Multi-detector row CT angiographic imaging of lower extremity vascular disease: A pictorial review

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Learning objectives

The purpose of this presentation is:

1. to learn the CTA scanning technique to acquire the data for the evaluation of patients with peripheral artery disease;
2. to describe the normal anatomy of peripheral arterial system on axial and reconstructed-3D images;
3. to illustrate the CTA findings of peripheral artery disease on axial and reconstructed-3D images.
Background

Digital subtraction angiography (DSA) is still considered the reference of standard in the assessment of lower limb arterial lesions, even if it is invasiveness, characterized by high cost and patient discomfort.

On the other hand, CT angiography is the application that has already most greatly benefited from the introduction of multi-detector row helical CT. Since the introduction of the first Multidetector-row CT scanners, additional improvements in scanner performance were observed, represented principally by the increased number of detector rows (up to 64 active detector rows) and faster tube rotation (less than 0.5 sec) with a subsequent decrease in the acquisition time. It allowed the analysis of large volumes (lower extremity) with thinner slice sections, improving spatial resolution (isotropic CT imaging) for the assessment of smaller arterial branches, principally including the peripheral arteries of the calves, with subsequent higher concordance with DSA.

In the last years some studies [1-5] have compared MDCT-angiography to DSA for the assessment of patients with peripheral vascular occlusive disease involving the lower limbs with excellent concordance, showing its potential as a screening modality alternative to DSA in selected patients prior to surgical/endovascular revascularization. MDCT-angiography, compared to conventional angiography, is non-invasively, less costly and faster, doesn’t require of an angiographic team to perform the exam and permits a wider variety of manipulation of the volumetric data set for image display. As a matter of fact, once acquired CTA data can be also viewed from unlimited projections in both 2D and 3D modes, such as maximum intensity projection (MIP), shaded surface display (SSD), or volume rendering technique (VRT) that are able to both analyze vascular anatomy as well as pathologic conditions. Furthermore, CTA provides in-depth information on the vessel lumen, vessel wall and surrounding structures.
CT angiography CTA exam has to be performed by using a 64-row scanner before and during infusion of contrast medium (370-400 mgI/ml). Patients were in the supine position with their feet first.

A thick-slice pre-contrast acquisition must always be performed to reveal calcifications and to plan the following contrast-enhanced examination, by selecting the volume of acquisition and placing a region of interest in the aorta at the level of the aortic arch.

Thin-slice arterial-enhanced images are obtained from 2 cm above the origin of renal arteries to the ankle. CTA-acquisition protocol parameters are the following: 0.625x64mm collimation, 0.7-second gantry rotation, pitch 0.9; scan duration ranged between 18 and 25 seconds.

Contrast-enhanced images are obtained during bolus intravenous injection of 80-120 ml of a high-concentration iodinated non-ionic contrast medium (370-400mgI/mL) + 40mL of saline solution, administered with an automated injector at a flow rate of 4 ml/s via an antecubital vein.

A very important achievement in CT-angiography is the optimal contrast-medium dynamic. As a matter of fact, scanning should start when the examined structured have reached an ideal level of opacification; therefore, scan delay has to be individualized per patient, using bolus-tracking software. However, with the increased speed of the new scanner generation (until 90 mm/sec possible with a 64-detector row scanners), if the CT data acquisition is initiated at the time of contrast medium bolus arrival in the aorta, the CT acquisition may outpace the bolus, with resultant inadequate opacification of arteries.

To avoid this problem, we suggest to decrease the table speed (until to 30mm/sec) increasing the scanning delay by selecting an appropriate "diagnostic delay" (interval of time between automated detection of the contrast medium bolus arrival within the target vessel and the real initiation of the CT angiographic data acquisition).

Our contrast-medium injection protocol suggest to use a bolus-tracking software capturing 150 HU on the abdominal aorta, at the level of the celiac trunk, to trigger scanning and ensure a correct peak enhancement, by adding a diagnostic delay of 8 seconds in order to avoid to outpace the bolus.

In a limited number of patients with large aorto-iliac and femoro-popliteal aneurysms, an optional second acquisition (from the knees to the feet) should be preprogrammed and initiated immediately after the first acquisition if reconstructions of the initially acquired CT data show no opacification of the distal arteries.
CTA examination must be complemented by postprocessing reconstructions, including maximum-intensity projection (MIP), curvilinear reformation (CVR) and volume rendering (VR).

NORMAL ANATOMY

Normal anatomy of peripheral system on axial and reconstructed-3D images is described and compared with anatomical and angiographic images (Fig 1-13).

STENO-OBSTRICTIVE DISEASE

Peripheral occlusive artery disease (POD) is estimated to be present in 1.4 to 1.9% of people at the age of 40-49 years, in 6.9% of people at the age of 50-59 years, and in 20% of people over 70 years. Critical limb ischemia has a mortality rate of 46% at 5 years and a percentage of 27% of amputations at 1 year [6-7]. However, revascularization strategies including surgical and endovascular procedures guarantees success in terms of functional recovery of the ill limb, as well as in terms of duration in time. Clinical evaluation and accurate and timely diagnostic work-up are mandatory in order to assess the morphological and functional features of the lesion to establish the appropriate therapeutic approach (medical/ surgical/endovascular therapy).

CTA is a highly accurate and precise technique for determining the degree and the length of stenosis. Initially, all images should be reviewed in the axial plane. 3D-images are always helpful.

The degree of stenosis is generally calculated according to criteria developed by the European Carotid Surgery Trial (ECST): measurements are made across the lumen through the narrowest portion compared to the original arterial outline. The degree of stenosis is reported as a percentage of stenosis: I: normal; II (1%-29%): mild; III (30%-69%): moderate; IV (70%-99%): severe; and V: occlusion (Fig 14).

Lesions may be smooth, irregular, or focal, or they may involve a long segment.

Special consideration must be given for critical degrees of stenosis, often termed the "string sign". The presence of contrast agent in a markedly restricted lumen may be an indication of a critical proximal focal stenosis or longer segmental narrowing.

Indirect signs of significant stenosis are represented by the presence of post-stenotic focal vessel dilation (reversible post-stenotic ectasia) as well as by the uniform vessel lumen reduction below the stenosis, indicative of a flux reduction (Fig 15).

CTA is also the best modality for analyzing plaque morphology because it allows visualization of the atheromatous plaque. There are three type of plaque: soft plaques, that shows a mean density of 14 ± 26 HU (ranging from -42 to +47 HU), intermediate plaques, that shows a mean density of 91 ± 21 HU (ranging from 61 to 112 HU), and
calcified plaques, that shows a mean density of 419 ± 194 HU (ranging from 126 to 736 HU). Detection of ulcerated plaques may prove to be mandatory, since it has been suggested that the presence of plaque ulceration is a risk factor for embolism.

CT sign of ulcerated plaques on axial images is represented by an intraluminal linear contrast material filling defect which has to be differentiated by intimal flap/dissection (Fig 16).

False-positive results are related to motion artifacts. Sudden movement, breathing, or swallowing by the patient during scanning may result in a misregistration of the axial images on 3D or multiplanar reformatted images. Principal limitation of CTA are represented by the presence of diffuse cuff calcifications in the smaller arterial branches of lower limbs which enable an accurate definition/grading of steno-obstructive lesions.

ANEURYSMAL DISEASE

Aneurismal pathology is a local, irreversible, vascular caliber increasing over 50% of the previous and next tract. They are usually found during the 6th and 7th decades of life and have a strong male predilection with a prevalence of 2% in population and 5% in population >65 years old.

Aneurysms are classified with regards: istopathology; morphology; etiology; location.

Istopathological classification divides aneurysm in true and false according to the complete or not interesting of all arterial wall layers. They are also divided in terms of morphological aspect into sacciform and fusiform depending of complete or not involvement of the vascular circumference. Aneurysms may rarely be associated with connective tissue diseases such as Marfan syndrome or Ehlers-Danlos syndrome or, even more rarely, with pregnancy. Almost all true aneurysms are non-specific. Historically, the nonspecific form of aneurysmal disease that affects the abdominal aorta and the iliac femoral, and popliteal arteries has been described as "atherosclerotic".

Risk factors associated with atherosclerotic disease are also associated with non-specific aneurysms. However, atherosclerotic disease and these risk factors incompletely define the cause of these aneurysms, which appears to be multifactorial. Finally they are classified in: central (aortic), visceral (splanchnic and renal) and peripheral (cervical and of limbs). 80% of aneurysm involves aortic wall under the emerging of the renal branches; 25% of them involve the iliac bifurcation too. Poplitreal aneurysms (PAAs) are the most common peripheral aneurysms (PAAs). PAAs are associated with aneurysms in other locations and are bilateral in 50%-70% of cases; as a matter of fact, in patients with a PAA, it is mandatory to look for Abdominal Aortic Aneurysm and/or a controlateral PAA [8-9].

Many patients with poplitreal aneurysms are asymptomatic at the time of diagnosis; symptomatic patients can present with a lower-extremity ischemia, which can manifest as
claudication, rest pain, or severe ischemia associated with thrombosis or embolization. As a matter of fact, patients with popliteal aneurysms have a risk of limb-threatening thrombotic complications, with embolization and above all rupture, with an incidence of 18-31% [10-11].

CTA allows identification of the aneurysm and differential diagnosis from ectasia (caliber increasing less than 50%), the description of the lesion, evaluating location, length, extension, transverse diameter (valuated always perpendicularly to major vascular board), presence of calcifications and location of thrombotic apposition (concentric/eccentric) measuring its maximum thickness, evaluating the look of its edges and excluding the possible presence of iperdensity that can suggest an instable nature of the thrombus.

3D-images are particularly useful in planning surgical/endovascular treatments, demonstrating the degree of extension of the aneurysm in the coronal and sagittal planes and the relationship between the aneurysm and the adjacent structures [10-11] (Fig 17).

**POST-TREATMENT LESIONS**

**SURGERY**

Infrainguinal arterial bypass (IGAB) is an established surgical procedure for the treatment of complications of peripheral vascular disease, aneurysms, and lower extremity trauma. IGABs are usually classified according to the location of the anastomoses. The most common type of bypass is the one created between the common femoral artery (CFA) and the popliteal artery, also known as a femoropopliteal bypass. This type is further classified as an above- or below-knee bypass, depending on the segment of popliteal artery used (Fig 1). More distal bypasses between the CFA and distal crural vessels are known as femorodistal bypasses. The type of material and technique used for the bypass are also commonly used to further describe the different bypass types. IGAB can be created with autogenous vein by using the greater saphenous vein (GSV) in a reversed or non-reversed fashion or with an in situ technique. When the GSV is not available, some surgeons may elect to use the lesser saphenous or arm veins. If multiple pieces of vein are put together, this is known as a spliced conduit. Biologic grafts include human umbilical vein, cadaveric cryopreserved vein, and arterial homografts. They have the advantages of being readily available. However, biologic grafts are not commonly used because they are very expensive and prone to aneurysmal degeneration. The use of biologic grafts is usually limited to limb salvage in cases of previous infections or when no other conduit is available [12].

Prosthetic grafts (tubular expanded PTFE: polytetrafluoroethylene -PTFE- and polyester -Dacron) are the material of choice in the absence of suitable autogenous vein. It is available with external support rings or coils (Fig 3), which are created to decrease mechanical external compression and avoid the risk of kinking when placed across the knee joint [13]. Prosthetic grafts have a higher frequency of thrombosis (Fig
(12), anastomotic aneurysms, intimal hyperplasia, and structural deterioration than autogenous vein bypasses, as well as a higher rate of graft infections and greater need for repeat surgery [13] (Fig 13).

Complications related with peripheral bypass are related to intimal hyperplasia, which occurs at anastomotic sites, areas of vein repair, and sites of valve incisions; on the other hand, it has to be excluded eventual aneurismal degeneration (Fig 14, 15) [13].

In the evaluation of peripheral bypass, it has to be evaluated the inflow and run-off and excluded eventual findings suggestive of graft infection (Fig 16) such a peri-graft fluid, pseudoaneurysm, air collection or fistula. It also has to be evaluated the caliber of bypass, excluding eventual structural alteration or extravascular compression (Fig 17). Finally, it's mandatory to detect/exclude other findings that may jeopardize the patency of the graft such as arteriovenous fistula or nonligated branches (Fig 18). Local complications are represented by hematoma (Fig 19) or lymphoceles [13].

**ENDOVASCULAR TREATMENT**

In recent years, peripheral arterial occlusive disease (intermittent claudication and critical limb ischemia) has been increasingly treated by endovascular procedures (PTA/stent placement).

Stents are expandable devices that are delivered to the peripheral artery via catheter and then expanded to preserve the luminal diameter.

However it's reported that the clinical incidence of restenosis after stent implantation is high to 22-66% for stainless steel stents and 15-49% for nitinol stents and it's frequently subclinical.

Occurrences that may limit the success of stent implantation include early and late complications. Early complications are different and include thrombosis, graft malposition or kinking, graft spasm, iatrogenic complications. Late complications are stent infections, embolism, late stenosis and occlusions.

The first mechanism for stent failure within is thrombosis, which result from a combination of endothelial and medial damage. Early stent occlusion can also derived from malposition or kinking but also from a postoperative spasm. Iatrogenic causes of early stent placement failure are the damage of vascular endothelium and vessel dissection.

Late reducing of flow throughout the stent derived from the progressive thickening of the media and neointimal formation, which begins within days of implantation and continues over months to years. These changes form a foundation for eventual atherosclerotic narrowing, which may ultimately lead to late graft occlusion.
CTA allows direct visualization of the stent struts and lumen and this is fundamental for a more reliable assessment of in-stent patency because distal run-off cannot be considered a reliable indicator of it, because contrast material can fill of the peripheral artery distal to the stent via collateral arteries, which may obscure the real pathologic lesion inside the stent.

The stent may be considered to be occluded if the lumen inside the device appears darker than the contrast-enhanced vessel lumen proximal to the stent.

Nonocclusive in-stent neointimal hyperplasia is characterized by the presence of a darker rim between the stent and the contrast-enhanced vessel lumen (Fig 20) and is secondary to the healing response to procedure-related vessel injury. If neointimal hyperplasia exceeds a luminal diameter reduction of 50%, the process is consistent with hemodynamically significant in-stent restenosis.

In the post-PTA follow-up, it has to be evaluated the patency or restenosis/occlusion of treated vessel, looking for procedural complications, as well as intimal dissection, vessel rupture and/or distal embolization [15].

TRAUMATIC LESIONS

Diagnostic queries concerning acute vascular disorders involving the arteries of the lower limbs are not very common, but have a significant clinical impact. An early diagnosis together with an accurate and detailed morphological and functional assessment of the involved arterial area is necessary to select the most appropriate treatment and give the patient the best chances of success.

In the last few years many studies have compared MSCT angiography to DSA for the assessment of patients with peripheral arteriopathy involving the lower limbs, with an excellent concordance between the two methods.

Traumatic arterial lesions are classified as a partial or complete obstruction (rapid change in caliber or loss of opacification of vessels) (Fig 21), arterial laceration (spreading of contrast medium), pseudoaneurysm (extravascular collection of contrast medium), arteriovenous fistula (early opacification of venous structures) (Fig 22), or intimal flap (intraluminal linear contrast material filling defect).

A limitation of MSCT angiography can be the possible presence of streak artifacts due to metal bodies in the event of penetrating traumas that may render the CT angiogram uninterpretable [16].
Fig. 0: Anatomy: aorto-iliac district. Axial images obtained at the level of abdominal aorta (a), aortic carrefour (b), common iliac arteries (c), and external and internal iliac arteries (d).

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Fig. 0: Anatomy: femoro-popliteal district. Axial images obtained at the level of common femoral artery (e), femoral bifurcation (f-h).
Fig. 0: Anatomy: popliteal-infrapopliteal district. Axial images obtained at the level of proximal popliteal artery (i), popliteal artery (j), distal popliteal artery (k), and anterior tibial artery and tibio-peroneal trunk (l)

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Fig. 0: Anatomy: infrapopliteal distric - foot. Axial images obtained at the level of anterior tibial, posterior tibial and peroneal arteries (m, n) and pedideal artery and plantar arch (o)

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Fig. 0: Anatomy: Aorto-iliac district. MIP- and VRT-images.

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Fig. 0: Anatomy: Femoro-popliteal district. MIP- and VRT-images.
Fig. 0: Anatomy: Infracpopliteal district. MIP- and VRT-images.
Fig. 0: Anatomy: Foot. VRT-images.

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Fig. 0: MIP- and VRT-images: steno-obstructive disease

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Fig. 0: MIP images: indirect signs of steno-obstructive disease

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**Fig. 0:** Axial and MIP-images: ulcerated plaque

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**Fig. 0:** MIP- and VRT-images: popliteal aneurysm

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**Fig. 0:** Axial and VRT-images. Bilateral femoro-popliteal bypasses (R: occluded; L: patent)

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**Fig. 0:** MIP- and VRT-images: aortic and peripheral bypasses

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Fig. 0: MIP-images: distal anastomotic peripheral bypass stenosis

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Fig. 0: MIP- and VRT-images. distal anastomosis peripheral bypass pseudo-aneurysm

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Fig. 0: Axial images: graft infection

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Fig. 0: Axial images: bypass structural alteration

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Fig. 0: Axial image: structural alteration

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Fig. 0: MIP-images: Femoro-popliteal bypass with a venous conduct: nonligated venous branches

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**Fig. 0:** Axial images: left inguinal hematoma

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**Fig. 0:** VRT- and MIP-images. Superficial femoral stenting

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**Fig. 0:** MIP- and VRT-images. Traumatic lesion

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Fig. 0: MIP- and VRT-images. Traumatic lesion

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Conclusion

Due to the rapid diffusion of the application of MDCT-Angiography in the assessment of patients with peripheral arterial disease, it's mandatory that not only vascular/interventional radiologists but every images should be familiar with the acquisition technique and the full gamut of possible anatomic variants as well as pathological alterations on both axial and 3D images.
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