Clinical applications

Application of live 3D tools in vascular interventional radiology

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An accurate morphological assessment of blood vessels and their relationship with interventional devices is essential in the management of vascular lesions, and digital subtraction angiography (DSA) has had a central role in the deployment of interventional procedures. The introduction of three-dimensional rotational angiography (3D RA) and flat panel detector technology has further contributed to diagnostic accuracy, faster procedures, and improved patient care [1-4].

The availability of 3D reconstructions also brings a wealth of 3D tools that can improve current procedural workflows, starting from disease assessment to treatment evaluation, navigation and treatment planning.

However, the use of 3D RA and associated tools in vascular interventional radiology (IR) is, however, not yet common practice. Although evidence of the clinical benefit and reduction in radiation exposure to patient and staff following the use of 3D RA has been extensively reported for vascular lesions of the neck and brain [5-10], there is not enough information in the literature on how the use of 3D tools can improve the (peripheral) vascular IR procedural workflow.

The objective of this article is to provide a showcase of minimally-invasive vascular IR applications where the availability of 3D tools was distinctly beneficial to achieving effective disease management in a busy day-to-day clinical practice.

Materials and methods

In order to provide a suitable range of extraneurologic vascular IR procedures, a total of ten patients were selected retrospectively from over 200 subjects treated between 2006 and 2007 with clinically indicated rotational angiography. The clinical indication was made by the interventional radiologist on a per case basis, based upon his judgment as to whether the 3D tools would help in problem solving or clarification of anatomy, offer potential time savings, possibly reduce contrast agent or X-ray dose to the patient, or uncover a suspected hidden lesion.

All rotational examinations were performed on an Allura Xper FD20 system (Philips Healthcare, Best, the Netherlands) using an automated “two-button” 3D acquisition process. A total of 120 frames were obtained during a 240° rotation for a total scan time of 4 sec and 3D reconstructions with a FOV of 25 x 19 x 25 cm and a matrix size of 128³, and displayed in real time.

For soft tissue visualization, CT-like 3D reconstructions were acquired using the XperCT technique over a scan range of 240°, resulting in 310 frames and a total scan duration of 10 sec. All consequent 3D analyses were also performed live by the physician who carried out the examination.

Clinical results

Vascular stenoses

Three-dimensional imaging is useful in the assessment and grading of vascular stenoses. It can not only provide a view of the anatomy from angles not achievable with 2D imaging, but also help in the detection of hidden stenoses not visible in 2D projections and other diagnostic images (Figures 1, 2).

By using 3D RA and quantitative tools, the radiologist can accurately evaluate the extension and grading of the stenosis and, for example, avoid the need for overlapping stents with the associated extra costs and risks of recurrent stenosis.

Visceral aneurysms

Accurate imaging information is essential in the treatment of aneurysms. Often, this type of information cannot be obtained, either from 2D DSA due to complex angles required to view the aneurysm neck, or from computed tomography angiography (CTA) and magnetic resonance angiography (MRA) because of inadequate spatial resolution, especially for small branch vessels.

⇒ Accurate morphological assessment is essential in the management of vascular lesions.

⇒ Three-dimensional imaging is useful in the assessment and grading of vascular lesions.
Figure 1. Renal artery stenosis in 81-year-old female. The patient was referred for treatment after failed medical management of hypertension.

Figure 1a. Pre-procedure contrast-enhanced MR angiography showing a tight ostial stenosis of the right renal artery (arrows) and a patent left renal artery (dashed arrows).

Figure 1b. Repeat antero-posterior (AP) arteriogram confirming the right renal artery stenosis.

Figure 1c. Selective DSA of the right renal artery showing stenosis (arrows) at the origin of the vessel.

Figure 1d. Selective DSA of the right renal artery showing successful stenting.

Figure 1e. AP view of the 3D RA reconstruction showing unremarkable left renal artery (dashed arrows) and the good post-stent appearance of the right renal artery (arrows).

Figure 1f. Oblique view (RAO -6°, CRAN -52°) revealing the presence of two overlapping vascular segments on the left side, which hide a very tight stenosis of the left renal artery (dashed arrow). The lesion was further confirmed with pullback pressure measurements. After stenting of the left renal artery, hypertension was successfully controlled.

Figure 2. Common iliac artery stenosis in 73-year-old male with history of AAA surgical repair, right nephrectomy, and left renal artery stenosis, now presenting with pain in right leg. No surgical records were available.

Figure 2a. AP view of aortoiliac arteriogram showing patent left renal artery stent and corrugated appearance of abdominal tube graft. Note that both common iliac arteries appear widely patent.

Figure 2b. AP view of color-rendered 3D RA reconstruction after injection of 24 ml of contrast at 6 ml/sec. A portion of an aortoiliac by-pass graft (arrow) appears to superimpose over the common iliac artery.

Figure 2c. Oblique view (LAO 45°, CAUD 27°) of the 3D RA rendering confirms the presence of aortoiliac bypass graft (arrow) and reveals a stenosis at the origin of the right common iliac artery (dashed arrow).

Figure 2d. DSA performed with the same obliquity using synchronization between C-arc and 3D RA reconstruction confirms the presence of approximately 60% stenosis (dashed arrow), along with sluggish flow in a failing aorto-iliac bypass graft. Conventional 2D angiography without 3D guidance had missed this lesion because of overlapping vascular anatomy. The lesion was subsequently treated with a balloon-expandable stent. Following stenting, the patient reported leg claudication had resolved.
Figure 3. Renal artery aneurysm in 55-year-old male.

Figure 3a,b. Selected views of diagnostic 3D MRA showing an aneurysm of the right renal artery. Although spatial resolution is inadequate for confident neck localization and sizing, the image in 3b provides an optimal view of the aneurysm neck. A similar view with 2D DSA would not be achievable as it would have required a very steep cranio-caudal oblique angle.

Figure 3c. Surface rendering of a selective 3D RA reconstruction of vascular aneurysm after the injection of 8 ml of contrast using a catheter placed into the right renal artery (captured on the image). The relationship between aneurysm and feeding vessels could be visualized at any angle. The aneurysm is isolated and shaded in blue using an automatic detection algorithm implemented in the computer-assisted aneurysm analysis tool. The visualization helps in the quantification of aneurysm size and shows how all three vessels feeding the kidney (arrows) arise from the aneurysm sac.

Figure 3d. Additional view offering a better depiction of the posterior vessel branch (dashed arrow). As endovascular repair with coils/covered stents was not a good option due to risks of non-target embolization, the patient was referred to a transplant surgeon for bench surgery and auto-transplantation along with a 3D RA video file to help them plan the best method of vascular repair. This resulted in minimizing the ischemia time of the explanted native kidney during repair, as much of the repair planning could be done prior to surgery.

Figure 4. IVC filter removal in 44-year-old male.

Figure 4a. 2D AP venography showing IVC and Cordis OptEase IVC filter.

Figure 4b. A magnified view of the filter suggests the correct positioning of the hook (arrow) in the middle of the vein’s lumen.

Figure 4c. 2D AP fluoroscopy showing an unsuccessful attempt to capture the filter’s hook using a snare.

Figure 4d. Four-second 3D RA reconstruction showing spine, tilted IVC filter and its relationship with the snare used to capture the hook.

Figure 4e. Lateral (84°) 2D fluoroscopy optimally showing filter tilting. The exact lateral angle was selected from the 3D image.

Figure 4f. Lateral (84°) 2D digital subtraction venography further exposing the relationship between the filter and the IVC. The filter is not only tilted but the hook (arrow) is also embedded into the vessel wall. Snare retrieval would have been physically impossible, and would have inevitably led to numerous unsuccessful attempts.
Three-dimensional RA offers high spatial resolution and can achieve a detailed 360° view of the vessels of interest. Computer-assisted aneurysm analysis tools can also be used to automatically define the aneurysm sac, calculate its dimensions and analyze its relationship with the surrounding vessels, facilitating both diagnostics and interventional planning (Figure 3).

Inferior vena cava filter removal
Most retrievable inferior vena cava (IVC) filters incorporate a “retrieval hook” that is used to capture the filter and, when properly placed, are typically removed with a snare and sheath within minutes. However, the removal process often requires several snare attempts and lengthy fluoroscopic exposures. Even symmetric filters, while appearing untilted in standard 2D venograms, may hide a significant degree of tilt, which is often revealed by unusual projection angles [11]. Our approach is therefore to routinely perform a rapid, 4 sec 3D RA at the start of the procedure to achieve a fast and confident removal, even in complex cases (Figure 4).

Figure 5. Uterine AVM in 26-year-old female with history of gestational trophoblastic disease (treated with dilatation and curettage a year earlier) presenting with pelvic pain. Patient wishes to become pregnant.

Figure 5a. Longitudinal grayscale endovaginal ultrasound of uterus.

Figures 5b,c. Longitudinal color Doppler ultrasound showing marked diffuse uterine hypervascularity. Subsequent MRA examination confirmed a large uterine AVM.

Figure 5d. AP view of 3D RA reconstruction of uterine vessels revealing complex malformation. The uterine arterial supply (arrows) was satisfactorily identified and could be inspected at any angle.

Figure 5e. Surface rendering of 3D RA reconstruction. The AVM nidus is depicted in blue after automatic detection with the advanced aneurysm analysis tool (dashed arrow).

Figure 5f. Angiography of left uterine artery (arrow) during embolization.

Figure 5g. Angiography of parasitized left ovarian artery following embolization.

Figure 5h. Pre-treatment 2D AP DSA.

Figure 5i. Post-treatment 2D AP DSA showing complete AVM embolization after treatment of right and left uterine and left ovarian arteries. The patient achieved pregnancy a few months after treatment and ultimately delivered a healthy baby with no complications.
Figure 6. Uterine fibroid embolization in 44-year-old female.

Figure 6a. 3D RA surface rendering showing complex bilateral supply of uterine arteries to the fibroid. The origin (arrow) of the left uterine artery (LUA) and other branches of the right and left common iliac arteries (RCIA and LCIA, respectively) are here visualized.

Figure 6b. Same view of cropped 3D RA surface rendering, which provides a cleaner outlook of the LUA origin (arrow).

Figure 6c. Oblique view of cropped 3D RA surface rendering showing the origin (dashed arrow) of the right uterine artery (RUA).

Figure 6d. Same view of gradient-rendered 3D RA volume. The advanced vascular analysis tool is used here to better assess the RUA morphology.

Vascular malformations
Three-dimensional RA offers detailed anatomical information that enables the radiologist to untangle the tangled web of vessels surrounding an arteriovenous malformation (AVM). A comprehensive treatment plan based on 3D RA is achieved with a single run and helps to minimize the number of 2D DSA and fluoroscopic images required during treatment.

The availability of 3D RA reconstructions makes it possible to quickly identify the AVM nidus, unravel the intricate vascular configuration of the feeding vessels, select the optimal working projections to access all feeding vessels, and achieve a complete embolization (Figure 5).

Uterine fibroid embolization
Uterine fibroid embolization (UFE) is an important application making use of 3D imaging [12]. Most interventional radiologists perform abdominopelvic aortography with additional, randomly chosen oblique selective internal iliac angiograms in hopes of localizing the origin of the uterine artery and guiding superselective catheterization of this vessel.

Figure 7. Uterine fibroid embolization in 41-year-old female.

Figure 7 a-d. Snapshots recorded during live 3D navigation with dynamic 3D roadmap. A single 3D reconstruction was used throughout the embolization procedure. The magnification and projection angle of the live fluoroscopy were automatically transferred to the 3D reconstruction so as to preserve their matching. The blending of the two types of data could also be controlled to, for example, highlight vascular landmarks or boost catheter visualization.
However, additional 2D angiographic roadmaps in other angles are often required. This increases procedural radiation dose, contrast administration and time. Our approach is instead to acquire one 3D RA at the beginning of the procedure to select optimal projections showing the origin of feeding vessels, produce 2D or, more efficiently, dynamic 3D roadmaps and swiftly access the feeding arteries with no need of additional contrast or DSA runs prior to embolization (Figures 6, 7).

Transarterial chemoembolization
The combination of live 3D tools is particularly valuable in transarterial chemoembolization (TACE) procedures to identify the vessels feeding the tumor, define treatment approach and chronology, and achieve a smooth catheter placement in the feeding vessels. In addition, soft tissue information obtained with the XperCT technique can be used to confirm treatment completion by comparison with pre-treatment CTA or MRA.

CT-like imaging in the interventional suite enables the interventional radiologist to promptly tackle possible tumor residuals and improves the clinical workflow eliminating the need of moving the patient to a CT unit (Figure 8).

Conclusion
The availability of 3D tools is indispensable in a busy day-to-day clinical practice and can be routinely used in synergy with 2D imaging to help the physician achieve more effective disease management and faster procedural workflow for a variety of applications. We encourage the use of 3D tools to achieve fast and confident decisions with a potential reduction in contrast agent administration and radiation dose to patient and staff.

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References


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