Multislice CT Evaluation of Coronary Artery Bypass Graft Patients

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Abstract: Continuous improvement in multislice computed tomography technology has further enabled advances in coronary artery bypass graft imaging. Multidetector platforms and retrospective electrocardiography gating have enabled sensitivities and specificities in the 95% to 99% range while avoiding the morbidity associated with invasive catheter angiography. Identification of bypass graft stenoses and bypass graft aneurysms/pseudoaneurysms is important in evaluation of these patients. Recognition of coronary artery bypass graft anatomy is particularly important to minimize the complications associated with reoperative cardiac surgery. The 3-dimensional demonstration of chest wall anatomy and its relationships to these coronary bypass grafts makes multislice computed tomography a superior technology in this patient population. Confident evaluation and assessment of the patient after coronary artery bypass graft surgery will become an increasingly important tool to the practicing radiologist.

Key Words: coronary artery grafts, multislice CT

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Coronary artery bypass grafting has been a historically significant advancement in the treatment of coronary artery disease from its inception in 1962. Despite significant improvement in patient's function and symptoms, recurrent chest pain has remained a common complaint after cardiac surgery. Although postoperative assessment of the cardiac surgery patient is traditionally performed with catheter angiography, the risk of stroke and hemorrhage, and also technical difficulties in accessing complicated surgical grafts, qualify its clinical usefulness.

Advances in multislice computed tomography (MSCT) technology have enabled unparalled cross-sectional imaging of coronary artery disease. Although current advances in the evaluation of ischemic coronary artery disease have showed continuous and exponential improvement, recognition of the ability of CT to evaluate coronary artery bypass grafts provided the imaging community its first insight in the power of this modality to evaluate coronary artery disease. This paper describes protocols, imaging findings, and future directions in coronary artery bypass graft imaging.

Although most of the advances of coronary artery graft imaging have focused on the technologic features of electrocardiograhy (ECG)-gated MSCT technology, reports defining coronary graft patency were first described by Brundage et al[1] with single slice nonspiral CT. Further reports by Tello et al[2] described the CT evaluation of coronary artery bypass graft (CABG) patency using nonspiral CT. Advances with electron beam CT used ECG gating technology to minimize cardiac motion. Early results described coronary artery graft assessment with sensitivities and specificities in the 90% range.[3] Advanced postprocessing techniques further improved evaluation of coronary grafts with electron beam CT.[4] The advent of MSCT has shown progressive improvement in coronary artery graft assessment. Research in bypass graft patency with 16-detector-row MSCT defined sensitivities and sensitivities in the 90% to 95% range.[5] Early results with 64-slice CT demonstrate further improvement in coronary artery graft assessment.[6]

CORONARY ARTERY GRAFT ASSESSMENT: PROTOCOLS

In all patients undergoing evaluation of bypass grafts, retrospective ECG gating is crucial. Although strict control of patient heart rates may be less crucial in bypass graft assessment than native vessels, normal sinus rhythm and pulse rates less than 65 bpm continue to be optimal for confident graft visualization. Injection rates of 4 to 5 mL/s are used with a 50 mL saline flush to optimize contrast delivery. In the assessment of coronary artery patency, knowledge of prior surgical procedures is needed. Evaluation of saphenous vein graft patency can be performed from the mid ascending aorta to the base of the heart. When internal mammary graft assessment is clinically indicated, imaging of the chest from the extrathoracic internal mammary origin to the cardiac apex is needed. In 16-slice MSCT systems, 100 to 125 mL of contrast (370 mg I) with a 50 mL saline flush is indicated, whereas faster anatomic coverage with 64-slice CT allows contrast volumes of 50 to 75 mL. Given the extended anatomic coverage required in 16-slice MSCT imaging of the internal mammary graft,

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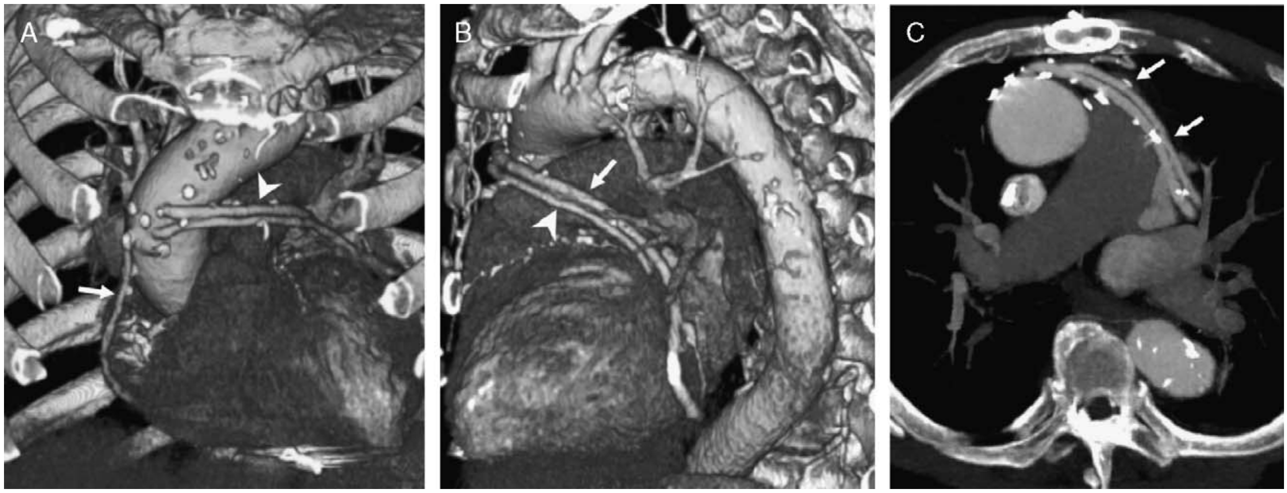

FIGURE 1. A 72-year-old man S/P CABG for postoperative graft assessment. A, Volume rendered image demonstrates anatomic course of patent saphenous vein grafts to right coronary artery (arrow) and left circumflex artery distribution (arrowheads). B, Sagittal oblique volume rendered image demonstrate course of saphenous vein grafts to the circumflex (arrow) and obtuse marginal branches (arrowhead). C, Axial MIP image demonstrates saphenous vein grafts from the anterior ascending aorta to the left circumflex artery territory (arrows).

imaging protocols require slice collimation of 2 mm with 1-mm imaging reconstruction intervals. 64-slice CT evaluation of coronary artery grafts can routinely be performed with 1-mm collimation with slice reconstruction thickness of 0.5 mm.

FIGURE 2. A 65-year-old man S/P CABG evaluated for graft patency. Sagittal volume rendered image demonstrates the appropriate retrosternal course of the patent LIMA graft to the LAD. Note separation of the LIMA graft from the inner table of the sternum (arrow).

Coronary artery bypass graft imaging uses well-recognized postprocessing techniques. All image protocols require 1 to 2-mm slice thickness with 50% reconstruction intervals to enable volumetric imaging. Although axial source images establish the diagnosis of coronary artery bypass patency, multiplanar maximal intensity projection (MIP) techniques allow rapid volumetric assessment of these bypass grafts. Volume rendered techniques are preferred by our surgical colleagues for its preoperative demonstration of chest wall and bypass graft relationships. Imaging reviews are routinely performed on 3-dimensional workstations with our referring cardiac surgeons.

CORONARY ARTERY GRAFT ASSESSMENT: ANATOMY

Assessment of coronary artery graft patency requires knowledge of coronary artery graft procedures and anatomy. Current surgical revascularization techniques of the diseased right coronary artery includes saphenous vein grafting. These venous grafts are achieved through surgical anastomoses from the anterior aspect of the ascending aorta to the native right coronary artery (Fig. 1A). Saphenous vein grafting to the left coronary system is often performed to revascularize the left-sided circulation. Although left internal mammary artery (LIMA) grafts are traditionally performed to restore the left anterior descending (LAD) circulation, saphenous vein grafting will often be used to revascularize diagonal and circumflex branches (Fig. 1B).

Although volume rendered images are helpful in assessment of the 3-dimensional nature of coronary bypass grafts, primary review of coronary artery graft

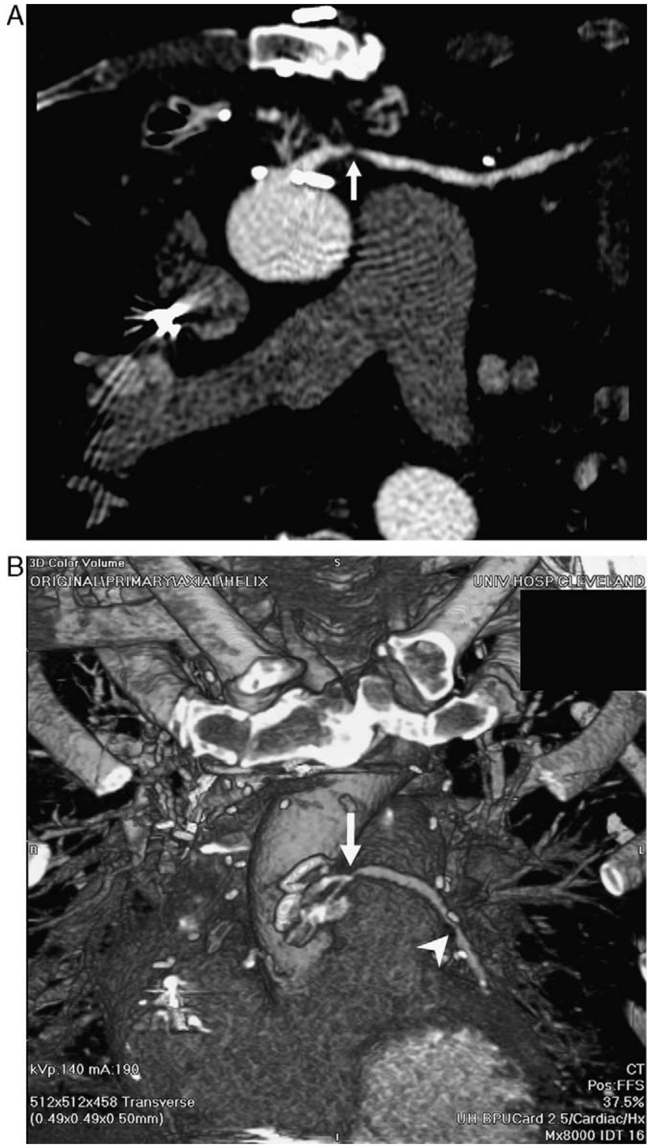

FIGURE 3. A 68-year-man with prior CABG complains of recurrent chest pain. A, Axial MIP images show focal stenosis of the mid portion of the saphenous vein to the circumflex artery (arrow). B, Volume rendered image redemonstrates significant stenosis of the patient's saphenous vein graft (arrow). Note second more distal stenosis (arrowhead).

patency is first performed by review of axial images. The saphenous vein graft origin will often be marked by surgical clips at the anterior aspect of the ascending aorta. The graft continues to travel lateral to the main pulmonary artery before its anastomosis to its distal left coronary artery targets (Fig. 1C). While surgical patency is important, relationship of the grafted vessel to the chest wall and sternum is also helpful in the reoperative cardiac patient.

The LIMA has become a significant surgical breakthrough in cardiac surgery. LIMA grafts have significantly improved long-term patency rates when compared with traditional saphenous vein grafting. Research has defined long-term patency rates of 85% to 90%.[7] LIMA grafts traditionally revascularize the diseased LAD. The LIMA graft travels anteriorly from its left subclavian artery origin to anastomose to the LAD. Similar to the saphenous vein graft, recognition of the LIMA to the chest wall and sternum is important in surgical planning of the reoperative cardiac patient (Fig. 2).

CORONARY ARTERY GRAFT ASSESSMENT: PATENCY

A significant body of research has defined assessment of saphenous graft patency. Saphenous graft assessment has described technical success in a number of studies; studies with 16-detector-row technology has defined 100% accuracy in saphenous vein graft patency.[8] Different manifestations of saphenous vein graft occlusion need to be recognized.

Proximal saphenous vein graft occlusion will often present with a focal outpouching from the ascending aorta. Evaluation of standard axial images is usually diagnostic of proximal graft occlusion. MIP and volume rendered images will improve visualization of the stenotic saphenous vein graft (Fig. 3). The biology of the saphenous vein graft is clearly different from the arterial LIMA graft. The lack of native nitric oxide production and exposure of venous graft to arterial pressure accelerates atherosclerotic disease in the saphenous vein graft.[9] Compared with the arterial LIMA graft, earlier and more extensive atherosclerotic disease and occlusion is identified throughout the diseased graft (Fig. 4). Although stenting is often performed in the diseased saphenous vein graft, in stent thrombosis of these diseased grafts can be identified with ECG-gated MSCT (Fig. 5).

The accelerated atherosclerotic disease seen in saphenous vein grafts is particularly evident in an uncommon but well-described complication of CABG surgery; the saphenous vein graft aneurysm. Although the early literature described less than 100 cases, MSCT has enabled improved recognition of the saphenous vein graft aneurysm. Saphenous vein graft aneurysms are often asymptomatic and are diagnosed years after CABG surgery (Figs. 6, 7).

CORONARY ARTERY GRAFT ASSESSMENT: CHEST WALL RELATIONSHIPS

As the population ages, reoperative cardiac surgery is preformed in increasing numbers. Studies describe a reoperative surgical rate of 9% at 10 years and 30% at 12 years. Although the perioperative infarction risk is 4% for initial cardiac surgery,

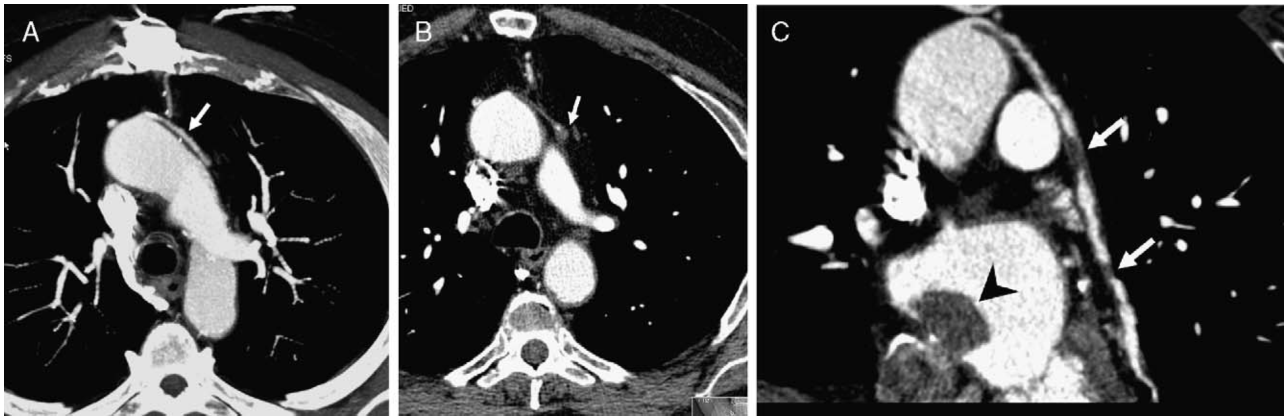

FIGURE 4. A 76-year-old man S/P CABG and history of atrial myxoma for preoperative assessment of graft patency. A, Axial MIP image demonstrates proximal patency with atherosclerotic changes of the saphenous vein graft (arrow). B, Axial image at the mid-portion of the graft shows significant luminal narrowing and mural thrombus of the vein graft (arrow). C, Coronal MIP images demonstrate significant stenosis of the mid-portion of the graft (arrow). Note left atrial myxoma (arrowhead).

perioperative infarction risk for reoperative cardiac surgery is 12%.[10] Particular reoperative complications include injury to existing coronary artery grafts. LIMA graft injury occurs in 5% of reoperative surgery. In those patients, LIMA graft injury will result in left ventricular infarction in 50% of patient.[11] In patients undergoing redo sternotomy, a medially displaced retrosternal course of the LIMA predisposes the patient to LIMA graft injury. Preoperative evaluation of the LIMA with CT enables comprehensive assessment of the course of the LIMA graft relative to the chest wall and sternum, minimizing LIMA injury and perioperative infarction (Fig. 8).[12] The increasing use of minimally invasive surgery further establishes the need for preoperative imaging assessment.[13] Studies have demonstrated that preoperative evaluation of the chest wall and coronary anatomy improves operative success in minimally invasive surgery.[14] MDCT and volume rendered imaging further improves the surgeon's assessment of critical structures in the reoperative cardiac surgery patient undergoing reoperative minimally invasive surgery (Fig. 9). Although LIMA graft assessment is most commonly assessed, recognition of the anteriorly displaced saphenous vein graft must also be assessed to avoid injury at resternotomy (Fig. 10).

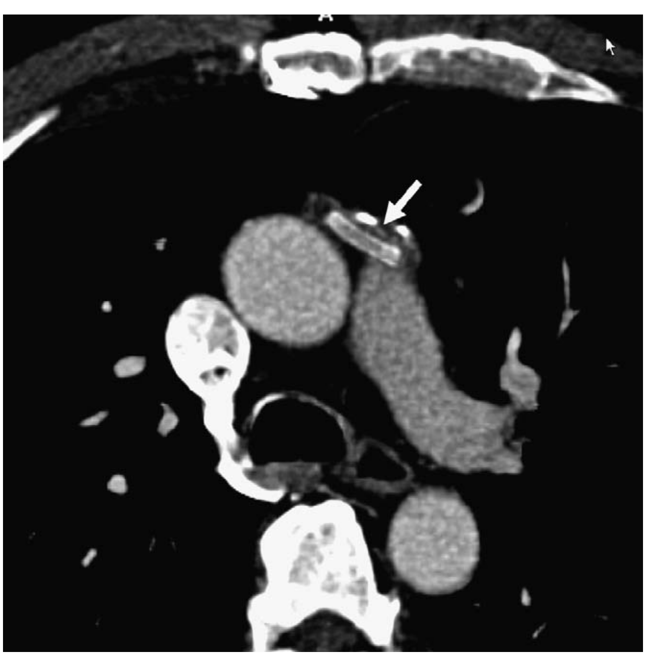

FIGURE 5. A 74-year-old S/P CABG for graft assessment. Axial MIP shows thrombosed saphenous graft with extensive in-stent thrombosis (arrow).

Success in LIMA grafting techniques has also increased the investigation of other arterial sources for bypass grafting. Radial artery and right internal mammary artery grafting have enabled patency rates comparable with LIMA revascularization (Fig. 11). The RIMA graft is used to revascularize the left coronary artery distribution. The anatomy of the RIMA requires a retrosternal course to anastomose to the LAD artery. MSCT techniques are increasingly used to avoid RIMA graft injury at reoperative cardiac surgery.[15] Recognition of this anatomy is critical to avoid transaction of RIMA in reoperative cardiac surgical procedures (Fig. 12).

Continued advances in continued coronary artery imaging have made diagnostic imaging of coronary artery grafts possible. Knowledge of coronary graft anatomy and important signs of graft stenosis offer a particular opportunity to further expand the thoracic radiologists role in the diagnosis of cardiothoracic disease.

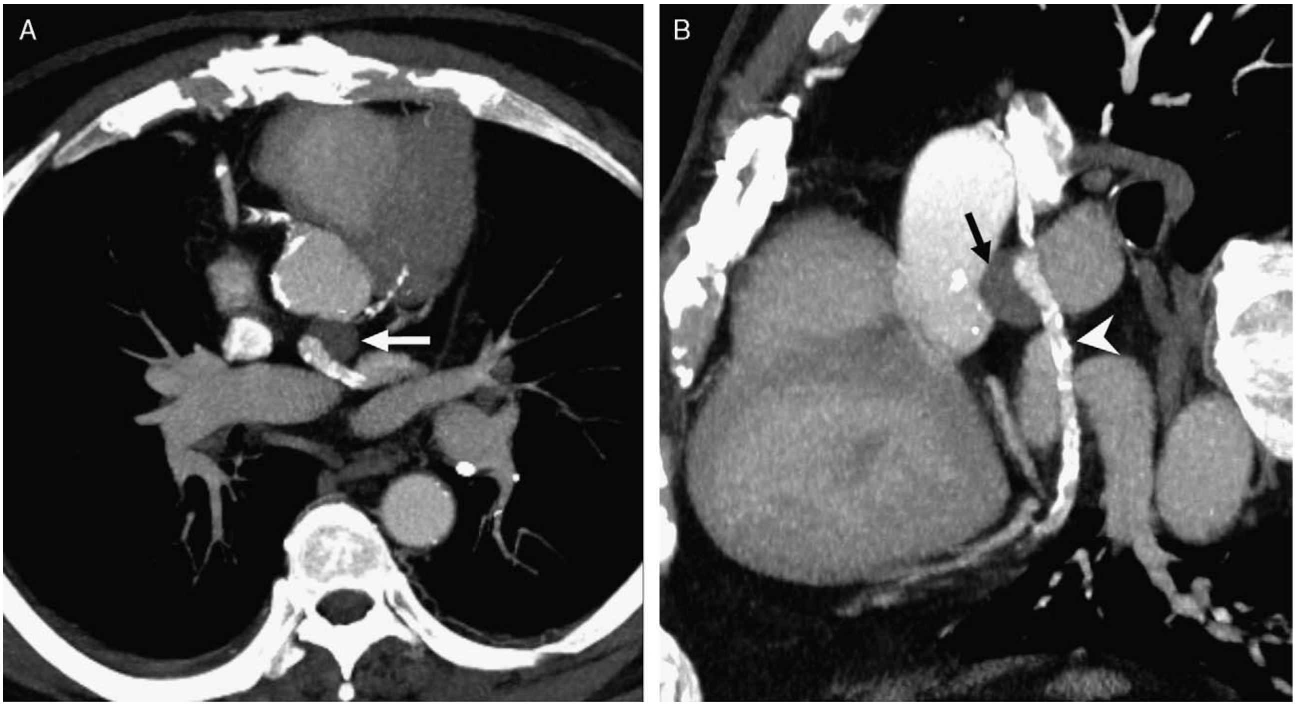

FIGURE 6. A 71-year-old man for aortic valve replacement surgery. CT requested for coronary artery graft anatomy. A, Axial MIP image demonstrates aneurysm of the patient's saphenous vein graft as it travels posteriorly to the aortic valve (arrow). B, Sagittal oblique MIP images demonstrate the relationship of the saphenous vein graft aneurysm to the posterior ascending aorta (black arrow). Recognition of the posterior course and aneurysmal disease of the saphenous vein graft is important to avoid injury at aortic valve surgery. Note diffuse disease of the saphenous vein graft (white arrow).

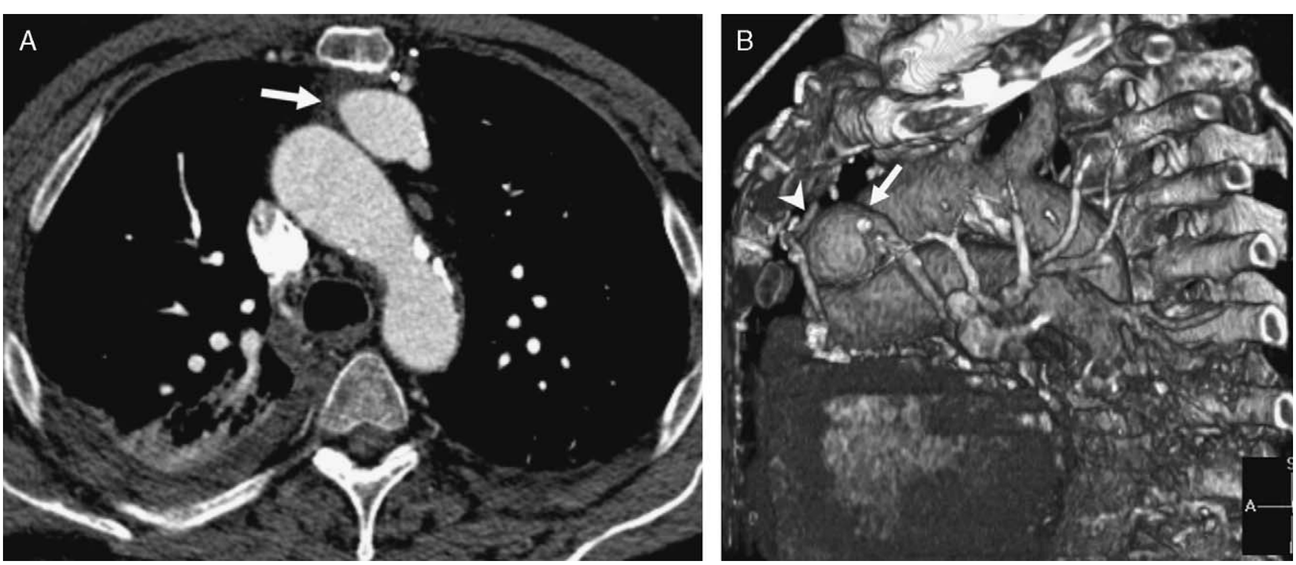

FIGURE 7. A 82-year-old man S/P CABG with limited coronary angiogram suspicious for aortic aneurysm. A, Axial MIP image demonstrates aneurysm at the site of the patient's prior saphenous vein graft (arrow). Clips mark the position of the patient's retrosternal LIMA graft. B, Sagittal volume rendered image demonstrates large aneurysm of the patient's saphenous vein graft (arrow). Note close apposition to the retrosternal LIMA and its relationship to the graft aneurysm (arrowhead).

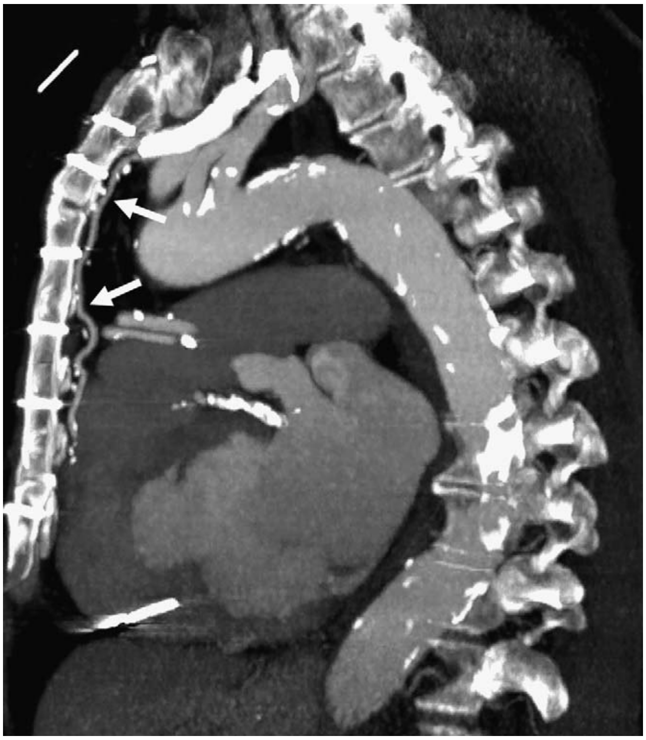

FIGURE 8. A 72-year-old with history of CABG admitted for aortic valve replacement. CT performed to assess LIMA anatomy in relation to the sternum. Sagittal MIP image demonstrates extensive adherence of the patient's LIMA graft to the inner table of sternum (arrow).

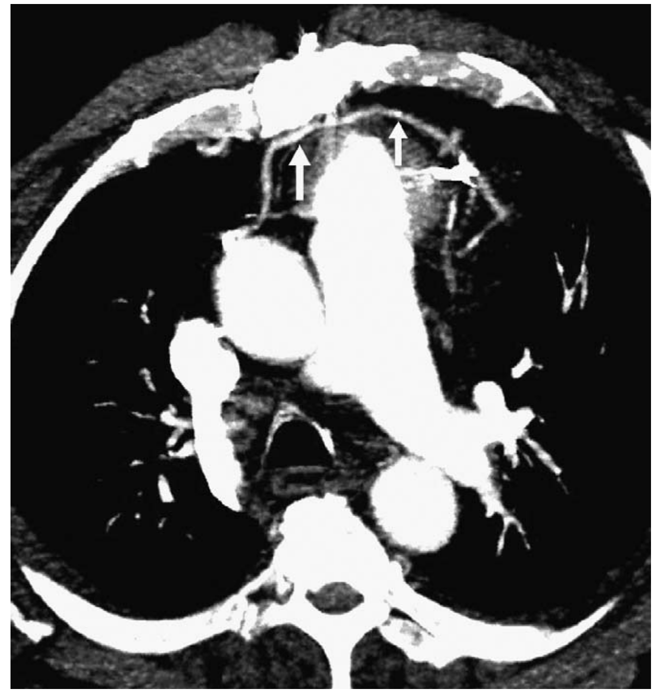

FIGURE 10. A 68-year-old man with prior CABG for reoperative cardiac surgery assessment. Axial MIP view demonstrates adherence of the saphenous vein graft to the inner table of the sternum (arrows).

FIGURE 9. A 81-year-old woman for evaluation of LV aneurysm resection. Oblique coronal volume rendered image defines the relation of the ribs, LIMA graft (arrow) and LV aneurysm (arrow).

FIGURE 11. A 72-year-old man for postoperative assessment of chest pain. Coronal volume rendered image shows radial artery graft from ascending aorta to circumflex territory (arrow). Note smaller caliber of the radial artery graft compared with the usual saphenous vein graft caliber.

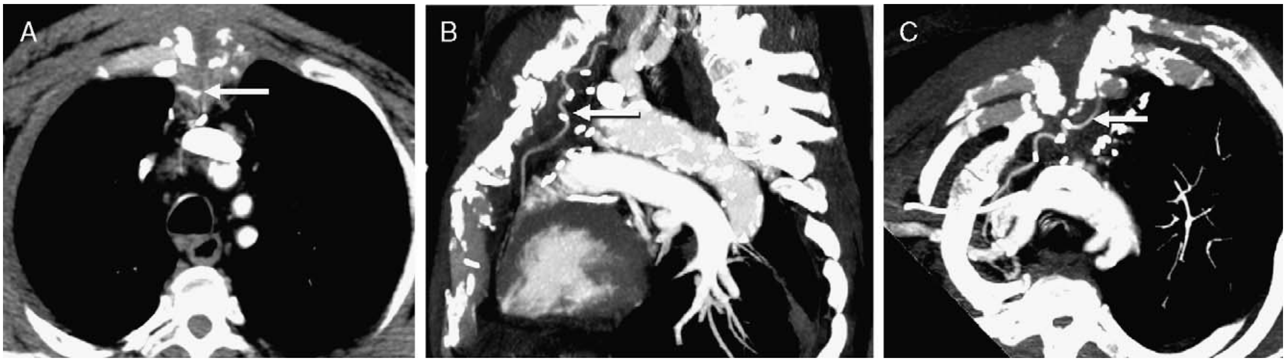

FIGURE 12. Patient with prior RIMA graft and postoperative mediastinitis. A, Axial image demonstrates enhancing vessel posterior to the sternum (arrow). B, Sagittal MIP views demonstrate the retrosternal course of the patient's RIMA graft through extensive mediastinal soft tissue (arrow). C, Curved MIP demonstrates the relation of the RIMA graft to dehiscent sternum and mediastinal soft tissue (arrow).

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