free acquisition approach in patients with atrial fibrillation when using the technological innovations of an ultra-high-end CT equipment.
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