CT Reconstruction in Critical Limb Ischemia Planning

An overview of the available CT reconstruction techniques to plan CLI treatment.

BY BIRAJ B. BISTA, MD, AND JOHN MORIARTY, MD

Lower extremity peripheral artery disease (PAD) is estimated to affect about 8 to 12 million Americans.[1] Critical limb ischemia (CLI), defined as chronic ischemic rest pain, ulcers, or gangrene attributable to objectively proven arterial occlusive disease, is the most advanced form of PAD.[2] Because CLI is a severe manifestation of PAD, these patients are classified in the more severe ends of the Fontaine classification (stage III–IV) or the Rutherford classification (grades 4–6).[3] Endovascular therapies and surgical bypass are the main treatment modalities at present, and primary amputation is reserved for patients who are not candidates for surgical or endovascular revascularization.

CURRENT CT TECHNOLOGY

Detailed anatomic description of the inflow and runoff arteries is critical in treatment planning. The development of multidetector CT and, more recently, dual-energy multidetector CT have revolutionized the ability of CTA to acquire high-resolution isotropic data sets in a shorter acquisition time with a large field of view coupled with simple but robust image processing techniques. Various postprocessing techniques can reconstruct images of the arteries that are comparable to digital subtraction angiography (DSA). Axial images display relevant extravascular anatomy and are helpful to get a first impression of vascular anatomy and abnormalities; however, for most vascular disease, transverse image viewing is insufficient and requires viewing reformatted images.[4] Multiple postprocessing techniques are now available for better visualization of vascular pathologies.

Maximum Intensity Projection

Maximum intensity projection (MIP) consists of projecting the voxel with the highest attenuation value on every view throughout the volume onto a
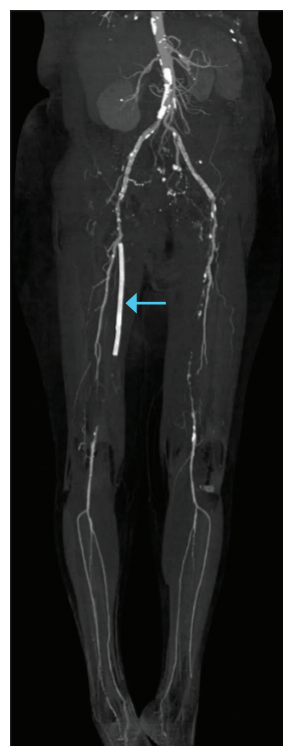

Figure 1. A MIP reconstructed image with automated bone removal. Patency of the stent (arrow) is not evaluable.

Figure 2. A 3D VR reconstructed image showing an iliofemoral bypass graft (arrow) and occluded native right pelvic arteries.

two-dimensional (2D) image. It provides the most "angiography-like" display of the vasculature, particularly when no or minimal calcification is present, and is ideal for communicating findings to the referring services and for creation of a "road map" for treatment planning (Figure 1).[4] One pitfall of MIP images is overestimation of the luminal narrowing in the presence of wall calcification because of partial volume effect and blooming artifact. In addition, MIP requires substantial editing of bone in most cases, which is a challenge when vessels lie close to bony cortex, such as near the anterior tibial artery and the tibia.[5] Newer automated bone removal software has shown promising results in this situation, although it is not a perfect tool. Another disadvantage of MIP images is the lack of three-dimensional (3D) relationship, which is why a combination of MIP and volume-rendered (VR) images is ideal for detailed comprehensive evaluation of the pathology.

Volume Rendering

Volume rendering displays a 2D projection of a 3D sampled data set and preserves the 3D depth information, unlike MIP (Figure 2). Bone may either be edited out or left for anatomic reference. Interactive adjustment of the opacity transfer function allows the user to blend in or carve out vascular detail when necessary.[4] It is the ideal tool for fast interactive exploration of peripheral CTA data sets. It should be noted that evaluation of vascular patency is limited in the presence of calcification and stents in MIP (Figure 1) and VR images. Hence, an adequate wide window setting (close to a bone window setting) is often used to help visualize the lumen of heavily calcified vessels and stents (Figure 3).

Multiplanar and Curved Planar Reformatted Images

Multiplanar reformatted and curved planar reformatted (CPR) images can prove very useful for evaluation of vascular patency in the presence of calcified plaque, diffuse vessel wall calcification, or endoluminal stents (Figure 3). CPR images display longitudinal cross-sections along a predefined vascular centerline. CPR does not require bone editing but entails manual or (semi-) automated tracing of the vessel centerlines and creation of at least two CPRs per vessel segment (eg, sagittal and coronal views) to fully evaluate eccentric disease process.[4]

Bony landmarks are not present in single CPR images, and hence, anatomic reference of a vascular lesion is not known. This limitation has recently been alleviated by reconstruction of multipath CPR images, which provide simultaneous longitudinal cross-sectional views
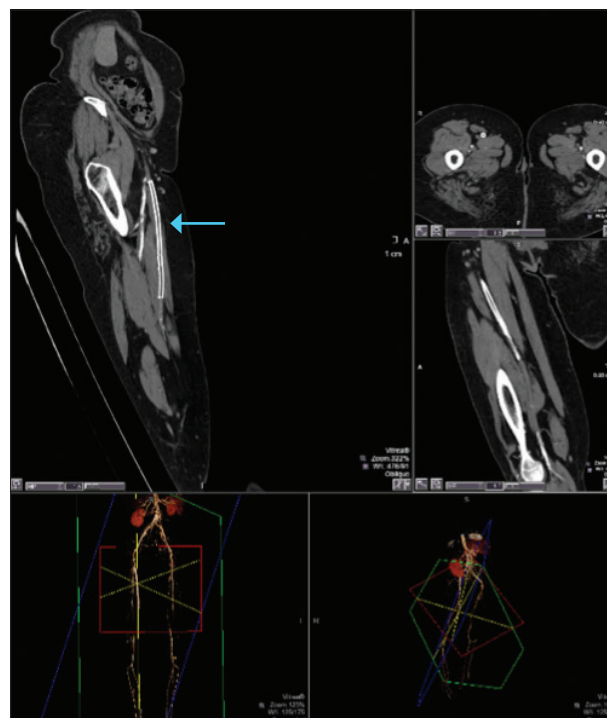

Figure 3. Multiplanar curved reconstruction with wide window setting shows occluded right superficial femoral artery stent (arrow). Simultaneous correlation with bony and soft tissue landmarks and 3D VR images are possible.

through the major conducting vessels without obscuring vessel wall calcifications and stents, while maintaining spatial perception (Figure 3).

Multidetector CT Limitations

Multidetector CT has some limitation regarding image postprocessing, particularly for bone removal and display of distal vessel segments in the presence of vascular calcification. Arteries in close proximity to bone, such as anterior tibial, peroneal, and dorsalis pedis, are frequently eroded by threshold-based bone subtraction technique.[5] Heavily calcified plaque in contact with the bone may also be removed along with bone. Such truncation can falsely resemble occlusion or worsen stenosis severity.[5]

Dual-Energy CTA

Dual-energy CTA is a new technique that offers differentiated tissue characterization based on CT density values derived from two synchronous CT scans at different tube voltages, and the iodine-calcium material differentiation reduces the incidence and severity of these artifacts.[6] In CTA of the lower extremities, two x-ray tubes operate at different tube potentials, usually 80 and 140 kV,

which leads to maximum density differences between contrast agent, bony structures, and vessel wall calcifications.[6] This offers optimum material differentiation that can easily be postprocessed using the automated dual-energy bone removal function in the post-processing workstation. Residual bone, if any, can be easily subtracted by user interaction in much less time.

Yamamoto et al showed that, overall, vessel visualization was significantly better when a dual-energy bone removal postprocessing technique was used compared with a manual bone subtraction postprocessing technique (Figure 4).[7] Using a combination of material attenuation differences and morphology, the software in dual-energy CTA identifies and removes calcified plaque from the vessel, leaving a lumenogram comparable to MRA or DSA images. Plaque removal works better in larger vessels (> 5 mm) and with higher concentrations of iodine within the vessels.[5] In smaller calf vessels with circumferential calcification, performance may be suboptimal because of accentuation of blooming artifacts and inability to remove the plaque by the image-based dual-energy calculations.[5,7]
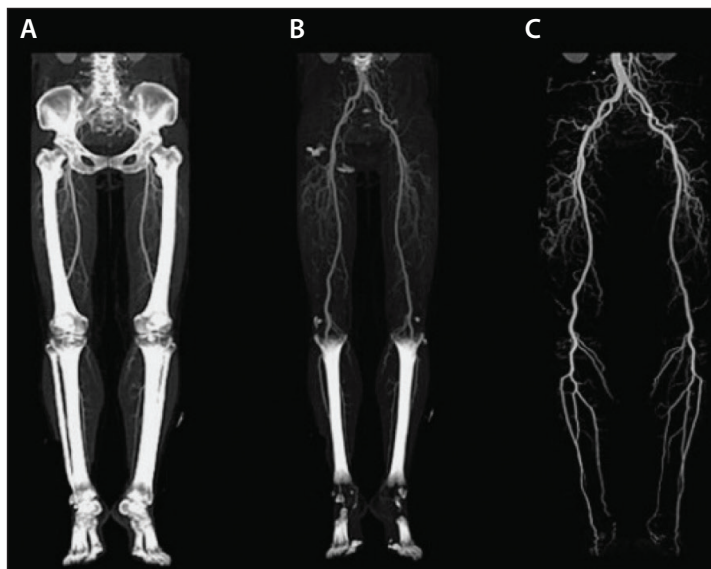

Figure 4. CTA images reconstructed with different algorithms. Original CTA data with no bone removal (A); arteries are largely obscured by bones. Manual bone subtraction: vascular tree partly obscured by bone remnants in the infrapopliteal region (B). Dual-energy bone subtraction: near-complete removal of bone remnants allows unobstructed visualization of arteries (C). Reprinted from Clinical Radiology, 64, Yamamoto S, McWilliams J, Arellano C, et al, Dual-energy CT angiography of pelvic and lower extremity arteries: dual-energy bone subtraction versus manual bone subtraction, 1088–1096, Copyright (2009), with permission from Elsevier.

CONCLUSION

Although significant refinements and advancement have been made in postprocessing techniques, including dual-energy bone subtraction and plaque removal, DSA is still superior for depiction of vascular stenosis and luminal diameter, especially in pedal runoff arteries. Hence, correlation with axial source images is very important. Further refinements of the software algorithm are needed to minimize vessel alteration in areas of heavily calcified plaques. However, due to the noninvasive nature of the study, rapid acquisition and reconstruction of high-quality images with great vascular detail and preservation of anatomic landmarks such as bony and soft tissue reference, CTA with proper reconstruction has become critical in planning surgical or endovascular revascularization in patients with CLI. ∎

1. Hirsch AT, Criqui MH, Treat-Jacobson D, et al. Peripheral arterial disease detections, awareness, and treatment in primary care. JAMA. 2001;286:1317-1324.
2. Schanzer A, Conte MS. Critical limb ischemia. Curr Treat Options Cardiovasc Med. 2010; 12:214-229.
3. Varu VN, Hogg ME, Kibbe MR. Critical limb ischemia. J Vasc Surg. 2010;51:230-241.
4. Fleischmann D, Hallett RL, Rubin GD. CT angiography of peripheral arterial disease. J Vasc Interv Radiol. 2006;17:3-26.
5. Vlahos I, Chung R, Nair A, Morgan R. Dual energy CT: vascular application. AJA Am J Roentgenol. 2012;199:S87-S97.
6. Brockmann C, Jochum S, Sadick M, et al. Dual-energy CT angiography in peripheral arterial occlusive disease. Cardiovasc Intervent Radiol. 2009;32:630-637.
7. Yamamoto S, McWilliams J, Arellano C, et al. Dual-energy CT angiography of pelvic and lower extremity arteries: dual-energy bone subtraction versus manual bone subtraction. Clin Radiol. 2009; 64:1088-1096.

Biraj B. Bista, MD
Clinical Fellow
Diagnostic Cardiovascular Radiology
David Geffen School of Medicine at UCLA
Los Angeles, California
bbista@mednet.ucla.edu
Disclosures: None

John Moriarty, MD
Associate Professor
Diagnostic and Interventional Radiology
Diagnostic Cardiovascular Radiology
David Geffen School of Medicine at UCLA
Los Angeles, California
(310) 825-0958; jmoriarty@mednet.ucla.edu
Disclosures: AngioDynamics, Argon Medical, and Sequent Medical.