Multidetector row CT scanners with submillimeter spatial resolution and high temporal resolution are now available and are increasingly used for noninvasive assessment of vascular disease including coronary arteries and grafts. The entire heart and graft course can be scanned within a single breath-hold, and contrast-enhanced images are reconstructed through retrospective ECG gating. In this pictorial review, we describe the CT findings of the most commonly used coronary artery bypass grafts on both axial images and two-dimensional and three-dimensional images providing a correlation with conventional coronary angiography.

Key words: coronary artery bypass graft; coronary artery disease; multidetector row CT

Abbreviations: CABG = coronary artery bypass graft; IMA = internal mammary artery; LAD = left anterior descending artery; LCx = left circumflex artery; LIMA = left internal mammary artery; MDCT = multidetector row spiral CT; MPR = multiplanar reconstruction; OM = obtuse marginal branch; PDA = posterior descending artery; RA = radial artery; RCA = right coronary artery; RGEA = right gastroepiploic artery; RIMA = right internal mammary artery; RVOT = right ventricle outflow tract; SVG = saphenous vein graft

Graft disease after coronary artery bypass graft (CABG) surgery is an important issue in cardiology, as reflected by the large number of patients with recurrent chest pain after myocardial surgery revascularization. As a matter of fact, late survival after CABG surgery is largely dependent on graft patency and the progression of coronary artery disease.1–4 Although conventional coronary angiography still represents the imaging procedure of choice for assessment of CABGs and the status of recipient vessels, IV angiography using multidetector row CT (MDCT) with retrospective ECG gating is emerging as a new noninvasive technique in the field of cardiac imaging.5,6 Since coronary arteries and coronary grafts are small vessels, 2 to 4 mm in diameter, and are characterized by both complex anatomy and continuous movements, high spatial and temporal resolutions are mandatory to visualize these vessels at CT. MDCT scanners characterized by submillimeter spatial resolution and a temporal resolution of 94 to 200 ms are now available and are increasingly used for cardiac imaging with promising results.7,8

Knowledge of CAbG anatomy and configuration as seen on MDCT is important for the radiologist in order to correctly assess graft patency and/or the presence of significant stenosis. This pictorial review illustrates CT findings of the most frequently used grafts together with a brief description of scanning protocols for noninvasive evaluation of CABGs using 4-row and 16-row MDCT scanners. A correlation with conventional coronary angiography will also be provided.
Imaging Technique

Scanning is performed with the patient in the supine position, during breath-hold. After placement of the leads for ECG recording on the chest wall and a check of the heart rate, a noncontrast CT scan image is acquired through the entire thorax in order to define the volume of the subsequent CT angiography and to detect associated or unsuspected findings. Hence, MDCT angiography is performed during ECG recording, from the subclavian arteries to the cardiac base; in patients with venous grafts, a smaller scanning volume starting from the lower third of the ascending aorta is usually sufficient. On the contrary, when a right gastroepiploic artery (RGEA) has been used, the scanning volume should include the upper abdomen. Working with a 4-row MDCT scanner, we usually select a collimation of 2.5 mm in order to cover the entire acquisition volume in a reasonable scanning time of approximately 25 to 28 s; thinner collimations in the order of 0.5 to 1.5 mm can be used with 16-row MDCT scanners. Low heart rates (<65 beats/min) are recommended to obtain high-quality CT scans, and in the absence of contraindications (heart failure, systolic BP < 100 mm Hg, atrioventricular blockade greater than grade I, and referred adverse reaction), β-blockers can be administered before CT acquisition.

A bolus of 100 to 120 mL nonionic contrast material (high iodine concentration is recommended) is IV administered using an automatic injector at a flow rate of 3 to 4 mL/s. Since the left internal mammary artery (LIMA) is the most fre-
usually used graft to the anterior cardiac wall, a right arm venous access is preferable in order to avoid streak artifacts from the left subclavian vein that may hamper a complete evaluation of LIMA course and takeoff.

Axial images are reconstructed in the mid-to-late diastolic phase, using a fraction (percentage; relative delay) of the R-R interval of the cardiac cycle. Depending on the scanning protocol used, 3-mm or 0.5- to 1-mm-thick images are reconstructed with 4-row and 16-row MDCT scanners, respectively. Multiplanar, maximum intensity projection, and volume-rendered images can be obtained to better understand and delineate CABG anatomy and course. Images included in this pictorial were obtained with a 4-row MDCT (Volume Zoom; Siemens; Forchheim, Germany) and a CT off-line workstation for image reconstruction (Leonardo; Siemens) or a 16-row MDCT (Lightspeed 16™; General Electric; Milwaukee, WI) and a dedicated CT workstation (Advantage 4.1; General Electric).

**INTERNAL MAMMARY ARTERIES**

Internal mammary arteries (IMAs) are characterized by unique resistance to atherosclerosis and extremely high long-term patency rates. These vessels do not have vasa vasorum, and the presence of a nonfenestrated internal elastica lamina inhibits cellular migration and intimal hyperplasia. Moreover, the medial layer of the IMA is thin and poor of muscle cells, with poor vasoreactivity, and the endo-

**Figure 3.** Three-dimensional volume-rendering CT images (left, A, and top center, B) and corresponding conventional angiograms (right, C, and bottom center, D) in a patient with arterial grafts. Sequential anastomoses of the LIMA to a diagonal branch (d1) and LAD are clearly shown (left, A, and right, C). The RGEA is used for the second graft course along the anterior hepatic surface (left, A) and the inferior cardiac surface (top center, B), where it is anastomosed to the PDA (top center, B; and bottom center, D). An in situ RIMA graft to the left cardiac wall was also present with surgical clips along its course (arrowheads in left, A); d2 = second diagonal branch of the LAD.

**Figure 4.** Three-dimensional volume-rendering CT image (left, A) and corresponding conventional angiogram (right, B) in a patient with a single LIMA graft to the LAD. Since a left mini-thoracotomy was performed, surgical clips are present only in the distal portion of the graft (arrowheads in left, A). St = sternum.
thelium is characterized by high production of vasodilator (nitric oxide) and platelets inhibitor (prostacyclin). Lipid and glycosaminoglycan composition of IMAs are less atherogenetic in comparison with saphenous veins.

LIMA

The LIMA is frequently used as an in situ arterial graft to supply the anterior cardiac wall. On axial images, the LIMA is no longer visible in its usual site, on the left side of the sternum, but courses in the anterior mediastinum along the right ventricle outflow tract (RVOT) [Fig 1]. Although in most cases LIMA grafts show a single distal anastomosis to the left anterior descending artery (LAD) [Fig 2] or a diagonal branch, multiple sequential anastomoses to both the LAD and diagonal branches are sometimes performed (Fig 3). Surgery revascularization with an LIMA requires a longitudinal median sternotomy; in some centers, however, the LIMA is distally anastomosed by a left minithoracotomy at the level of the fourth anterior rib space and mobilization of the

**Figure 5.** Curved MPRs (top left, A, and bottom left, B) and corresponding conventional angiogram (right, C) in a patient with a "Y" free grafted RIMA between the LIMA and the OM of the LCx. Both proximal (arrow in top left, A) and distal (arrowheads in top left, A, and bottom left, B) anastomoses of the free graft are shown on the CT images. The LIMA was used as an in situ graft to the LAD; however, the second portion of the LIMA, distal to the anastomosis with the RIMA, is not visualized because it is occluded.

**Figure 6.** Axial (left, A) and volume-rendering CT images (right, B) in a patient with the RA grafted to left cardiac wall. Numerous and quite big surgical clips are present along the arterial conduit and are responsible for streak artifacts that hamper a complete and satisfactory evaluation of the graft.

**Figure 7.** MDCT images (top left, A; top right, B; bottom left, C) and conventional angiography (bottom right, D) in a patient with an SVG to the RCA, previously treated with stenting of the coronary artery (arrowhead in bottom left, C, and bottom right, D). On the axial CT image (top left, A), the SVG is seen at its proximal anastomosis along the anterior wall of the ascending aorta and coursing in the anterior mediastinum, lateral to the RVOT. Distal anastomosis to the RCA can be seen on both curved MPR (top right, B) and maximum intensity projection reconstructions (bottom left, C). A partial retrograde filling of the RCA is also shown on CT image (bottom left, C) and conventional angiogram (bottom right, D). See Figure 1 legend for expansion of abbreviations.
distal portion of the artery (Fig 4).\textsuperscript{4,9–12} Surgical clips are routinely used to occlude collaterals and to avoid arterial bleeding and can be seen either adjacent to the graft or at the original site of the LIMA (Figs 1–4).

**Right IMA**

The right IMA (RIMA) is rarely used as an \textit{in situ} graft for the right coronary artery (RCA); it is more commonly used as “free” graft from the ascending aorta to the RCA or from the LIMA to the left circumflex artery (LCx) or obtuse marginal branches (OMs) [Fig 5]. As already described for LIMA grafts, surgical clips are used to occlude collaterals.

**Radial Artery**

The first use of the radial artery (RA) as arterial conduit for coronary revascularization has been de-
scribed by Carpentier et al in 1972. The RA is a muscular artery characterized by a pronounced medial layer and high vasoreactivity, with short to mid-term patency rates. Generally, the RA from the nondominant arm is used. The RA is occasionally used when a third arterial graft is necessary or to avoid a venous graft when an IMA cannot be used. The RA is often grafted to supply the left cardiac wall (LCx, OM). Since the RA is a muscular artery, the number of surgical clips used to close collaterals along the graft is usually higher than with LIMAs or RIMAs. This may represent a limit for noninvasive assessment of RA grafts with MDCT because of artifacts from surgical clips hampering a complete visualization of the graft (Fig 6).

**RGEA**

The use of the RGEA was first described by Pym et al in 1984. Although it has been originally used in reoperation, in the absence of other suitable conduits, RGEA is now used as secondary, tertiary, or quaternary arterial conduit to provide all-arterial revascularization. The biological characteristics of RGEAs are similar to IMAs, but unclear benefits for third or fourth arterial grafts, the increment of surgery time, and the involvement of an additional body cavity are the main drawbacks limiting the widespread use of this conduit. The preoperative assessment of the RGEA is not well defined, but gastric surgery or mesenteric vascular insufficiency contraindicates the use of this vessel.

Occasionally, the RGEA is used to supply the inferior cardiac wall and is anastomosed as an in situ graft to the posterior descending artery (PDA) (Fig 3). In these cases, the mobilized artery is seen coursing anterior to the liver and through the diaphragm to reach the site of anastomosis; small clips can be identified at the original site of the RGEA, near the small curvature of stomach.

**Saphenous Vein Graft**

The use of the saphenous vein graft (SVG) as a bypass graft has many advantages, including availability, accessibility, easy of harvest, resistance to spasm, and versatility. The main drawbacks are lower patency rates, varicosity, and sclerosis. The SVG has poor compliance after arterIALIZation, with subsequent atherosclerosis. The great saphenous vein is the vein routinely used for CABG surgery; the proximal anastomosis of the venous graft with the ascending aorta is usually performed cranial to the origin of coronary arteries and as distal as the proximal portion of the aortic arch (Fig 7). The distal anastomosis of the graft, particularly with the RCA or one of its branches, may lie on the phrenic wall of the heart. Venous grafts are larger than arterial grafts and are not accompanied by surgical clips along their course; sometimes a circumferential clip can be identified at the site of proximal anastomosis with the ascending aorta.

SVGs may present a horizontal or slightly oblique course on axial images, especially when the distal anastomosis is placed on the LCx or a diagonal branch to supply the left cardiac wall. In these cases, the graft can be recognized in the fatty tissue of mediastinum, posterior to the sternum and anterior to the RVOT (Fig 8).

**Conclusions**

MDCT with retrospective ECG gating provides high-quality images and allows noninvasive assessment of CABGs. This tool could play an important role in patients with recurrence of chest pain or with unclear stress test results after myocardial surgery revascularization. Furthermore, the newest technological development of the CT scanner could strengthen the role of MDCT, allowing the consensual assessment of the native coronary arteries. Understanding of CABG anatomy as well as knowledge of the type and number of grafts used during surgery are fundamental for a correct interpretation of both axial and two-dimensional or three-dimensional images. Surgical clips, especially when big or numerous, may still represent a potential limit for MDCT assessment of graft patency or stenosis.

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