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Research paper

CT features in the early and late stages of chronic total coronary occlusions

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ABSTRACT

Objectives: To investigate the morphologic characteristics of early and late stages of chronic total coronary artery occlusions (CTO) in coronary computed tomography angiography (coronary CTA).
Methods: We retrospectively analyzed patients who underwent coronary CTA and invasive coronary angiography and had at least one CTO with known duration. The following parameters were obtained in coronary CTA: calcification of the occluded segment; stump morphology; lesion length; remodeling index; presence of intra-occlusion linear contrast enhancement; and density of non-calcified CTO components. CT parameters were compared between patients with early (duration $\leq$ 12 months) and late (duration > 12 months) stage CTO.
Results: One-hundred and twelve patients with 124 chronically occluded coronary arteries were analyzed. Fifty nine patients had early stage CTOs (62 lesions) and 53 patients had late stage CTOs (62 lesions). Calcification was more severe in late-stage versus early CTOs (Agatston score: early stage, 27.4 ± 46.7 *vs.* late stage, 58.3 ± 112.4; p = 0.049). Remodeling index was lower in late-stage CTOs (early stage, 0.96 ± 0.2 *vs.* late stage, 0.88 ± 0.22; p = 0.034). In patients with late stage CTO, the presence of intra-occlusion linear enhancement was more likely (45.2% vs 14.5%, p < 0.001), and the density of non-calcified components was significantly higher (85.4 ± 27.2 HU vs. 65.7 ± 30.1 HU, p < 0.001). Stump morphology was not different between the two groups.
Conclusions: Coronary CTA reveals differences between chronic total coronary occlusions of longer and shorter duration. A long duration is associated with focal calcification and negative remodeling, as well as intra-occlusion enhancement and a higher density of non-calcified components.

1. Introduction

Chronic total occlusions (CTOs) are frequently encountered in patients with obstructive coronary artery disease referred for invasive coronary angiography (ICA).[1] Percutaneous coronary intervention (PCI) for CTO, despite its technical difficulties, is associated with improvement of symptoms, quality of life, left-ventricular function, and survival.[2–6]

Pathologic analyses of CTOs from human-autopsy studies have facilitated the development of PCI methods, thereby leading to improved success rates for revascularization. Histologic studies of CTOs have shown the influence of duration on the presence of calcification, inflammation, and neovascularization upon outcome.[7–8] Several studies have demonstrated the potentially important role of coronary computed tomography angiography (CTA) for characterization of CTOs, as compared with invasive coronary angiography (ICA), and established this modality as a

Abbreviations: CTA, computed tomography angiography; CTO, chronic total occlusion; ICA, invasive coronary angiography; PCI, percutaneous coronary intervention.

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potentially useful adjunct to invasive angiography for certain indications.[9–11] However, the imaging features of different stages of CTOs in coronary CTA have not been explored.

2. Methods

2.1. Ethical approval of the study protocol

Institutional review board approval was obtained for this retrospective study, and the informed consent was waived.

2.2. Patient population

Between April 2011 and December 2013, consecutive patients with CTO lesions as identified by ICA were retrospectively included in this study. Inclusion criteria were: (i) patients with CTO lesions confirmed by ICA; (ii) patients who underwent coronary CTA <1 month before initial ICA or underwent coronary CTA after identification of a CTO in ICA; (iii) duration of CTO lesions was known.

Exclusion criteria were: (i) history of acute myocardial infarction (AMI) within 3 months; (ii) history of attempted coronary revascularization of the target lesion (PCI or bypass surgery); (iii) unknown duration of CTO; (iv) uninterpretable coronary CTA.

2.3. Coronary CTA protocol

A 128-slice multi-detector CT system (Definition AS; Siemens Medical Solutions, Forchheim, Germany) was used. Oral beta-blockers (25–75 mg) were administered 1 h before examination if patients had a heart rate (HR) > 65 bpm. Nitroglycerin was given sublingually in all patients. A bolus of contrast medium (Iopamidol, Isovist®, 370 mg iodine/ml; Schering, Berlin, Germany) was injected into the antecubital vein at 4.5–5 ml/s followed by a saline flush (20–40 ml). The amount of contrast medium was determined according to patient weight and scan time. Patients with a HR < 70 bpm underwent prospectively ECG-triggered coronary CTA at 70% of the R-R interval. Retrospectively ECG-gated coronary CTA was performed in patients with a HR ≥ 70 bpm. Imaging parameters were as follows: collimation = 64 × 0.6 mm; reconstructed slice thickness = 0.6 mm; reconstructed slice interval = 0.5 mm; rotation time = 300 ms; pitch and current were modified by ECG, and the effective current was set at 200 mA (an ECG-dependent dose modulation method was applied, with full dose during the R-R interval of 40–70%); tube voltage = 120 kVp.

2.4. Reconstruction and analyses of coronary CTA

Data were transferred to an offline workstation (Syngo™, Siemens) for further analyses. Axial images, cross-sectional view, curved planar reformation (CPR), multiplanar reformation (MPR), three-dimensional (3D) volume rendering (VR) and 3D maximum-intensity projection (MIP) images were available for evaluation.

Duration of CTO was estimated by angiographic or clinical means. It was calculated as the time from the first index event (myocardial infarction defined by clinical history, increase in enzyme level, and Q waves in the electrocardiogram) or the first invasive angiogram that demonstrated a CTO to the date of CTA acquisition. The stage of CTO was classified into early (3–12 months) and late (>12 months) according to estimated duration.

Various morphologic parameters were determined in coronary CTA. Briefly, the total length of the lesion was measured from the proximal end to the distal end of the filling defect. To quantify calcification, the Agatston score was used. The stump was assessed on 3D-MIP and classified as “blunt” or “tapered”. The minimum remodeling index (RI) was calculated as the ratio of the smallest vessel cross-sectional area of the lesion to the proximal reference luminal area.[12] The vessel area of the CTO was corrected for the influence of normal tapering (1.2 mm^2/cm) if the length of the CTO was >10 mm.[12] “Intra-occlusion linear enhancement” was defined as the presence of a linear enhanced opacity that traversed the non-opacified occluded segment, was scattered and did not connect to the proximal or distal end of the lesion.[9] The density of the occluded segment was measured in intervals of 3 mm with careful exclusion of calcification. In this way, the proximal, middle and distal mean density of the non-calcified components of the occlusion was recorded.

Two experienced radiologists blinded to clinical histories and previous ICA results (if any) analyzed all lesions independently. Disagreements between the two observers were resolved by consensus.

2.5. ICA procedure

ICA was undertaken using standard methods. At least two different projections were obtained for each main vessel. Two skilled observers blinded to the results of coronary CTA evaluated all segments. Presence of CTO was defined as obstruction of the native coronary artery without luminal continuity or interruption of antegrade blood flow as assessed by ICA with thrombolysis in myocardial infarction grade ≤1, and duration of occlusion ≤3 months estimated from clinical events or proven by previous angiography.[1] ICA findings served as the reference standard for the diagnosis of CTO if patients were included retrospectively.

2.6. Statistical analyses

Statistical analyses were undertaken using SSPS v13.0 (IBM, Armonk, NY, USA). Quantitative variables are expressed as the mean ± standard deviation (SD). The Student's *t*-test and Pearson test were used for normally distributed data. The Mann–Whitney U-test was used for data that were not distributed normally. Continuous and categorical variables were compared using the Mann–Whitney U-test or χ^2 test. Fisher's exact test was used to compare proportions. Any $p < 0.05$ (two-tailed) was considered significant.

3. Results

3.1. Clinical characteristics

Initially, 163 patients were eligible based on the presence of a ICA-confirmed CTO lesion. Subsequently, 15 patients with a history of attempted coronary revascularization of target lesions (PCI or bypass surgery) and 6 patients with a history of AMI within 3 months were excluded. Eleven patients were excluded due to partially uninterpretable coronary CTA studies. Nineteen patients with an unknown duration of CTO lesions were also excluded.

Therefore, 112 patients [mean age: 65.9 ± 12 (range, 38–91) years; 88 males (mean age: 65.5 ± 12.9 (range, 38–91) years, and 24 females (mean age: 67.1 ± 8.4 (range 52–83) years; $p = 0.487$] were included in our study (Fig. 1).

Among the study cohort, 33 patients underwent coronary CT before ICA, 42 patients underwent CT before staged PCI and 37 patients had follow-up CT for untreated CTOs diagnosed by previous ICA. Duration of CTO was determined according to the first index event in 33 patients and according to previous angiographic findings in 79 patients.