MDCT angiography in the evaluation of arteriovenous fistulas and grafts in patients undergoing haemodialysis: when, how and why.

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Learning objectives

The increasing number of patients with end-stage renal disease now undergoing hemodialysis needs maintenance of an adequate vascular access function. A patent arterio-venous fistula (AVF) is related to better prognosis and quality of life for these patients. When an AVF failure (AVFf) is suspected, multi-detector computed tomography angiography (CTA) is an effective non-invasive tool for evaluating the entire vascular tree and determining reversible conditions to treat. The aim of this exhibit is to present the basic concepts regarding the clinical indications, acquisition technique and diagnostic capabilities of CTA, illustrating the conditions related to early and late AVFf.
Background

Native AVF comes the closest to be an ideal vascular access in patients undergoing long-term hemodialysis when compared to synthetic grafts, the first having the best long-term primary patency rates and requiring fewest interventions [1]. Either a native or graft AVF has a lower morbidity and better prognosis than a central intravenous catheter [2]. However, immediate thrombosis, failing to mature AVF or even early fistula failure might develop. Repeated AVF puncture may lead long-term fistula failure and other complications such as stenosis, infection, arterial steal syndrome, venous hypertension, aneurysm formation and congestive heart failure [3-4]. These complications account for much of the morbidity, hospitalization (15% of all admissions) and costs incurred by chronic dialysis patients. Since patency and function of an AVF are related to the prognosis and quality of life of patients [5], when a complication at vascular access sites is suspected, early diagnosis and salvage before failure is important [6].

Types of AVF

The three basic types of AVF are herein listed in their order of preference for creation as recommended by the National Kidney Foundation K/DOQI guideline 3 [7]:

1) Radial-cephalic
2) Brachial-cephalic
3) Brachial-basilic transposition
4) Arterio-venous graft

The arterio-venous anastomosis can be achieved in different ways (Fig. 1 on page 8):

1) Side to side
2) End to side
3) Side to end
4) End to end

Radial-cephalic fistula
It is easily created through an end-to-side vein to artery surgical anastomosis (Fig. 2 on page 8). The previously used Cimino-Brescia fistula was created through a side-to-side anastomosis and could be complicated by venous hypertension in the hand. The radial-cephalic has lower blood flow with respect to the other two varieties of native AVF, but its use as first access preserves the upper arm for later attempts. It has been demonstrated the primary patency of this fistula to be inferior with respect to brachial-cephalic and brachial-basilic ones [8].

**Brachial-cephalic fistula**

It is more easily created than the brachial-basilic one, unless a long segment of cephalic vein needs to be mobilized closer to the skin, as happens in obese patients (Fig. 3 on page 9a). Due to the lateral and superficial location of its outflow tract, this fistula presents a long segment from which to select cannulation sites. This access can ensure higher blood flow than the radial-cephalic one but also presents a higher incidence of steal syndrome.

**Brachial-basilic transposition**

It requires more surgical skills in its creation and is associated with more patient morbidity (Fig. 3 on page 9b). To make the basilic vein suitable as a dialysis access, it must be both elevated (to make it superficial in its proximal tract) and transposed (to move it from a medial position to an accessible location). Because of its deep location, it tends to be better preserved and less involved with thrombotic and post-phlebitic changes. However, basilic vein is shorter than the cephalic one, especially if it joins brachial vein very low in upper arm. Therefore, the brachial-basilic fistula has got a less potential cannulation area with which to work. Steal syndrome tends to be more common due to the larger size of basilic vein and because this venous outflow is primarily used in patients with multiple prior failed access procedures, hence with higher incidence of atherosclerotic disease.

**Arterio-venous graft**

The possibility of creating each of the three types of native AVF should be exhausted before consideration is given to the insertion of a synthetic graft, since each of them is superior to it [9]. Grafts are constituted by polytetrafluoroethylene (PTFE) implants. The two most common types of arterio-venous graft are shown (Fig. 3 on page 9c-d).

**Clinical assessment**

Evaluation of AVFf must begin with careful analysis of clinical information and a thorough physical examination. Insight into the problem is often obtained by talking with the dialysis personnel and finding out where dialysis needles were located. According to the literature [10] a complete physical examination of an AVF should comprise:
- Inspection of the arm, shoulder, breast, neck and face, with assessment of edema or collaterals
- Palpation from anastomosis up to the chest wall, with assessment of pulse (hyper-pulsatile, normal, weak) and thrill (continuous, discontinuous) characteristics
- Auscultation

A high-venous resistance on dialysis, venous hypertension with swelling of the hand, loss of the thrill or bruit, replaced by prominent pulsation, are all suggestive of proximal vein stenosis or occlusion. On the contrary, poor arterial inflow is indicative of a stenosis below the arterial needle, usually in the peri-anastomotic section of proximal vein. These findings alone can almost always localize the site of lesion and are of great value to the radiologist in planning subsequent diagnostic procedures. The following maneuvers can also be performed [11]:

- Pulse augmentation test (to evaluate inflow) complete occlusion of the access several centimeters beyond arterial anastomosis and evaluation of the strength of pulse: negative if the portion of fistula upstream from occluding finger demonstrates pulse augmentation

- Arm elevation tests (to evaluate outflow) elevation of the AVF arm and examination of normal collapse of the access: positive if the fistula remains plump

Physical examination, measurement of recirculation flow, monitoring of venous pressure and non-invasive imaging techniques, such as color-Doppler sonography (CDS), are used to screen patients for possible complications of the AVF [12]. Before repeating surgery, digital subtraction angiography (DSA) was the method of choice for detecting and grading an AVF stenosis [13], with the possibility to perform percutaneous interventions. Recently, new applications have been found for magnetic resonance angiography (MRA), but a key role has been assumed by computed tomography angiography (CTA).

**Computed tomography angiography**

Rapid advancements in multi-detector computed tomography (CT) with three-dimensional (3D) reconstruction techniques have resulted in new diagnostic applications. CTA is known to have high spatial and temporal resolution, with great anatomic coverage, becoming an established, minimally invasive tool to image most major vessels. Research
on various portions of the vascular system, such as the brain, chest, abdomen and lower extremities [14], has shown CTA to clearly depict stenoses, ulcers, pseudoaneurysms, calcifications, plaques, intimal thickening and stent ingrowth [15]. CTA has been reported to be reliable for assessing peripheral arterial grafts, being capable of correctly identifying the different causes of AVF [16]. This modality allows imaging a hemodialysis access with very high overall accuracy, sensitivity, specificity, positive and negative predictive values for lesion detection, these values being 98.3%, 98.7%, 97.5%, 98.8%, and 97.2% respectively in a study by Ko et al [14]. Furthermore, CTA allows to plan, in accordance with the clinician, the surgical/interventional treatment most adequate for each patient. Multi-detector scanners from 4-slices to superior are feasible for evaluating the complete vascular tree of an AVF [17]. We will share the protocol we use with our 64-slices CT scanner.

**CTA examination protocol**

Before examination, an 18-20 gauge cannula is placed in a superficial vein of the arm contralateral to the AVF side. We prefer positioning the patient supine, raising the AVF arm overhead in order first to reduce beam attenuation artifacts due to presence of the body near to examined limb, secondly to spare radiations to the patient. Conversely, some authors prefer to place the AVF arm alongside the body, leaving a small gap between the two in order to avoid vein compression, performing the CT acquisition in a cranio-caudal orientation [19], so as to avoid motion artefacts due to the uncomfortable position assumed with the arm raised up by usually older patients.

Compared with central arteries, those of the upper limb have a typical slow distal flow because of branching and decreasing diameters of vessels. Thus, to opacify native arteries supplying the hand, particularly in case of an AVF stealing blood to peripheral districts, a relatively low flow rate and long post-threshold delay are needed. The acquisition range should extend from thoracic outlet to the end of fingers in a dynamic phase in which both the AVF arterial inflow and venous outflow tract up to right atrium, are filled with contrast. The bolus-tracking technique is employed, with a region of interest (ROI) placed in ascending aorta. To obtain reproducible and good enhancement in patients with different body weights, the contrast-covering time (CCT) concept is used for determining flow rate and post-threshold delay [20]. The key point of CCT is to emphasize total duration of contrast injection, not just contrast volume or flow rate alone. Good and homogeneous enhancement will be obtained if scanning starts in the middle of contrast injection interval, that is bolus geometry will be optimal if scanning time window "rides on" the peak of time-attenuation curve. According to our experience, a post-threshold delay of about 10 s and a flow rate of 3 ml/s can be used to obtain a reproducible enhancement. Therefore, as CT attenuation exceeds 150 HU in the ROI, scanning will start in a caudo-cranial direction. About 90 ml (350-370 mgI/ml) iodinated contrast medium are injected followed by 30 ml saline chase. Acquisition parameters are:

- pitch 1.2
• collimation 64 ×0.625 mm
• rotation time 0.5 s
• tube voltage 120 kV
• planned effective tube current 180 mAs (automated tube current modulation turned on)
• field of view (FOV) 40 cm

Axial source images are reconstructed for interpretation using an interpolation algorithm of 1 mm slice thickness and 1 mm interval, with a soft-tissue filter. Mean effective dose is generally inferior to 1.5 mSv [21].

Image interpretation and post-processing

Since an AVF for hemodialysis contains dilated, tortuous, and displaced vessels, it is difficult to realize its structure basing solely on axial images, even if they are useful in evaluating the relationship with extra-vascular structures. Thus, a dedicated post-processing workstation should be used for interpretation. We start scrolling 1 mm slice thickness axial images examining the aorta, subclavian artery, feeding artery, the arterio-venous anastomosis and its draining veins up to SVC, to determine if there is an anomaly. For any suspect lesion, two-dimensional (2D) image reconstructions, such as maximum intensity projection (MIP), multi-planar reformation (MPR), curved multi-planar reformation (cMPR), as well as 3D volume rendering (VR) techniques, should be used interchangeably to complete the evaluation [22]. In addition, a variable degree of opacity can be chosen for both vascular and surrounding structures, avoiding difficulties in interpretation due to superimposition [23]. Axial MIP images can be obtained using 10 mm thickness and 5 mm gap to cover a longer segment in the axial plane, whereas coronal MIP are constructed using 5 mm thickness and 3 mm gap. VR images are viewed by the radiologist in the axial, sagittal, and coronal orientations. In some cases, VR with soft tissues visualized in transparency are useful to show the position of clinically hidden vessels suitable for puncture (Fig. 4 on page 9a), whereas VR images for skin well depict the course of collateral vessels, (Fig. 4 on page 9b).
Fig. 1: Different types of arterio-venous anastomosis.

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Fig. 2: Surgical view of a side to side (a) and side to end (b) radio-cefalic AVF.
Fig. 3: Schematic view of a brachio-cephalic (a) and brachio-basilic transposed (b) AVF. Diagrams illustrate the most common types of arterio-venous grafts: straight radial artery-antecubital vein (c) and brachial artery-antecubital vein"loop" or bridge graft (d). Grafts are shown in green. A: artery, V: vein.
**Fig. 4:** VR with soft tissues in transparency (a) may indicate the position of a non palpable vessel suitable for cannulation, while VR for skin (b) are optimal for visualization of collaterals.

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Findings and procedure details

Once a fistula is created it must develop to the point that it is usable. This requires adequate blood flow volume (> 500 mL/min) and physical characteristics allowing for repetitive cannulation. After creation of an AVF, changes in pressure and flow will stimulate vessels to remodel. Normally within 4-8 weeks, the AVF dilates and matures enough to sustain the flow needed for efficient hemodialysis (Fig. 5 on page 19) [24]. The AVF physical characteristics are somewhat harder to judge, some of these being measurable, others involving subjective elements difficult to quantify. Generally they relate to the AVF size, position in the arm, configuration depth and how it feels. However, chances that a fistula will be adequate for dialysis are 95% if a 0.4 cm minimum fistula diameter and a 500 ml/min minimum flow volume are obtained, versus 33% if none of this criteria is met [25]. Nevertheless, 20-50% of all AVFs fail to mature [26]. Failure is classified as early and late.

Early fistula failure

It is defined as an AVF which never developed to the point that it could be used or one that failed within the first 3 months [24]. The distinction between early and late failure is made because there are certain lesions that are seen in each of the two categories only. CTA is effective in evaluating these causes. It is important to realize that most of problems can be obviated by proper patient evaluation prior to perform an attempt at access creation.

Arterial stenosis

Both maturation and adequacy of an AVF are dependent upon pressure and volume of flow. Early failure can be correlated with pre-existing arterial anomalies, such as an artery that is too small for creation of a functional access or presence of atherosclerosis. If there is a stenotic lesion localized from aorta up to the feeding artery, blood flow is restricted and cannot dilate the AVF. Fortunately, an arterial stenosis can be preoperatively surveyed by patient history (subclavian steal syndrome), non-invasive tests (blood pressure difference between arms) and physical examination (Allen test). Moreover, preoperative vessel mapping using CTA is also helpful in identifying such lesions.

Juxta-anastomotic stenosis

Juxta-anastomotic stenosis (JAS) is a specific type of stenosis located within 5 cm from the anastomosis, usually on its venous side, and is the most common cause of early fistula failure [27, 28]. The underlying pathophysiology of JAS is considered to be neointimal hyperplasia, occurring in the segment of vein that is mobilized and manipulated by the surgeon in creating the fistula [24]. It may be related to stretching, torsion or other types
of trauma. This lesion can generally be successfully treated by percutaneous angioplasty [28] or surgery [29]. It is important to realize that JAS can be easily diagnosed by physical examination [10, 11], being also characterized by a typical appearance on CDS (Fig. 6 on page 19).

Proximal vein stenosis (from anastomosis to central veins)

It is the second most common cause of early fistula failure. Veins too small for fistula development, fibrotic or stenotic due to past trauma such as venipuncture, can be the cause. Thus it is important to identify critical stenoses before long-segment thrombus formation to improve the rate of AVF salvage. According to the literature [24], if no extrinsic compression or preexisting stenosis can be identified, proximal vein stenosis is most likely caused by neointimal hyperplasia.

Central vein stenosis (subclavian, brachiocephalic veins and SVC)

Central vein stenosis is usually caused by previous dialysis catheter insertion (Fig. 7 on page 19), less commonly by a thoracic outlet syndrome (TOS). Even without previous catheter insertion, central vein stenosis could still develop solely due to increased flow. Left brachiocephalic vein is also prone to stenosis because it courses between the sternum and aortic arch, especially in post-sternotomy patients.

Accessory veins: dispersed flow

Since flow is dispersed in several branches, it causes decreased wall shear stress, which is a key factor in vessel dilatation and remodeling, leading to AVF maturation failure. The presence of accessory veins is usually recognized and treated by the surgeon at the time of fistula creation. However, all veins receiving drainage from the newly created anastomosis enlarge, a small accessory vein usually dilating with time. The vein constituting an AVF may have side branches, referred to as accessory veins, which should be distinguished from pathological collaterals, always associated with a downstream stenosis. The presence of accessory veins, single or multiple, may be viewed as an advantage, since the patient may develop additional venous channels suitable for cannulation. However, because of the increased effective cross-sectional area represented by multiple vessels, downstream resistance decreases and this can result in early AVF. Surgical ligation or endovascular occlusion of accessory veins could be an effective salvage procedure to convert a branched unusable fistula into a functional AVF [30]. Not all accessory veins need to be obliterated. Significance of an additional venous structure can be judged by its size and apparent blood flow, small accessory veins seldom contributing significantly to fistula failure. In general, an accessory vein less than one-fourth the diameter of main fistula is unlikely proven to be significant. Accessory veins, along with JAS, represent the two most common causes of early AVF failure.
that have been properly evaluated prior to access creation [24], these two lesions often occurring together [31].

**CT findings**

CTA is an effective diagnostic tool, as sensitive as DSA, in detection and grading of stenoses at various segments of the entire vascular tree (arterial, juxta-anastomotic, venous) in dysfunctional hemodialysis fistulas [14]. A vessel is defined stenotic if reduced in caliber, some authors using a 5-point grading scale to classify a lesion [17]:

- grade 0 for stenoses from 0 to 25%
- grade 1 for stenoses from 25 to 50%
- grade 2 for stenoses from 50 to 75%
- grade 3 for stenoses greater than 75%
- grade 4 incase of total occlusion

However, an AVF diameter reduction of 50% or more is considered hemodynamically significant, whereas an exact differentiation of flow-limiting grade 2 from grade 3 stenosis, from a practical standpoint, is not absolutely necessary, both conditions requiring interventional angioplasty.

Axial images are useful for better grading of stenoses, but VR guarantees a good panoramic view for AVFs. However, inflow arteries and the anastomosis itself cannot always be visualized clearly on VR images, so that an AVF should always be interactively evaluated on a workstation monitor to find viewing angles appropriate for different segments. Sometimes VR images show decreased enhancement and inadequate visualization of a vascular segment whose continuity is not clear (Fig. 8 on page 20a). A vessel not visualized on VR does not necessarily mean that is occluded, since this segment could be severely stenosed or of small caliber. Therefore 2D post-processing techniques, such as MPR, should be used for confirmation (Fig. 8 on page 20b). Moreover, if no extrinsic compression or pre-existing stenosis can be identified, proximal vein stenosis is most likely due to neointimal hyperplasia.

**Late Fistula Failure**

It is defined as a failure occurring 3 months after fistula creation. Primary causes of late failure are venous stenosis and acquired arterial lesions. These anomalies manifest as pathological changes in the fistula from increased pressure and decreased flow, leading to inadequate dialysis and eventually thrombosis. It is important to realize that lesions typical of early failure are also commonly seen during this late period, since they are not addressed in a timely fashion. It is also possible that these lesions of early failure have progressed in their ability to cause dysfunction.
Neointimal hyperplasia or stenosis

Intima of the venous side of an AVF sometimes abnormally proliferates in response to the wall shear stress, causing neointimal hyperplasia and, subsequently, stenosis [24]. Venous stenosis more frequently occurs with synthetic than native AVFs. Nevertheless, it is the most common cause of late fistula loss [25]. Unlike the case of grafts, venous stenoses associated with an AVF generally develop more centrally, at areas of vein bifurcation, pressure points and in association with venous valves. The development of collateral vessels is frequent and often preserves flow in the access. Percutaneous angioplasty has come to be the treatment of choice for these lesions, with a success rate greater than 95%. Long-term primary patency rates are in the range of 84% at 3 months, from 57 to 67% at 6 months and 35 to 51% at one year [32].

Thrombosis

It occurs because of stenosis, occlusion or, sometimes, extrinsic compression. Occasionally, thrombosis can develop from prolonged compression after dialysis. The most commonly identified etiology is neointimal hyperplasia, typically occurring at the juxta-anastomotic vein. Recent reports have documented excellent success rate in the treatment of thrombosed fistulas, ranging from 88 to 94%. Long-term primary patency has been reported in the range from 63 to 89% at 3 months, 52 to 74% at 6 months and 27 to 47% at one year [33, 34]. These numbers are considerably better than those seen for the treatment of thrombosed grafts.

Infection

Repeated puncture and cannulation predispose the patient to cutaneous bacterial infections. In patients with a graft AVF, the prosthetic PTFE segment, is even more prone to infection. Infections can be treated successfully by surgical debridement and/or systemic antibiotics [35].

Aneurysm

Increase in blood flow in an AVF occurring with time has a tendency to cause the vessel to continue enlarging. Over a period of years, the AVF can dilate to aneurysmal proportions. A marked degree of aneurysmal change in a fistula is generally indicative of downstream venous stenosis. In addition, localized aneurysm formations can occur along the arterialized vein after repeated needle punctures. In general, an aneurysm is no more than a cosmetic problem unless it is associated with stenosis or thinning of overlying skin. If a stenosis present, it should be treated appropriately. Skin thinning should be evaluated carefully, this eventually leading to aneurismal rupture with severe hemorrhage and even death. Indications for AVF revision relative to an aneurysmal formation are herein reported [36]:
• Compromise of skin overlying the aneurysm (thin, atrophic, translucent)
• Risk of rupture/ulceration, with evidence of spontaneous bleeding
• Cannulation sites physically limited
• Inadequate cosmetic appearance

Pseudoaneurysm

It usually develops after incomplete hemostasis (Fig. 9 on page 21). If a pseudoaneurysm is large, turbulent and slow flow could result in thrombus formation and even infection.

CT Findings

CTA is an effective diagnostic tool even in the detection of thrombosis and infections. In case of thrombosis, axial and MPR images show an occluded segment with lumen obliteration (Fig. 10 on page 21a), while in case of infection abnormal fluid or air collection surrounding the AVF are usually present (Fig. 10 on page 21b).

Usefulness of 2D and 3D reconstructions

MIP images create a vascular map for the referring physician, useful for rapid demonstration of collateral vessels, whereas VR always accurately depicts 3D relationships [22]. Concerning the detection of venous stenosis, the highest sensitivity rates are found with coronal MIP, being more difficult to evaluate focal stenosis on axial images alone. The low sensitivity encountered by some authors especially for the brachiocephalic and subclavian vein stenosis, relates to the difficulty in evaluating central veins, as the clavicle, ribs and sternum are superimposed on these structures (Fig. 11 on page 22) [23]. During VR reconstruction it is possible to remove bones, thus providing a clearer view of vessels. However, bones in the area of central veins are located very close to vessels, in some cases producing real osteo-vascular conflicts, such as the TOS, making it difficult to achieve accurate automated separation of these structures without losing anatomic detail. Due to this relative limitation, central vein complications should be carefully evaluated on axial source images. As regards the detection of aneurysms, CTA results very accurate, allowing to measure the length and diameter of aneurysms. VR is somewhat better than axial images in detecting these lesions. However, thrombosed segments are visible only on MIP reconstructions since VR images outline the margins of a vessel without depicting anything in the lumen. As a result, for most of pathologies an all-planes assessment of CTA gives the highest sensitivity and accuracy values compared to other single-plane evaluations alone (Fig. 12 on page 23).

Comparison with other imaging techniques
COLOR-DOPPLER SONOGRAPHY (CDS)

It has been used to detect, locate and characterize vascular complications at hemodialysis access sites, but the technique does not allow vascular mapping and may not show sufficient anatomic detail. Due to its non-invasive nature, some authors considered this modality as the first step technique in monitoring vascular access function [37] (Fig. 13 on page 24). Actually, the only feature that makes CDS invaluable with respect to other imaging techniques is the quantification of an AVF flow rate, this being defined as the section of vessel multiplied by the mean perpendicular velocity of blood through it (1m/s in a normally functioning fistula). For the same reason, CDS is the only technique capable of identifying an hemodynamically significant stenosis, by calculating the ratio between the velocity of blood measured at the stenosis site and upstream. However, it has a low diagnostic accuracy on proximal vein stenosis and, most of all, it is an operator-dependent technique. This limitation, combined with the need for an angiographic map before surgery, makes conventional fistulography or CTA necessary in most cases. In particular, CTA turns out invaluable when both ultrasonography and fistulography are inconclusive.

DIGITAL SUBTRACTION ANGIOGRAPHY (DSA)

Conventional fistulography was considered the gold standard for assessing an AVF. This method provides accurate depiction of the fistula anastomosis site, its potential outflow veins and central veins [38]. All fistulographies should be performed by an experienced interventional radiologist, using a digital subtraction system. After antegrade puncture of the AVF venous side, as close as possible to surgical anastomosis, diluted iodinated contrast medium should be manually injected via a 18-20 gauge cannula. Three to five injections are required, 5-15 ml each, with a total volume of contrast medium usually inferior to 50 ml (vs 90 ml of CTA). DSA of the entire venous outflow tract, from anastomosis to SVC, including axillary, subclavian and brachiocephalic veins, should be performed. A tourniquet could be placed proximal to the anastomosis in order to obtain retrograde opacification of proximal venous segment, the surgical anastomosis and distal part of afferent artery. Furthermore, all significant stenoses and short occlusions could be treated through percutaneous balloon angioplasty, additional stenting being performed only in cases with elastic recoil of a flow-restrictive intimal flap (Fig. 14 on page 25, Fig. 15 on page 26). Other forms of endovascular treatment include thrombolysis, thromboaspiration and mechanical thrombectomy [39].

Van der Linden et al [40] reported not every significant stenosis to be correctly identified through DSA. This is especially true for the anastomosis site, mainly because of preferential filling of collaterals or opacification of overprojecting veins. Even with the use of a tourniquet, the AVF feeding artery may not be depicted in its entirety because of incomplete retrograde filling [41]. Thus, in certain cases, direct arterial puncture is needed to assess the anastomosis site and inflow pathologies. Furthermore, for subsequent percutaneous intervention, a second puncture in a different site, with related morbidity,
may be required [42]. Among minor complications there are extravasation of contrast material and puncture site hematoma (Fig. 16 on page 27).

Differently from CTA, DSA is not capable of showing extravascular structures, nor reveal detailed information about an extrinsic compression, depicting only the lumen of a vessel and not its wall. This technique cannot even visualize partial thrombosis of an aneurismal sac. On the contrary CTA, through acquisition of 3D data sets, can overcome the problem of vessel overlapping and the misdiagnosis of stenoses not evident on DSA because of inherent limitations of a 2D projective technique. CTA is also more useful than DSA in the assessment of AVF morphology [43]. Finally, DSA has still an advantage over CTA in the possibility of performing corrective interventions on a dysfunctional fistula. Nevertheless, in centers where an angiography suite is not available, CTA is the only option.

**MAGNETIC RESONANCE ANGIOGRAPHY (MRA)**

It is an alternative for imaging hemodialysis fistulas. Lack of radiations and avoidance of iodinated contrast medium are two advantages of this method. Recently time resolved 3D MRA with parallel imaging has been introduced for higher spatial and temporal resolution in the visualization of vascular access complications, by achieving a large FOV covering the AVF and its entire inflow-outflow course (Fig. 17 on page 28) [44]. However, this technique is expensive and often requires long-examination times. Time-of-flight or phase-contrast images frequently show artifacts due to the tortuosity of vessels and flow turbulence at the AVF site, with possible overestimation of the severity of stenoses [45]. It is contraindicated in patients with pacemakers, ferromagnetic implants, claustrophobia and vascular metallic stents. Finally, there is the impossibility to develop endovascular interventions.

Main advantages and drawbacks of each imaging technique are summarized in Table 1 on page 28.

**Limitations of CTA**

CTA is a technique with inherent ionizing radiations. Pregnancy is the only major contraindication. For children and adolescents, the risk of carcinogenesis and longer life expectancy should be weighted, before examination, against the potential benefit of a correct diagnosis. To reduce the dose in this radiation-sensitive population, the arm-up position and a lead apron to cover the area not scanned are helpful. In fact, the estimate of effective dose based upon the dose-length product (DLP) should consider an organ dose-based calculation of 0.001 mSv/mGy for upper limbs, according to publication 103 of the International Commission on Radiological Protection (ICRP). Thus, placing the AVF arm overhead, patient radiation dose generally remains inferior to 1.5 mSv per examination, so that a dysfunctional fistula can be subjected to multiple CTAs in order to obtain high patency rates.
Another disadvantage of CTA is that it requires the intravenous administration of iodinated contrast medium in a population of chronic dialysis patients, in which preservation of residual renal function is correlated to better survival and quality of life. However, contrast-induced nephropathy could be minimized by scheduling CTA immediately before a routine hemodialysis session, so that contrast material would be cleared soon from circulation after procedure.

With the arm stretched overhead to prevent compression of basilic or axillary veins, motion artifacts could be present due to the lack of comfort of this position. Pseudostenoses of subclavian artery have been described at its exit from thoracic outlet, so much that in some cases the patient was required to put examined arm alongside the body. However these problems were never observed in our case series. Furthermore, we avoid placing the arm next to the body because pseudostenoses of axillary vein due to vessel compression have been described in the arm-down position as well.

**Information to highlight in the radiological report**

- To identify the type of arterio-venous anastomosis and fistula
- To estimate caliber of the arterio-venous anastomosis, its inflow artery and outflow vein
- To evaluate presence of arterial parietal calcifications, atheromasic lesions determining stenosis or eventual arterial kinking
- To look for intraluminal arterial thrombosis
- To quantify the grade (percentage) and length (cm) of a stenosis, as well as to establish a reference diameter to reach with an eventual angioplasty (target diameter, corresponding to normal caliber of the health tract of a stenotic vessel)
- To search for perivascular hematoma, air or fluid collections with eventual rim contrast enhancement or air bubbles within
- To look for central vein stenosis or thrombosis, as well as TOS
- To provide the clinician with exemplificative 2D and 3D images
- To look for collateral findings, mainly due to secondary hyperparathriodism of chronic renal failure patients: articular and soft tissues calcifications (pseudogout), osteoporosis, osteosclerosis or phalangeal subperiosteal erosions (osteitis fibrosa)
**Fig. 5:** CDS showing normal patency of an arterio-venous side to side anastomosis (a) and mean flow velocity (>1 m/s) consistent with efficient functioning of the AVF (b).

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**Fig. 6:** CDS shows a stenosis at the anastomosis site determining a significant increase in blood flow velocity (about 5 m/s).

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Fig. 7: VR (a) and MPR (b) images showing a left and right subclavian vein stenosis respectively, both caused by previous central catheter insertion.

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**Fig. 8:** Failure to display the continuity of a vessel on VR (a) does not mean it is occluded, as exemplified by the corresponding MPR image (b).

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**Fig. 9:** CDS of an AVF pseudoaneurysm showing the typical to-and-fro flow signal at its neck (a) and the "Korean flag sign" within the sac (b). A surgical view is also reported (c).

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Fig. 10: MPR images showing fluid and air collection around a PTFE graft (a), indicating infection, as well as thrombosis within left subclavian vein and its confluence with internal jugular vein (b).

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Fig. 11: VR of thoracic outlet showing superimposition of the ribs and clavicle (partially removed) upon vessels.

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Fig. 12: CTA all-planes evaluation allows demonstration of the patency of an AVF on axial images (a), detection of a venous stenosis on coronal MIP (b) and its comprehensive visualization on VR reconstructions (c).

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Fig. 13: CDS panoramic view of a graft AVF showing patency of the anastomosis (a), high resistance flow (poor diastolic component) within the graft (b), neo-intimal thickening at its distal tract (c), high flow velocity (>4 m/s) in correspondence of a proximal vein stenosis (d) and post-stenotic non-arterialized flow downstream (e).

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**Fig. 14**: DSA showing a proximal vein stenosis (a) successfully treated with percutaneous balloon angioplasty (b).

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Fig. 15: CTA showed a stenosis of right subclavian vein (a) also demonstrated by DSA (b) and subsequently treated by balloon angioplasty (c). In this case stenting of the subclavian vein was performed due to elastic recoil of an intimal flap (not showed). In the second case, DSA demonstrated stenosis of SVC with collateral circles draining into the azygos system (d). Corresponding CTA (e) could also visualize the internal jugular vein, non apparent on fistulography.

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Fig. 16: Complication of repeated punctures: an organized hematoma (a) determining significant stenosis of a proximal vein by extrinsic compression (b).

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Fig. 17: 3D MRA of an AVF arm depicting its complete vascular tree and showing a JAS (a). A proximal vein stenosis (b) is demonstrated in another case.

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**Table 1**: Advantages and drawbacks of each imaging technique. CDS: color Doppler sonography, DSA: digital subtraction angiography, MRA: magnetic resonance angiography, CTA: computed tomography angiography, +: poor, ++: satisfactory, +++: optimal

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Conclusion

CTA is a fast, non-invasive and accurate technique, which is to be considered as a first step panoramic examination in case of clinically suspected AVFf. Radiologists familiar with this modality can help improving the prognosis and quality of life of long-term hemodialysis patients. CTA may offer reliable solutions to evaluate a dysfunctional hemodialysis fistula, including its entire arterial inflow and venous outflow, in order to establish if DSA with subsequent percutaneous interventions o direct surgical revision is needed.
References


