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Multidetector-row CT: cardiosurgery indications

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Abstract This article critically evaluates the role of multidetector-row CT before and after cardiosurgical procedures. In addition, technical aspects, such as scan protocols, optimal image reconstruction intervals, image reformation techniques, and data evaluation, are presented and briefly discussed.

Keywords Multidetector-row CT · Cardiosurgical procedures · Technical aspects

Introduction

With the advent of multidetector-row technology, spiral CT has finally entered the field of non-invasive cardiac imaging. Retrospective ECG gating combined with improved temporal resolution allows continuous image reconstruction during any phase of the cardiac cycle from the volume data sets [1, 2, 3, 4]. In addition, near isotropic spatial resolution of almost 0.5×0.5×0.6-mm enables depiction of even smallest coronary artery structures [5, 6]. Whereas coronary angiograms are still superior in the evaluation of coronary artery disease, MRI in the assessment of functional data, respectively multidetector-row CT (MDCT), is gaining increasing importance as adjuvant diagnostic tools prior to or following cardiosurgical interventions. Its main advantage lies in the combination of large scan-volume coverage, high spatial resolution, proper identification of calcifications, and simultaneous registration of other thoracic structures.

This article thus concentrates on potential fields of application for cardiac MDCT before or following cardiosurgical procedures.

Technical aspects: data acquisition and image reconstruction

Most relevant cardiosurgical problems are solved by using multidetector-row scanners of the newest generation which allow for an ECG-gated image acquisition. In our studies we used both 4-row (Somatom Plus 4 Volume-Zoom, Siemens, Forchheim, Germany) and 16-row (Somatom Sensation 16, Siemens, Forchheim, Germany) CT scanners. Sixteen-row technology made possible sufficient evaluation even of small vessels (≥1 mm) and resulted in fewer motion artifacts at elevated heart rates (>75 bpm) as compared with 4-row scanners, thus general leading to better overall image quality. In addition, due to the favorable combination of high contrast-media flow rates and fast scan times, streak artifacts caused through undiluted contrast medium flowing into the right atrium were distinctly reduced.

Scanning was done on both scanners with 120 kV and 300 mAs. For the Somatom Plus 4 scanning, parameters were 500 ms rotation time, 4×2.5-mm collimation and 3.8-mm table feed per rotation for the plain series, 4×1-mm slice collimation, and 1.5-mm table feed per rotation

Table 1 Scanning and image reconstruction parameters for multidetector CT (MDCT) cardiac imaging. Comparison between 4-row MDCT and 16-row MDCT. *FOV* field of view.*CM* contrast medium

		Four-row MDCT	Sixteen-row MDCT
Plain series			
Scanning parameters	Rotation time (ms)	500	500
	Temporal resolution minimum	125	105
	Temporal resolution maximum	250	210
	kV	120	120
	mAs	300	300
Collimation	4×2.5	16×1.5	
	Table feed/rotation	3.8	5.7
Image reconstruction	FOV (mm)	220	220
	Kernel	B 35	B 35
	Slice thickness (mm)	3	2
	Increment (mm)	1.5	1
Contrast-enhanced series			
Scanning parameters	Rotation time (ms)	500	420
	Temporal resolution minimum	125	105
	Temporal resolution maximum	250	210
	kV	120	120
	mAs	300	300
	Collimation	4×1	12×0.75
	Table feed/rotation	1.5	2.8
	CM (ml)	140	100
	Flow rate (ml/s)	–	–
	Phase 1: CM (>350 mg I/ml)	50 ml at 4.5 ml/s	30 ml at 4.5 ml/s
	Phase2: CM (>350 mg I/ml)	90 ml at 2.5 ml/s	70 ml at 2.5 ml/s
	Phase 3: NaCL	30 ml at 2.5 ml/s	30 ml at 2.5 ml/s
Image reconstruction	FOV (mm)	220	220
	Kernel	B 35	B 35
	Slice thickness (mm)	1.25	1.0
	Increment (mm)	0.6	0.5

for the contrast-enhanced series, respectively (Table 1). All patients received 140 ml of a non-ionic contrast medium with at least 350 mg iodine per milliliter. Contrast media was infused through an 18-G intravenous antecubital catheter at a flow rate of 3.5 ml/s. Start delay was calculated using Test Bolus Technique with a region of interest (ROI) placed in the ascending aorta (30 ml contrast medium at a flow rate of 3.5 ml/s; Table 1).

For the Somatom Sensation 16 scanning parameters were 420-ms rotation time, 16×1.5-mm collimation, and 5.7-mm table feed per rotation for the plain series, and 16×0.75-mm slice collimation and 2.80-mm table feed per rotation for the contrast-enhanced series, respectively (Table 1). In these patients only 100 ml of a non-ionic contrast medium (Ultravist, Schering, Berlin, Germany) was infused with a flow rate of 4.0 ml/s. Using Bolus Triggering technique no additional contrast media was necessary to determine the start delay. After contrast media injection scanning started automatically as soon as a certain trigger point (usually 140 HU) was reached in an ROI placed in the ascending aorta (Table 1).

Image reconstruction was performed using retrospective ECG gating, a technique which allows continuous image reconstruction from volume data sets during any phase of the cardiac cycle [1, 2, 4, 7]. For image reconstruction on both scanners the adaptive cardiac volume reconstruction algorithm (ACV) was used, which is standardized provided with the Siemens Heart View (Siemens, Erlangen, Germany) software. Image reconstruction was performed antegrade and proportional in relation to the previous R-peak. Reconstruction parameters for Somatom Plus 4 and Somatom Sensation 16 examinations were 220-mm field of view, kernel B35, a medium soft tissue kernel, 3-mm effective slice thickness, and 1.5-mm increment for the plain series (Table 1). For contrast-enhanced series image reconstruction was done on the Somatom Plus 4 with 1.25-mm effective slice thickness and 0.6-mm increment, with 1.0-mm effective slice thickness and 0.5-mm increment on the Somatom Sensation 16, respectively (Table 1).

Patients with heart rates higher than 65 bpm always received a short-lasting beta-blocker (Brevibloc, 100 mg, 1 ml/10 kg b.w.) before the examination in order to decrease the heart rate below 60 bpm. Choice of a suited reconstruction interval proved to be critical for optimal image quality [8]. Our research suggested that optimal

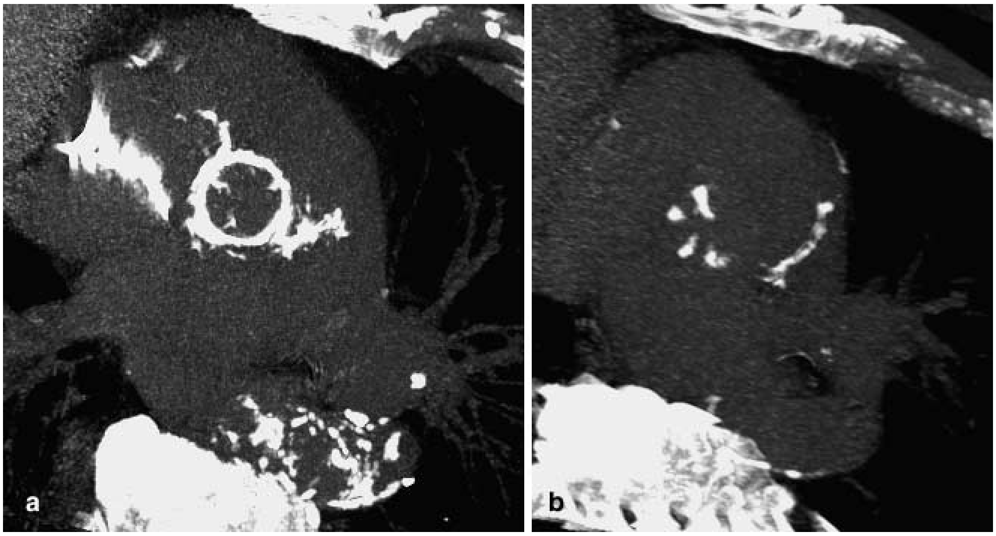

Fig. 1a, b Different aspect of a calcified aortic valve. **a** Heavily calcified annulus with only distinct calcifications of the leaflets. **b** Calcified leaflets only. Preoperative distinction of calcifications allows the surgeon to early apply a suited surgical strategy, such as valve replacement in case of the calcified annulus or valve reconstruction in cases where only the leaflets are concerned

image quality may only be observed between 20–70% of RR; thus, each data set was reconstructed several times in steps of each 5% within this interval. For each coronary artery subsequently a prevailing optimal reconstruction window was determined. First results indicate that at lower heart rates (less than ~67 bpm) all three vessels showed best results in the end diastole (~60% of RR) and at elevated heart rates (RR>67 bpm) in the end systole (~20% of RR) [9]. For proper assessment of calcified plaques both contrast-enhanced and plain examinations were used.

Technical aspects: image reformation and evaluation

For cardiosurgical indications it often is valuable to perform secondary, i.e., multiplanar (MPR) and three-dimensional, reformations in addition to transverse scans. This may not only facilitate demonstrations in the surgical morning round and intra-operative orientation for the surgeon, but it also helps the radiologist to assess complex three-dimensional structures, such as, for example, the course of different kind of bypasses.

Spectrum of cardiosurgical indications

Generally, a differentiation has to be made between preoperative and postoperative indications. Typically, preoperative fields of applications are assessment of the aortic and mitral valve before valve reconstruction/replacement, staging of cardiac tumors, evaluation of the ascending aorta in case of aneurysm/dissection, and planning of minimally invasive surgical procedures.

The role of MDCT in the assessment of the mitral/aortic valve is primarily seen in the identification and quantification of calcifications, which may not be depicted adequately by other methods [10]. Exact preoperative distinction of calcifications allows the surgeon to apply early a suited surgical strategy, such as valve replacement in cases of calcified annulus and calcified leaflets, or merely valve reconstruction in cases of only calcified leaflets (Fig. 1). Although first studies on the

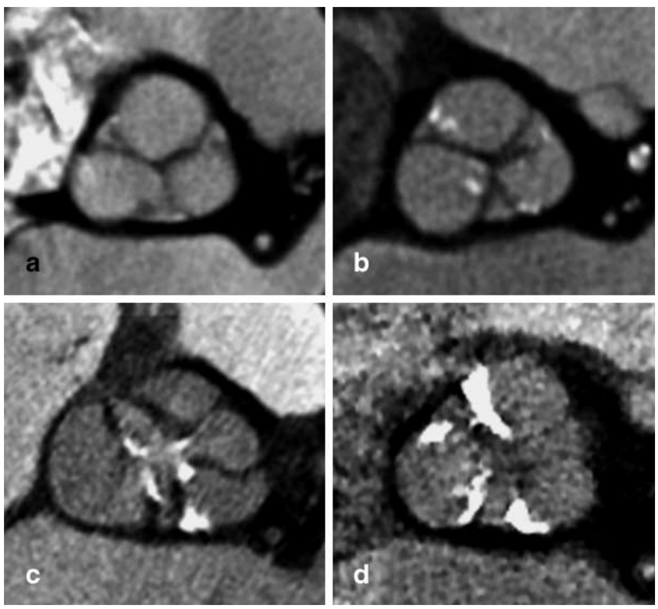

Fig. 2a–d Different degrees of aortic leaflet calcifications. Grades 1–4 (starting with **a**). There seems to be a significant correlation between degree of calcification and 4-year survival rate without surgery. Rosenhek et al. were able to show that grade-1 and grade-2 calcifications showed a survival rate of 75% as compared with only 20% for grade-3 and grade-4 calcifications [13]. These findings allow use of MDCT in preventive medicine

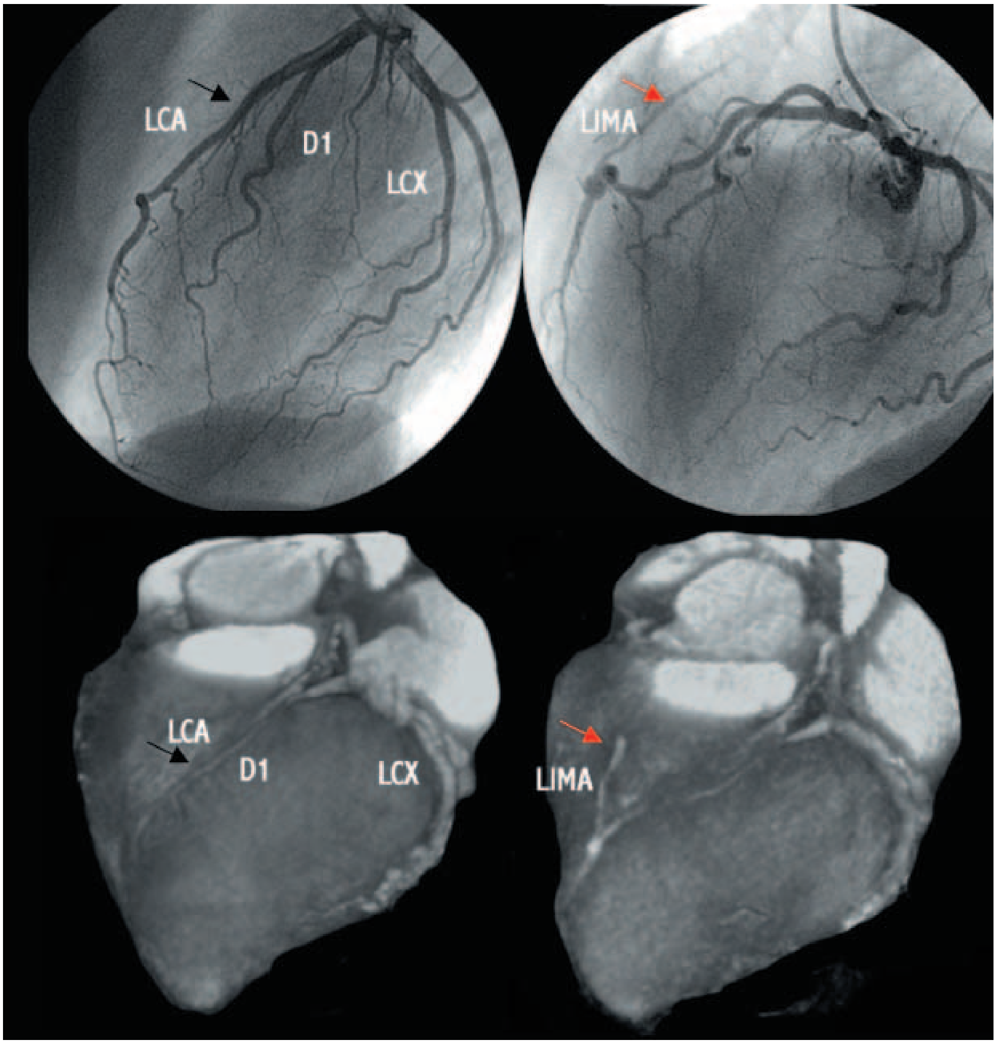

Fig. 3 Angiographic and MDCT findings in patient scheduled for totally endoscopic coronary artery bypass grafting. Coronary angiography and MDCT revealed a 90% stenosis of the proximal left coronary artery (segment 6); however, only MDCT showed that the medial section (segment 7) of the left coronary artery (*LCA*) was hidden deep inside the epicardiac fatty tissue. Bypass anastomosis in this region thus is difficult. Following the MDCT results preoperatively a more distal site for bypass touchdown was chosen and the surgical approach changed accordingly (*Left* preoperative findings, *right* postoperative results, *upper row* coronary angiography, *lower row* MDCT. *LIMA* left inferior medial artery

mitral and aortic valves showed significant correlations between surgery and MDCT findings, both lack direct comparison to echocardiography [11, 12]. An interesting observation was made by Rosenhek et al. [13] who demonstrated significant correlations between amount of aortic valve calcification and 4-year survival rate without surgery. Having identified four different groups, they were able to show that groups one and two presented a survival rate of 75% as compared with only 20% for groups three and four (Fig. 2) [13]. They concluded that MDCT consequently may play a future role in preventive medicine. The effective benefit of preoperative MDCT in the assessment of cardiac valves nevertheless still remains obscure, particularly as low temporal resolution (105 ms at its best) prevents sufficient assessment of other important data such as, for example, valve movement, regurgitation, and pressure gradients. Further studies and new technical approaches such as, flat-panel technology, may help in overcoming these drawbacks.

Due to low soft tissue contrast and bad contrast media uptake, preoperative staging of cardiac tumors by using MDCT is restricted mainly to the identification of calcifications (e.g., in myxomas) and the determination of tumor localization. Further-reaching classifications may be undertaken much better on MRI scans [14, 15, 16, 17].

With the advent of multidetector-row technology, which now allows thin slice coverage of large scan volume within one breath-hold period, CT without doubt has become an important diagnostic tool in the preoperative evaluation of the aneurysmatic/dissected ascending aorta [18]. Thin-slice technique now allows depiction of smallest vessels, such as, for example, the artery of Adamkewitz [19, 20, 21]. Elaborated post-processing software enables exact preoperative planning by using multiplanar and three-dimensional reformations. In this respect, the use of oblique MPRs, cut along the aortic arch, is strongly recommended since only this technique allows proper assessment of both the aortic root and the supra-aortic vessels.

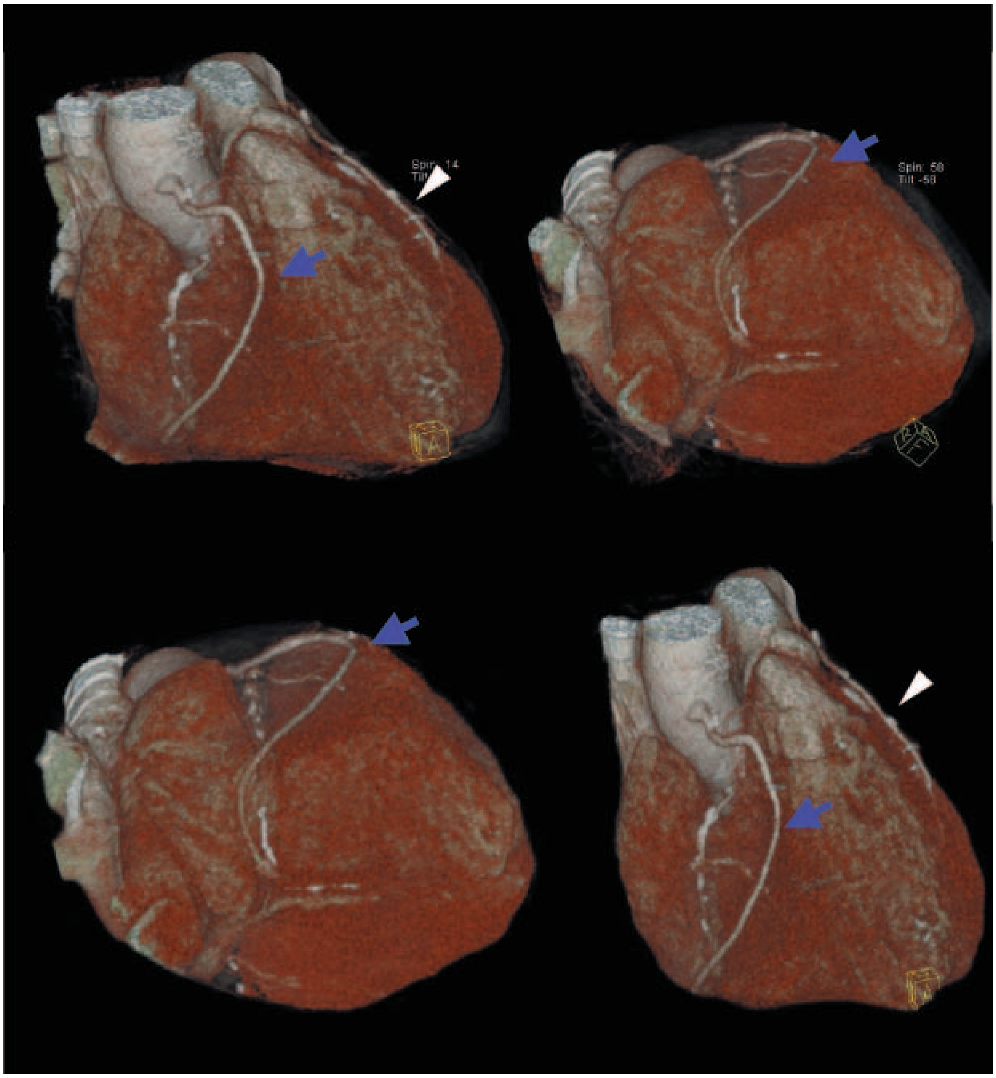

Fig. 4 Coronary artery jump-graft bypass to the RPLD and the RIVP (*arrows*) and LIMA bypass to the LCA (*arrowheads*). The MDCT easily depicts the course of both bypass grafts, the proximal anastomosis of the saphenous vein graft and the distal anastomosis of the LIMA graft. Distal anastomosis of the vein graft and subsequent small coronary segments are difficult to judge

A new but very promising application for CT displays its use in the preoperative planning of microsurgical interventions such as totally endoscopic coronary artery bypass (TECAB) or minimally invasive direct coronary artery bypass operation (MIDCAB) [18, 22, 23, 24]. The MDCT not only delivers valuable information on the degree and localization of coronary artery calcifications, but also reliably depicts the cardiac course of the vessels, i.e., it is able to identify bridging through myocardium or epicardiac fatty tissue (Fig. 3) [22]. The MDCT thus is able to provide extended information on the coronary target site and therefore helps the surgeon to preoperatively gain better orientation and to choose the most suitable surgical approach and technique.

After surgery, MDCT examinations particularly ease early identification of severe postoperative complications such as mediastinitis, leakage of anastomosis, or pericardial tamponade [25]. In addition, it can be used to postoperatively assess coronary artery bypass grafts [26]; however, although bypass patency can be judged easily using MDCT, the method nevertheless may be restricted to short-term controls, as distal and small coronary artery segments cannot be displayed sufficiently (Fig. 4). Another drawback lies in its inability to assess flow pattern of the bypass grafts; however, recent research has tried to overcome this problem by proposing a new approach that combined shaded-surface display and volume-rendering technique, varying threshold values and cine-loop video applications [27]. Further studies in this direction may help to clarify the effective value of this indeed interesting approach.

Conclusion

In conclusion, MDCT is able to support the surgeon in the preoperative planning of complex microsurgical interventions such as valve reconstructions/replacements, MIDCAB/TECAB procedures, or surgery of the ascending aorta. In addition, cardiac MDCT may play a role in the preoperative work-up before cardiac valve surgery and may also be used in preventive medicine. Postoperatively it helps to identify severe complications at an early stage and is proves to be valuable in short-term controls of coronary artery bypass patency. New technological developments, such as 16-row MDCT or flat-panel scanners, may further increase the spectre of cardiosurgical indications.

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