Cardiac MDCT: A One-Stop Shop?

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The first attempts to image the coronary arteries were made more than a decade ago and involved the use of electron-beam computed tomography (CT), a dedicated type of CT scanner with a temporal resolution of 100 ms [1]. The slice thickness of this scanner, however, was limited to 3 mm, hampering the assessment of coronary-artery stenoses. Multi-detector-row CT (MDCT) offered high spatial resolution but only moderate temporal resolution. The introduction of 64-detector-row CT combined high spatial and high temporal resolution, allowing its clinical application in cardiac patients [2]. Since then, 64-slice CT and the new dual-source CT have become the state-of-the-art scanners for cardiac imaging. Dual-source CT furthermore improves temporal resolution and combines two detector rows in a line for fast acquisition of all X-ray projections needed for image reconstruction.

Optimal image quality is mandatory for the diagnosis of coronary-artery disease and requires particular effort in patient preparation and image post-processing. For a 64-detector-row CT with 160-ms temporal resolution, patients with a heart rate > 60 beats per min should receive a β-blocker in order to avoid cardiac-motion artifacts [3]. The CT scanner with the highest currently achievable temporal resolution is dual-source CT, which allows for an exposure time down to 80 ms. For motion-free images in the diastole phase, β-blockers may only be necessary for patients with a heart rate significantly above 70 beats per min. Alternatively, images may also be reconstructed with dual-source CT during the systolic phase at almost any heart rate, and even in patients with atrial fibrillation, without any motion artifacts [4].

The use of β-blockers may also be preferred in obese patients, in whom image quality is frequently impaired by severe noise and low enhancement. Lowering the cardiac output by the administration of β-blockers increases the enhancement, while lowering the heart rate allows reconstruction of the images with a longer temporal resolution in order to reduce the noise. However, in these patients, high iodine flow rates are also needed to ensure good enhancement and to improve image quality.

For optimal scan results, it is also mandatory to administer nitroglycerine, as dilation of the coronary arteries improves visualization of the peripheral segments and side branches [5]. Nitroglycerine may be easily and safely administered sublingually a few minutes prior to the investigations.

Concerning the administration of contrast media, the highest possible concentration is preferred to achieve the greatest enhancement of the coronary arteries [6]. High-level enhancement improves the visualization and segmentation of the coronary arteries and shortens post-processing time (Figs. 1-3). Bolus tracking is the preferred method for contrast and scan timing [7], and a saline chaser helps to avoid artifacts in the superior vena cava [8]. With today's faster MDCT scanners, it is now possible, by adapting the contrast bolus to the scan length, to achieve selective enhancement of the left ventricle and the coronary arteries (Fig. 4).

Warming the contrast media up to body temperature lowers its viscosity such that it can be administered at high flow rates [9]. Although flow rate and highly concentrated contrast agent are not considered risk factors for extravasation, careful injection via a large-caliber plastic catheter in the cubital vein is recommended. In the rare event of an extravasation, limb elevation, ice packs, and careful monitoring by a surgeon are advised [10].

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By overcoming the above-described limitations, cardiac CTA has reached a robustness that recommends its use in the clinical routine for a variety of clinical situations. Numerous studies, involving more than 1,400 patients, have compared 64-detector-row CT of the coronary arteries with cardiac-catheter-based detection of coronary-artery stenoses. According to these reports, 95% of all coronary seg-

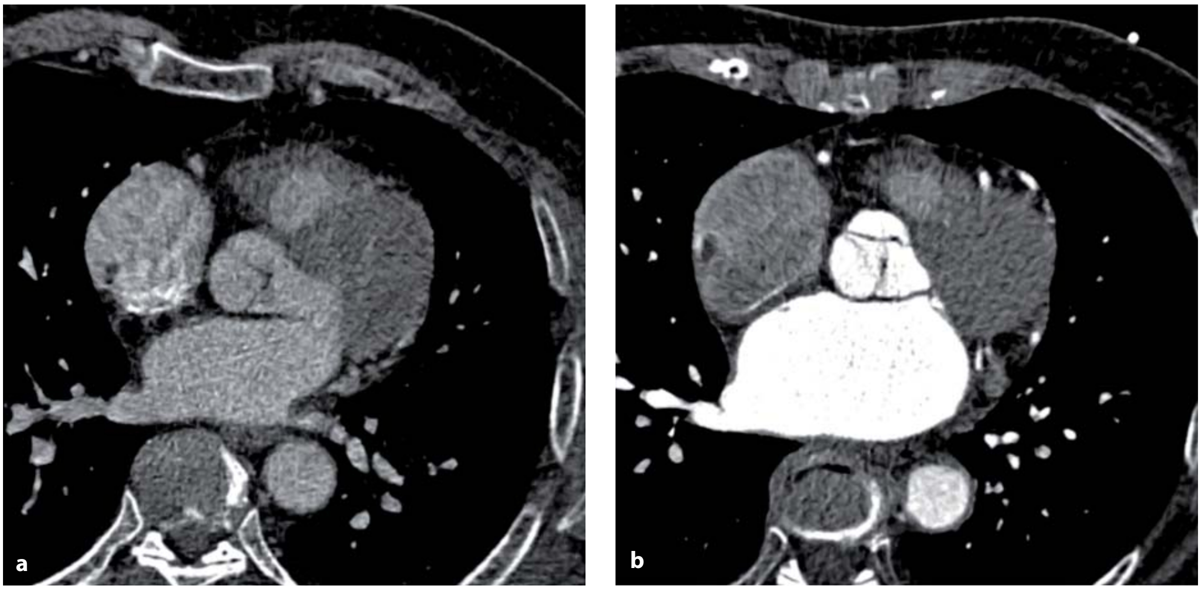

Fig. 1 a, b. A comparison of iodine concentrations of (**a**) 300 mg/ml and (**b**) 400 mg/ml administered with the same flow and volume in two different patients. The latter concentration leads to significantly higher enhancement of the left atrium, left ventricle, and coronary arteries

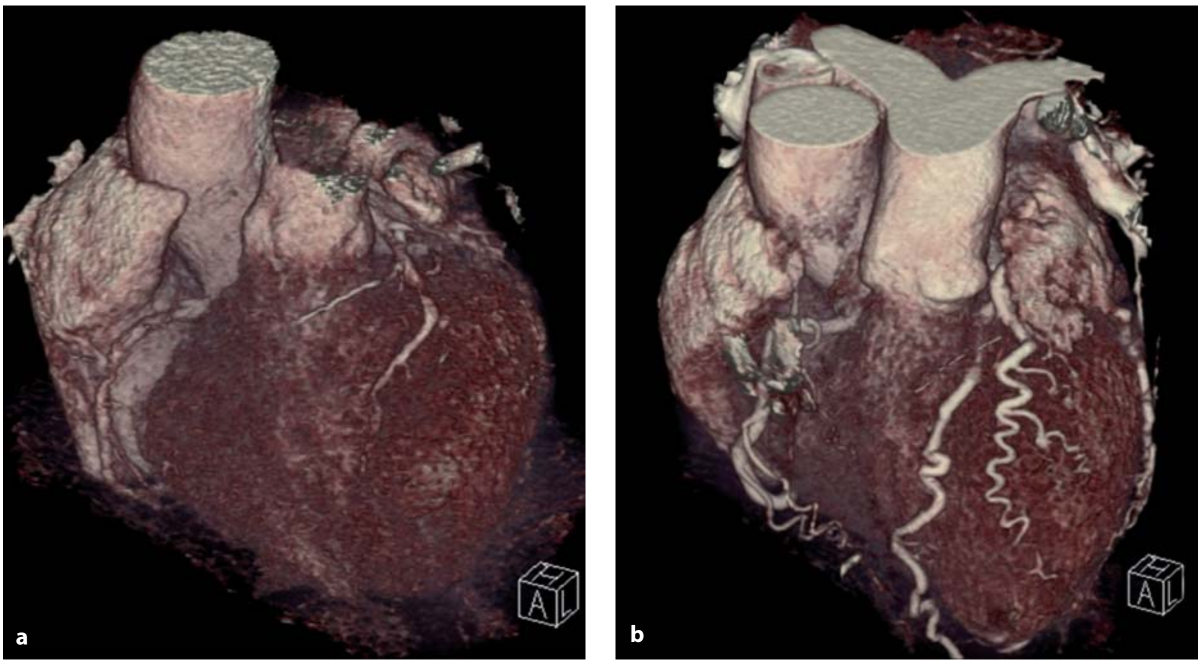

Fig. 2 a, b. Volume rendering results in higher enhancement of the coronary arteries (**b**) and thus better visualization above the myocardium than achieved with lower enhancement (**a**)

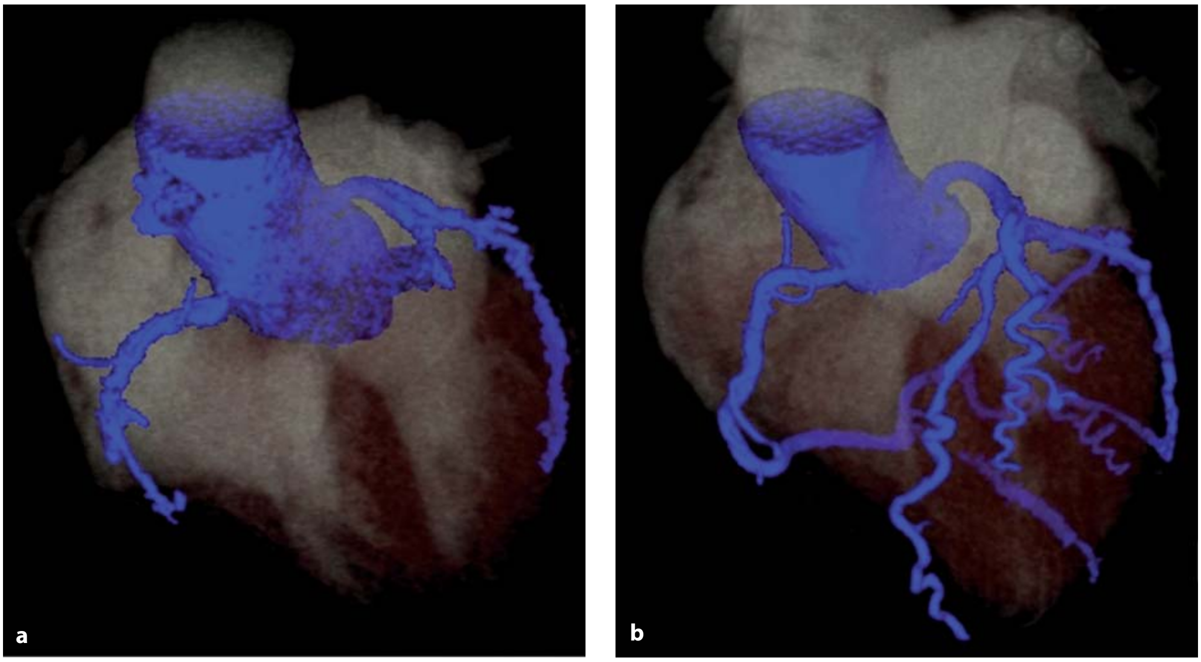

Fig. 3. Automatic segmentation of the coronary arteries is based on the density and therefore is more reliable in coronary segments with higher enhancement. More peripheral segments and side branches are detected automatically if an iodine concentration of 400 mg/ml is used

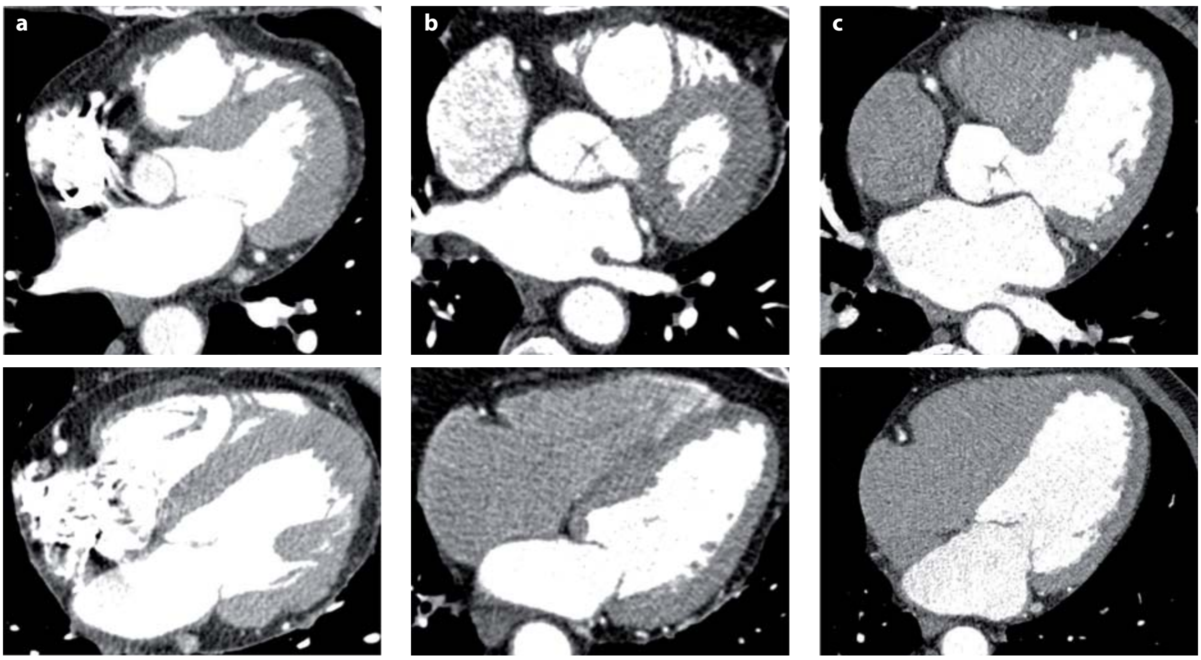

Fig. 4 a-c. With more modern CT scanners and shorter scan times, the amount of contrast media can be reduced. The scan time for the entire heart lasts around 40, 20, or 10 s for a 4-slice (**a**), 16-slice (**b**), or 64-slice CT (**c**), respectively. Flow rate and contrast volume changes accordingly: 120 ml with 3 ml/s (**a**), 100 ml with 4 ml/s (**b**), and 60 ml with 5 ml/s (**c**). In addition, artifacts in the right atrium may be avoided and selective enhancement of the left ventricle and the coronary arteries can be achieved ments were fully accessible by MDCT and the results were comparable to those obtained with cardiac catheterization (Fig. 5).

In summary, these studies showed a sensitivity, specificity, and positive and negative predictive values of 85, 96, 85, and 96%, respectively. Due to the high negative predictive value, 64-slice CT holds promise in reliably ruling out coronary-artery disease. Most of the investigators focused on a cohort of patients with a low likelihood of the disease, in whom the mean was prevalence was 22% [11-14]. Pitfalls for the detection of coronary-artery stenoses may still occur and involve collateral flow, retrograde filling, plaque formation with positive vessel remodeling, and extensive calcifications.

Cardiac CT is non-invasive and thus cannot be directly compared to cardiac catheterization; rather, it should be viewed as a tool to triage patients requiring an invasive approach. Thus, CTA is better-compared with the nuclear stress test or stress ECG treadmill testing. In a side-by-side comparison with the stress ECG test, cardiac CT proved to have a significantly higher sensitivity (91 vs. 73%) and specificity (83 vs. 31%). In addition, far fewer patients in that study were non-assessable with CT (8%) than with stress ECG (19%) [15].

The reliability and efficiency of cardiac CT very much depend on the pre-test probability of the patient of having coronary-artery disease. With a pre-test probability of < 50%, cardiac CT is economically more efficient than cardiac catheterization, stress echo, or stress ECG in the work-up of patients with suspected coronary-artery disease [16]. In clinical terms, patients with non-anginal chest pain and women with atypical angina may benefit from cardiac CT as a rapid test for excluding coronary-artery disease. Consequently, in younger male patients with atypical and younger female patients even with typical angina, cardiac CT may also serve as an alternative to immediate cardiac catheterization for ruling out disease [17].

In practical terms, cardiac CTA may also be well-suited for assessing patients with acute chest pain. In a recently published trial, Goldstein et al. reported on a cohort of patients ($n = 200$) with acute chest pain who were randomly assigned to either the standard of care procedure with nuclear stress testing or an alternative pathway that included cardiac CT evaluation as the first-line modality to triaging patients for further work-up. The study authors reported that patients underwent a work-up that was faster (3.4 vs. 15 h) and cheaper ($1,586 versus $1,872) with cardiac CT than with the conventional diagnostic pathway. Furthermore, in the CT group only two patients returned with recurrent chest pain, in contrast to seven patients in the standard of care arm [18].

Most recent data suggest that CTA is a valid alternative in patients with coronary-artery stents [19] (Fig. 6). However, cardiac CT does not provide information about myocardial perfusion in patients with coronary stents and is therefore only of limited value when coronary symptoms are present. Further-

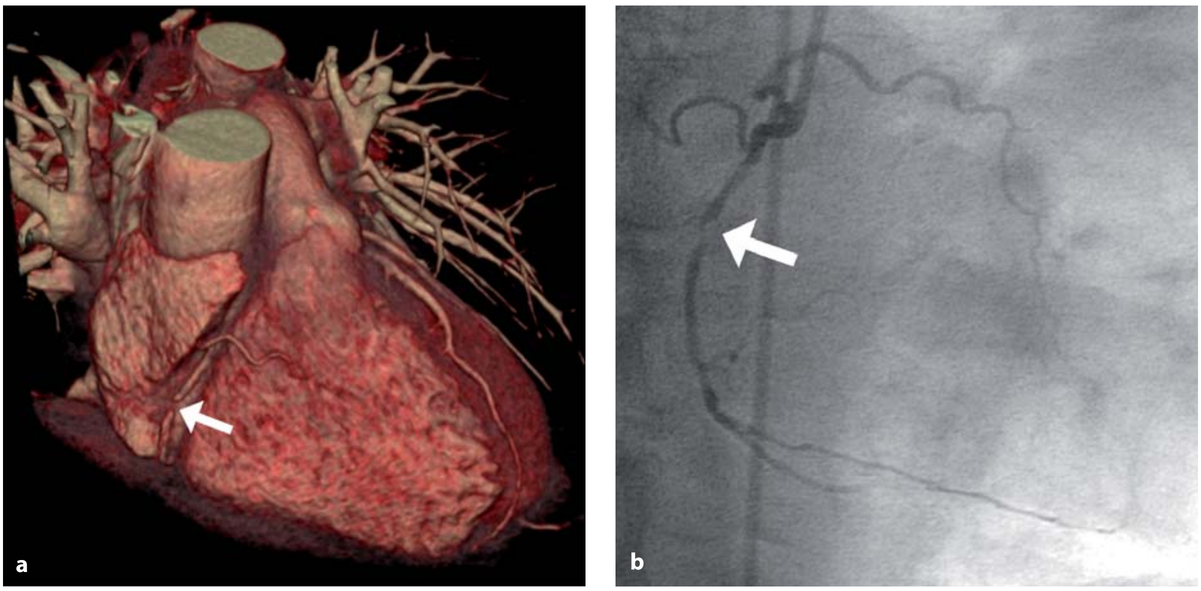

Fig. 5 a, b. The robustness of 64-slice CT includes its ability to present detailed findings. Short-term coronary-artery stenosis in the right coronary artery in (**a**) the CT volume-rendering image and (**b**) conventional coronary angiography more, small stents are still difficult to assess and in-stent stenosis can rarely be ruled out.

The assessment of coronary-artery bypass grafts has gained reliability since the introduction of 64-detector-row CT. The accuracy for either arterial or venous graft is in the range of 98% (Fig. 7). However, distal run-off or non-grafted coronary-artery segments are commonly difficult to evaluate since the original vessels in patients with bypass grafts are frequently severely calcified [20].

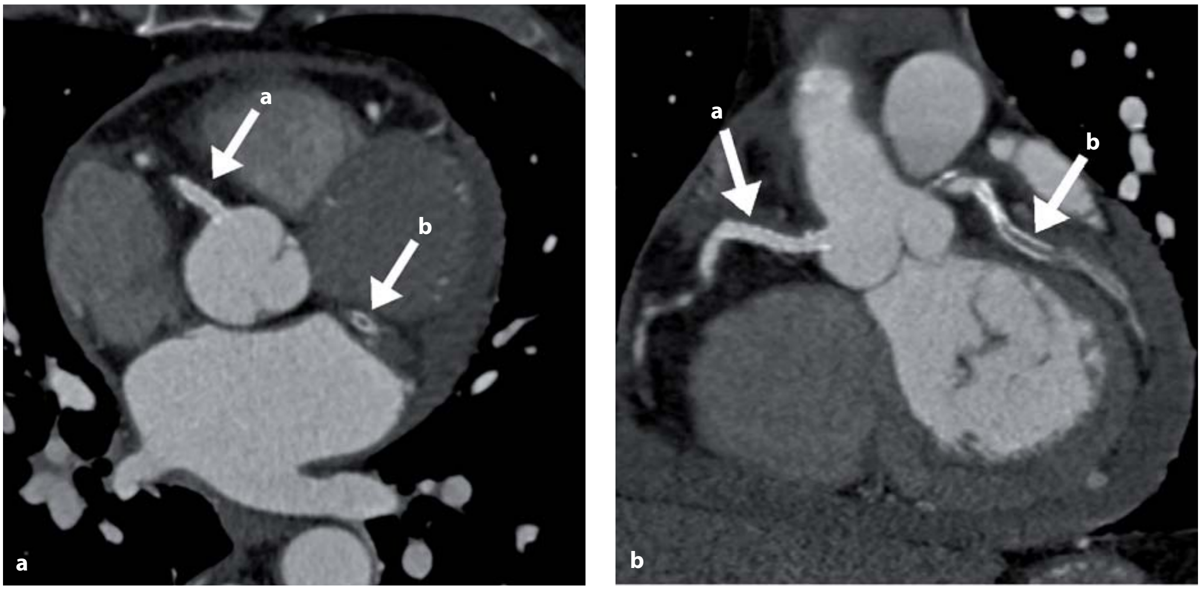

Fig. 6 a, b. Patients with stents in their right and left coronary arteries. The stent in the right coronary artery (**a**) is patent whereas the stent in the circumflex coronary artery (**b**) is thrombosed. A pericardial effusion is also present at the lateral wall of the myocardium (*asterisk*)

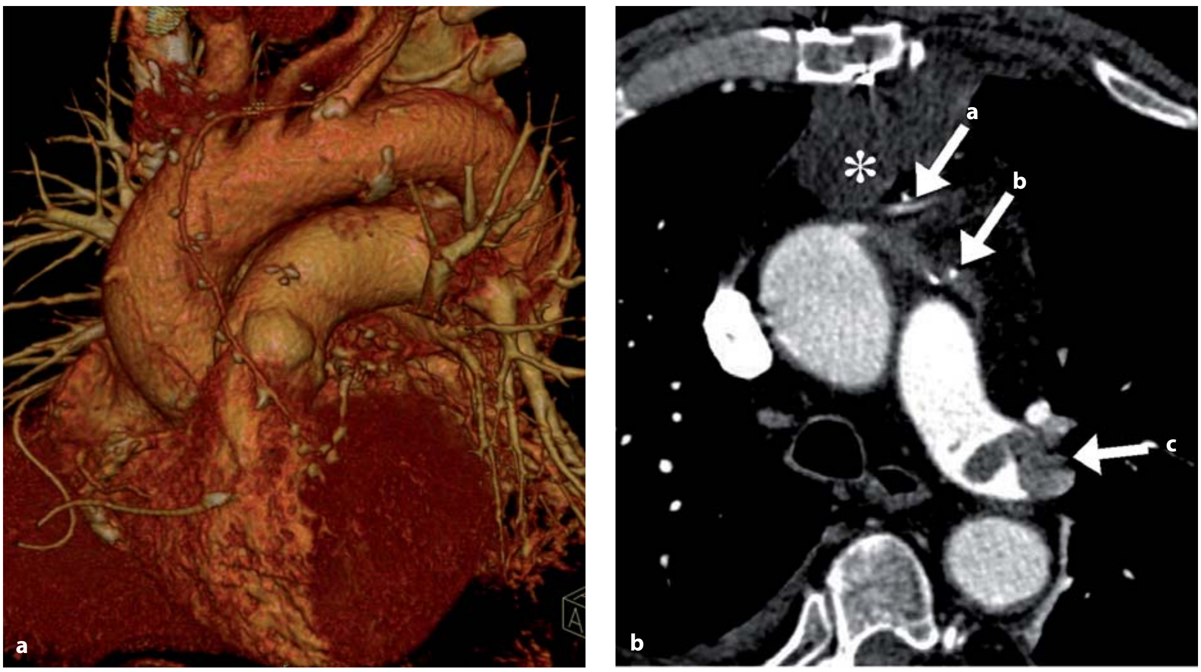

Fig. 7 a, b. Shortly after bypass surgery, this patient was referred for CT to evaluate his chest pain. The CT shows a retrosternal hematoma (*asterisk*). Thrombosed venous (**a**) and patent arterial (**b**) bypass graft as well as thrombus formation in the pulmonary artery (**c**) were detected

Patients who must undergo re-operation after bypass surgery benefit from cardiac CT, which provides concise visualization of the grafts, particularly those running behind the sternum [22]. Cardiac CT for this purpose has clear advantages over conventional radiography and cardiac catheterization [22]. Cardiac CT also seems to be a preferable screening tool for patients undergoing cardiac surgery for non-coronary reasons [23].

In patients with atrial fibrillation who are scheduled for catheter ablation, cardiac CT is frequently a surgical prerequisite. Visualization of the left atrial anatomy helps the surgeon to determine any accessory or anomalous courses of the pulmonary veins [24]. CT data from the heart are analyzed using commercially available software that assists in planning and guiding the procedure [25]. In this particular cohort of patients, it is important to rule out coronary-artery disease before prescribing anti-arrhythmic medical therapy.

In patients with ambiguous symptoms in the chest, it may be desirable to investigate the entire chest and thus to achieve a high and homogenous enhancement of the coronary arteries, the aorta, and the pulmonary arteries all at the same time. To this end, it is necessary to maintain the contrast bolus for at least the scan time and the passage time of the contrast media from the pulmonary arteries to the coronary arteries [26]. This protocol for evaluating chest pain can easily provide comprehensive information on the differential diagnosis of chest pain, such as aortic dissection, pulmonary embolism, degenerative spine disease, esophagitis, or tumor manifestation.

In addition to the above-mentioned indications, cardiac CT may be used in patients suspected of having a coronary anomaly or cardiac mass. A comprehensive overview of the appropriate indications for cardiac CT is available in a literature review [27] that lists several appropriate indications for CT but also considers MRI for addressing certain clinical questions. As a rough summary, CT is superior for displaying the morphology of the coronary arteries whereas MRI better provides information about myocardial function. It is therefore unlikely that CT will become a one-stop-shop for assessing cardiac disease. Cardiac CT, however, will certainly fit into the cardiologic environment as a cost-effective modality primarily used in patients with a moderate likelihood of coronary-artery disease who may require an invasive procedure.

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