Intravascular ultrasound (IVUS) for endovascular procedures in interventional radiology - Seeing the unseen

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Introduction

Angiography is the standard imaging modality of choice in endovascular procedures in interventional radiology. Nonetheless, it carries inherent limitations including:

- Two-dimensional representation of three-dimensional vascular structures.
- Limited ability to assess intra-luminal details including plaque burden and morphology, as well as limited sensitivity to detect intramural hematomas and dissections.
- Requires radiation exposure and contrast usage

The usage of intravascular ultrasound (IVUS) may complement the assessment of angiography, with a well-established role and evidence to support its usage in coronary interventions with increased patency of the treated lesions and reduction in complications.

The application of IVUS to interventional radiology procedures including arterial, venous and aortic interventions may also potentially derive similar benefits by complementing the assessment of conventional angiography. In this pictorial review, we aim to illustrate the additional information derived from IVUS usage, its impact on treatment decision and potential clinical benefits in these conditions.

Methods

Consecutive patients who underwent both angiography and IVUS assessment in Prince of Wales Hospital between October 1, 2023 and October 1, 2024 were retrospectively identified from the Radiology Information System (RIS).

Clinical information, procedural records, imaging including angiogram and IVUS images and post-procedural clinical outcome were reviewed.

Total of 31 cases were identified including:

- Arterial interventions: 6 cases for lower extremity, native and transplant renal arteries
- Venous intervention: 10 cases for benign and malignant venous steno-occlusions
- Aortic interventions: 15 cases for thoracic aortic pathologies

Illustrative cases demonstrating the additional value of IVUS complementing evaluation of conventional angiogram were selected for demonstration in this pictorial review.

Basic principles and setup of IVUS system

An IVUS system generates soundwaves via transmission of an electric current through a piezoelectric transducer. The generated soundwaves are reflected off the adjacent tissues and returns the energy of the ultrasound to the transducer, which is in turn created into an image displayed to the operator.

The frequency of the piezoelectric transducer dictates the resolution of the image and maximum diameter penetration. Transducers with higher frequency (i.e. up to 60MHz) produce images with higher spatial resolution but with a smaller maximum field of view and are therefore optimal for assessment of smaller vessels. On the contrary, transducers with lower frequency allow assessment of larger vessels which are better geared for assessment for aortic pathologies.

Certain IVUS systems are also capable of displaying color to demonstrate blood flow.

Device	Manufacturer	Maximum guidewire	Transducer frequency	Maximum field of view	Suitable applications
OptiCross HD	Boston Scientific	.014"	60MHz	6mm	High-fidelity imaging suitable for small-sized (3-4mm) vessels
OptiCross 18	Boston Scientific	.018"	30MHz	12mm	Suitable for medium-sized vessels
OptiCross 35	Boston Scientific	.035"	15MHz	70mm	Suitable for large-sized vessels (e.g. aortic interventions)
Eagle Eye Platinum	Philips	.014"	20MHz	20mm	Suitable for medium-sized vessels. Capable of demonstrating blood flow

Table 1. List and characteristics of IVUS catheters utilized in this study.

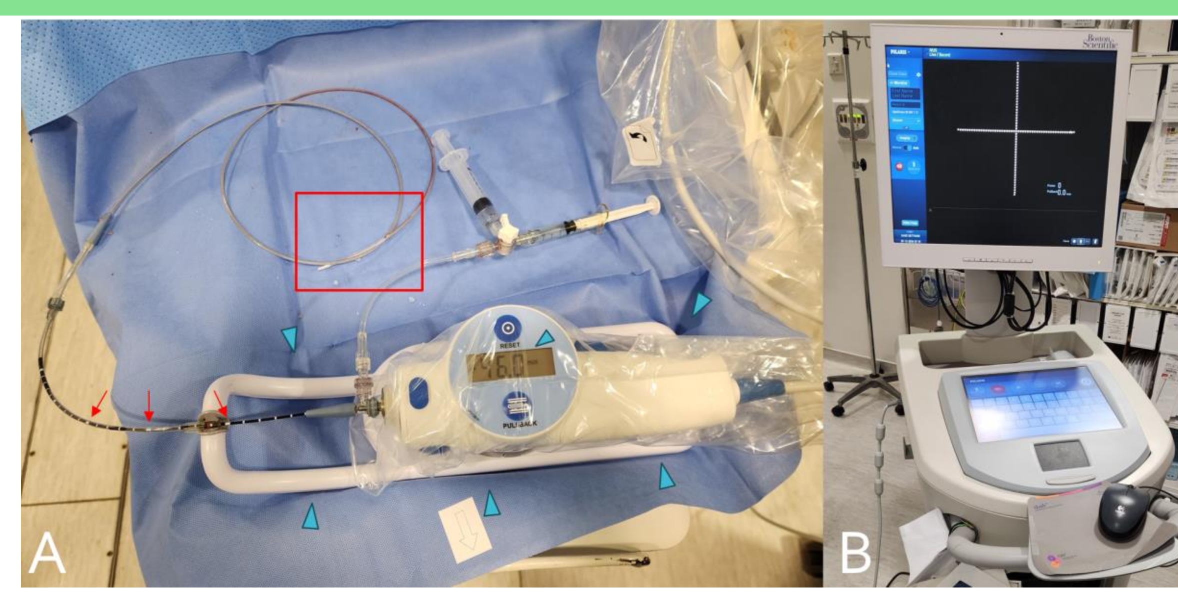

Figure 1. A. Basic setup of the IVUS system. An OptiCross 35 IVUS system is displayed in this figure. The system consists of a transducer at the distal end of the IVUS catheter (red box) which is introduced into the vessel of interest by an over-the-wire technique. Distance markings are present at the proximal end of the catheter (red arrows) which allows the operator to determine the length of the interest during pullback. An automatic pullback sled (blue arrowheads) is also available which allows for more precise length measurements and generates a longitudinal view of the vessel.
B. Console of the IVUS system for image review and measurements of the vessel of interest.

Arterial interventions

Normal arterial anatomy and plaque morphology

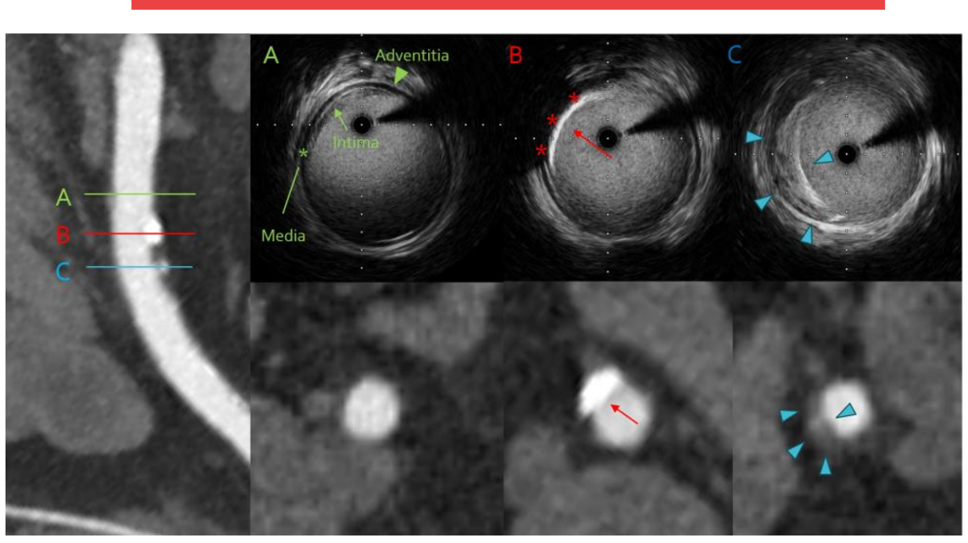

Figure 2. Side-by-side comparison of IVUS and computed tomography angiogram (CTA) images of the right external iliac artery at different levels in evaluation of a patient with suspected iliofemoral stenosis / dissection.

A. Normal appearances: IVUS clearly demonstrates the three normal layers of the artery with a hyperechoic intima (green arrow) followed by a thin hypoechoic layer of media (green asterisk) and then a hyperechoic adventitia (green arrowhead). The arterial wall details are not visible on CTA.

B. Calcified plaque: IVUS demonstrates a markedly echogenic plaque (red arrow) with dense acoustic shadowing (red asterisks) compatible with a calcified plaque. CTA demonstrates corresponding findings of a calcified plaque (red arrow) with blooming artefacts which may lead to over-estimation of the stenosis.

C. Fibro-fatty plaque: IVUS demonstrates presence of a plaque with mixed echogenicity (blue arrowheads) compatible with a plaque with both fatty and fibrous components. CTA vaguely demonstrates presence of the hypoattenuating plaque (blue arrowheads),which is less discrete due to presence of surrounding fat.

Improved dissection and intramural hematoma detection

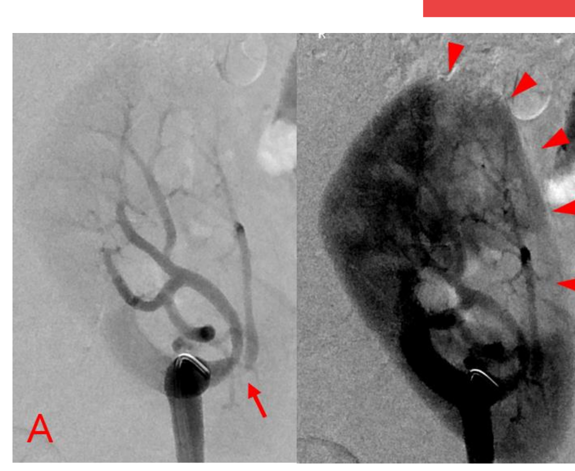

Figure 3A. Patient with transplant kidney suffering from suboptimal blood pressure control and renal function. Renal biopsy showed acute tubular injury with suspected ischemia. Angiogram performed showing severe stenosis at an early bifurcating segmental artery (red arrow) causing diminished perfusion to the anterior portions of the kidney (red arrowheads).

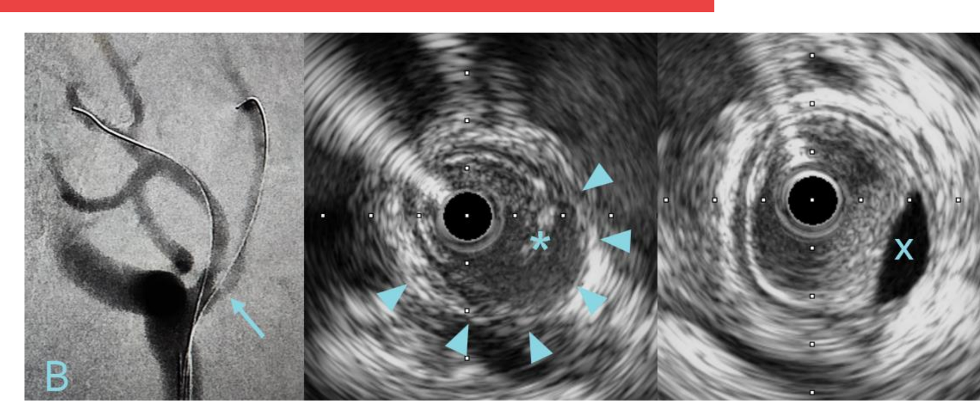

Figure 3B. Balloon angioplasty was performed with a 3.0mm non-compliant balloon. Initial angiogram showed apparent improvement of the stenosis (blue arrow). However, IVUS evaluation demonstrated presence of a dissection flap (blue asterisk) with the dissection arc approaching 180 degrees (blue arrowheads) and presence of adjacent intramural hematoma (blue cross). These were not discernable on angiogram alone. Decision to proceed to stenting was made based on the IVUS findings.

Accurate landing zone assessment

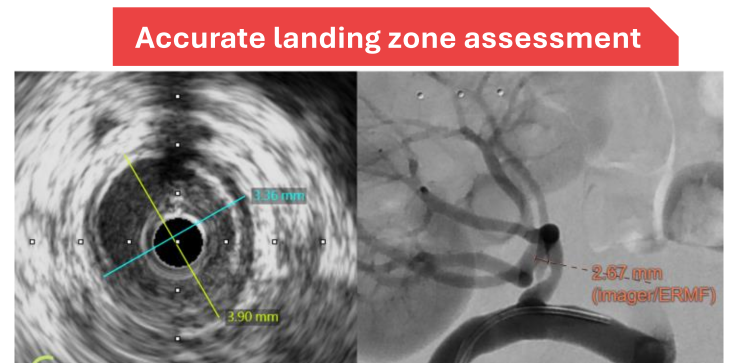

Figure 3C. Comparison of IVUS and angiogram-derived measurements of the landing zone. Angiogram significantly underestimated the vessel caliber by ~30% compared to IVUS. Angiogram has inherent limitations in its accuracy for assessing small vessels.

Comprehensive post-stenting evaluation

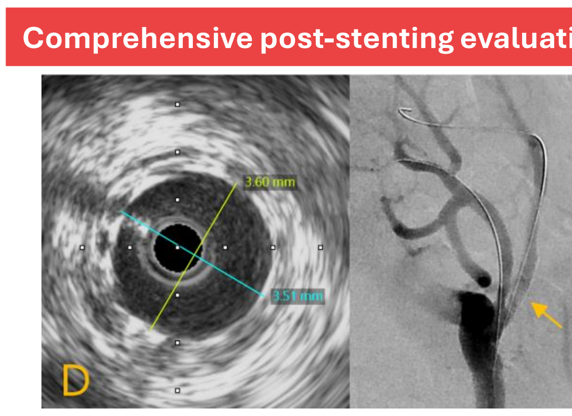

Figure 3D. Post-stenting IVUS showed optimal stent expansion and wall apposition. Satisfactory occlusion of the dissection flap was confirmed. Angiogram demonstrates satisfactory luminal gain (orange arrow). The blood pressure and renal function of the patient improved after the procedure.

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Aortic interventions

Real-time assessment of aortic condition and evaluation of landing zones

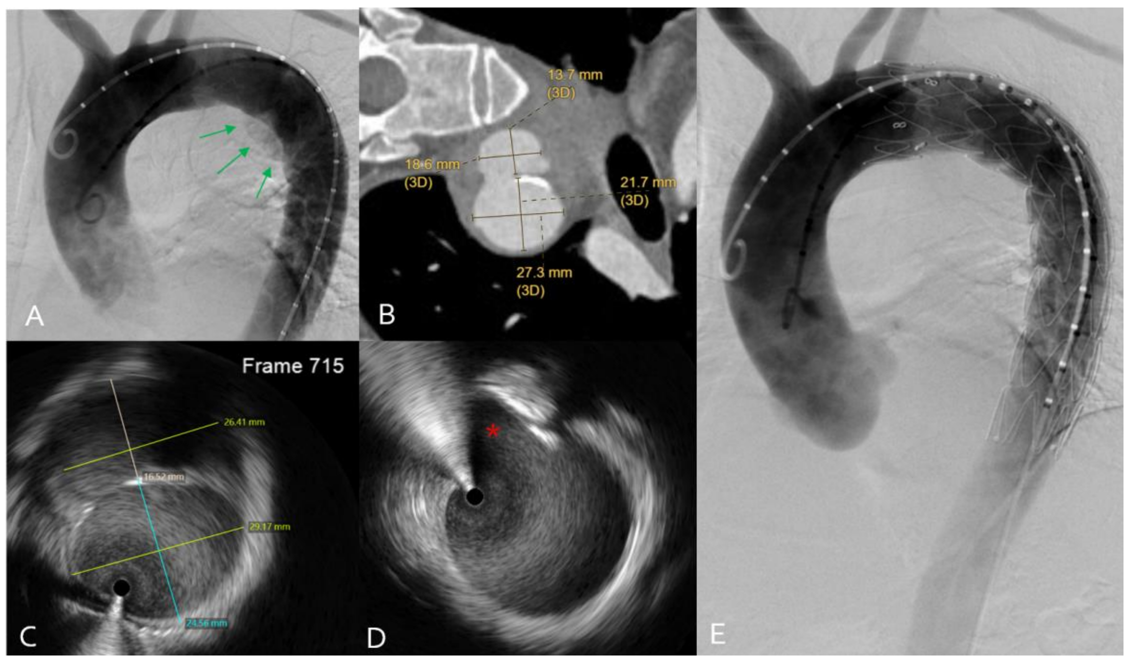

Figure 4. Patient with an enlarging mycotic arch pseudoaneurysm despite antibiotics treatment. Decision to proceed to thoracic endovascular aortic repair (TEVAR) was made after multi-disciplinary discussion amongst the aortic team.

A. Pre-procedural aortogram demonstrating faint opacification of the aortic arch pseudoaneurysm (green arrows). Assessment of the exact size of the pseudoaneurysm is suboptimal due to overlap with the native aorta.

B and C. Comparison of the pre-procedural CTA and intra-procedural IVUS images three days apart, demonstrating interval enlargement (~30%) of the pseudoaneurysm. IVUS provides a most up-to-date assessment to inform treatment decision including stent size, length and landing zones. This is of paramount importance in acute aortic pathologies such as dissection or pseudoaneurysms as the aortic condition may evolve within a short timeframe as illustrated in this case.

D. Identification of supra-aortic branches (red asterisk) and condition of the aorta for identification of an appropriate healthy landing zone for the stent graft.

E. Post-procedural aortogram showed satisfactory occlusion of the pseudoaneurysm and patency of the supra-aortic branches.

Confirm true lumen positioning and dissection evaluation

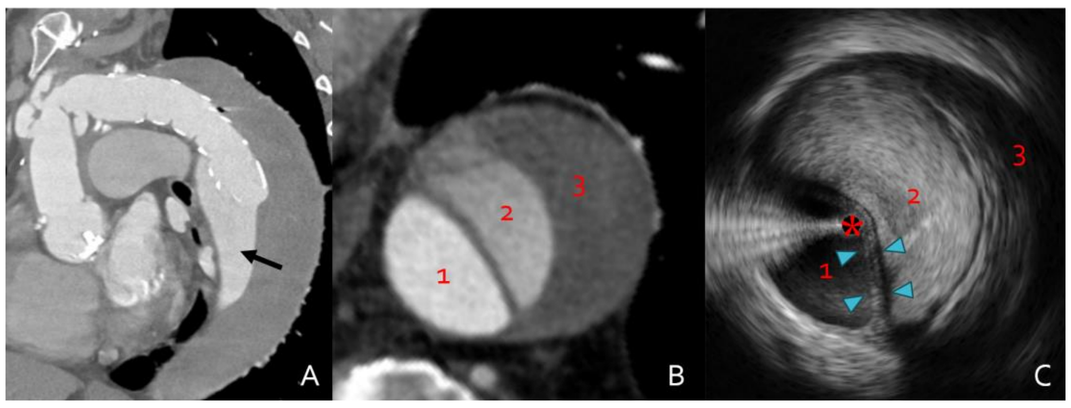

Figure 5. A. Patient with total arch replacement with frozen elephant trunk (TAR-FET) who developed a large distal stent graft-induced new entry tear (SINE, black arrow). **B and C.** Side-by-side comparison of CTA and IVUS images. The true lumen, perfused false lumen and thrombosed false lumen are identified on both images (layers 1 – 3 respectively). True lumen positioning of the guidewire (red asterisk) throughout the dissected segment is confirmed on IVUS. Inadvertent placement of the stent graft within the false lumen is a catastrophic complication of TEVAR and confirmation of appropriate guidewire positioning prior to stenting is mandatory, which can be confidently achieved by IVUS. Characteristics of the dissection flap (blue arrowheads) including its thickness and mobility can also be evaluated on real-time images which is described to be dictate subsequent prognosis in the literature.

Improved evaluation of stent graft expansion

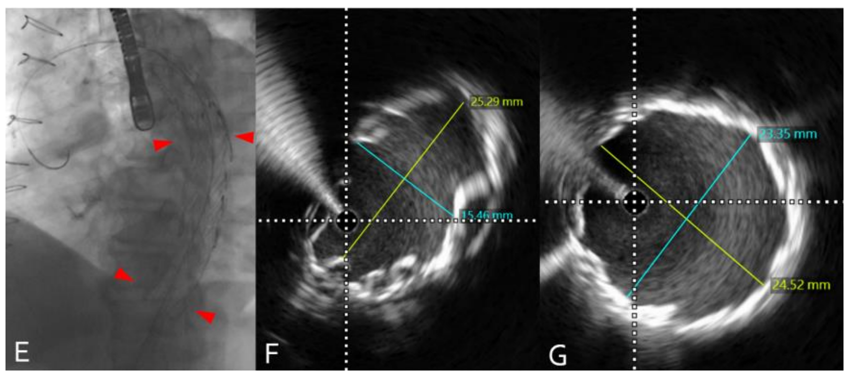

Figure 5. E. Two additional stent grafts with distal tapering were deployed (red arrowheads). The expansion of the stent grafts could not be assessed on fluoroscopy due to the overlapping stent constructs. **F.** IVUS clearly demonstrated suboptimal and eccentric expansion at the overlapping portions of the stent graft.

G. Significantly improved stent graft expansion achieved after balloon re-modelling. IVUS enables evaluation of the stent apposition without need of contrast injection or radiation exposure.

Venous interventions

Normal venous anatomy: Morphology and phasic variations

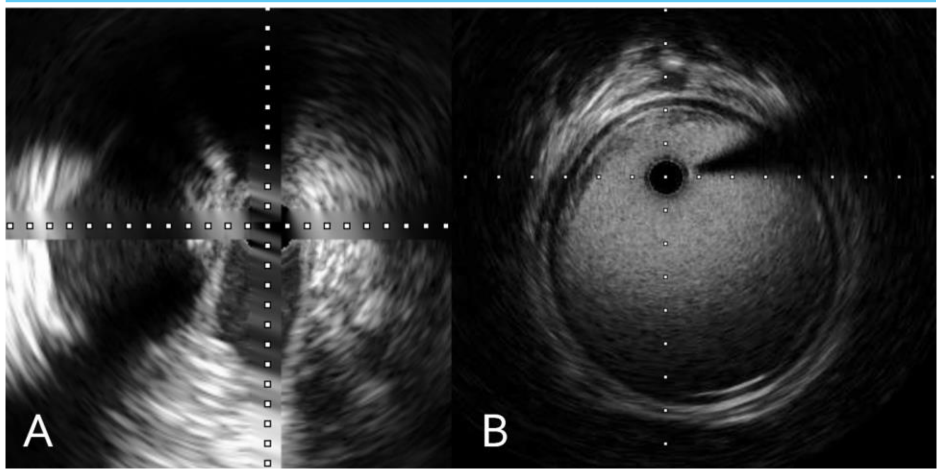

Figure 6. A and B. Side-by-side comparison of an external iliac vein to an external iliac artery. The media of the veins are much thinner than arteries and are therefore not readily discernable on IVUS. Venous structures also demonstrate an elliptical shape as compared to rounded arterial structures and therefore assessment on single-plane angiography may be inadequate.

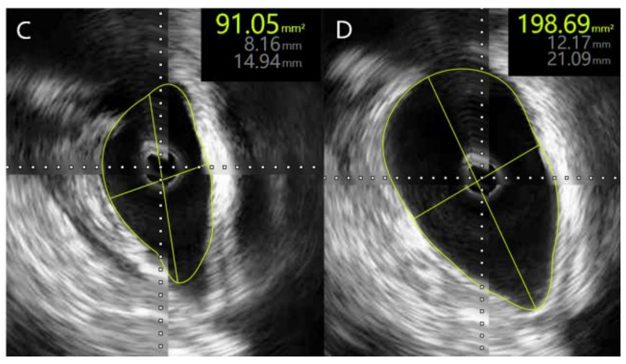

Figure 6. C and D. Significant phasic variation causing a two-fold area change in the superior vena cava. The dynamic nature of the venous caliber should be taken into account for treatment decisions.

Evaluation for extrinsic compressions

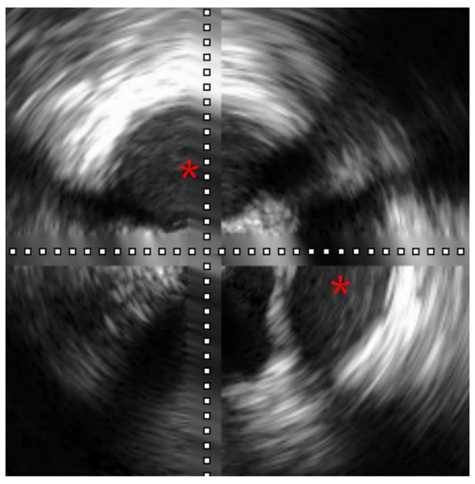

Figure 7. IVUS image of common iliac vein with adjacent common iliac arteries (red asterisks). Certain venous conditions including May-Thurner and nutcracker syndrome may be caused by extrinsic compression from adjacent arterial structures. IVUS allows evaluation of the relationship between the venous and arterial structures with incorporation of dynamic assessment such as Valsalva maneuver to determine whether the stenosis is fixed. No significant extrinsic iliac vein compression is demonstrated in this patient.

Three-dimension assessment of venous structures

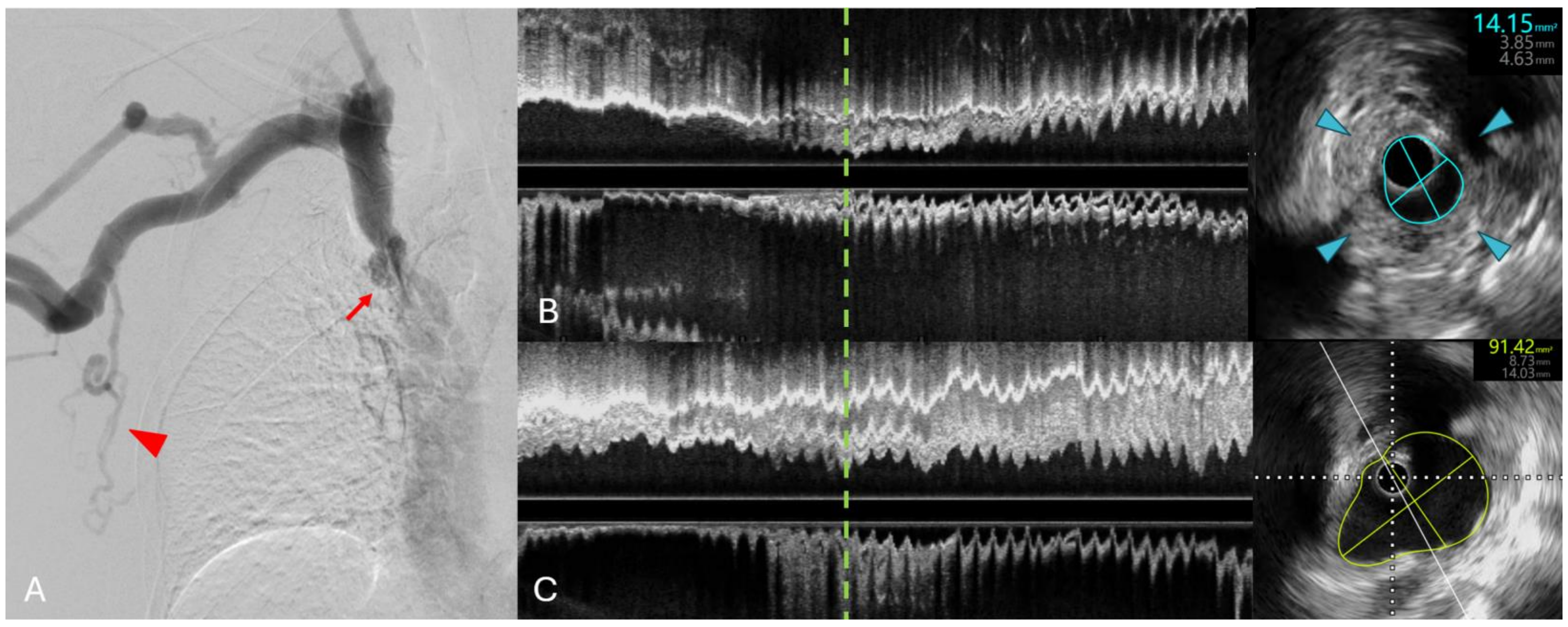

Figure 8. Patient with end stage renal failure (ESRF) with hemodialysis via a right arm arteriovenous fistula presented with facial and arm swelling concerning of central venous obstruction. **A.** Venogram shows suspected stenosis at the superior vena cava (red arrow) with venous collateral formation (red arrowhead) in the right arm. Degree of stenosis and the caliber of the lower superior vena cava (SVC) are not well assessed due to suboptimal opacification downstream to the stenosis.

B. Longitudinal IVUS view generated by automatic pullback allows for a three-dimensional assessment along the full length of the evaluated venous structure. Severe stenosis with circumferential isoechoic wall thickening (blue arrowheads) compatible with chronic scarring causing 90% area reduction compared to adjacent healthy SVC (not shown) is present. Accurate assessment of the venous caliber enables appropriate sizing for angioplasty and stenting decisions.

C. Post angioplasty IVUS view shows significant luminal gain at the site of stenosis with comparable caliber to adjacent healthy venous segments. The symptoms of upper limb and facial swelling rapidly subsided after the intervention.

Improved evaluation of intra-luminal pathologies

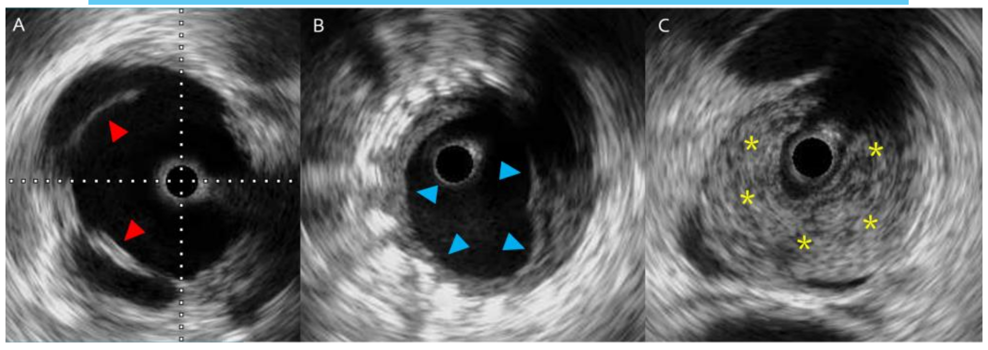

Figure 9. Illustrative examples of other intra-luminal pathologies revealed on IVUS.

A. Intra-luminal venous web / synechiae (red arrowheads) within the brachiocephalic vein in an ESRF patient presenting with symptoms of recurrent central venous obstruction.

B. Circumferential, irregular hypoechoic thickening along the stent lumen (blue arrowheads) suggestive of neo-intimal hyperplasia in a long-dwelling SVC stent. Patient presented with symptoms of recurrent central venous obstruction.

C. Large, near-occlusive thrombus (yellow asterisks) within the SVC in a patient presenting malignant SVC obstruction. Catheter is seen at the center of the thrombus after rendezvous crossing of the thrombus, with stenting performed afterwards.

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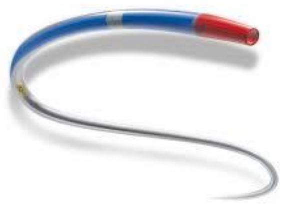
Benefits of IVUS utilization in endovascular procedures



General benefits

- Reduced contrast usage
- Reduced radiation exposure

Arterial interventions

- Characterization of plaque morphology and burden
- Improved stenosis and native vessel caliber assessment (particularly in small vessels)
- Improved sensitivity for dissections and intramural hematoma
- Comprehensive post-stenting evaluation: stent expansion, wall apposition, ensuring coverage of diseased segment and absence of edge dissections

Aortic interventions

- Real-time / up-to-date assessment of aortic condition (particularly relevant in acute aortic pathologies, e.g. dissection)
- Confirm true lumen positioning of the guidewire in dissection cases
- Evaluation of morphology of dissection flap to inform prognosis
- Identification of location of side branches for determination of landing zones
- Evaluation of stent graft expansion

Venous interventions

- Gateway to understanding of unique anatomy of venous structures: elliptical shapes, presence of phasic variations
- Cross-sectional evaluation of venous disease
- Evaluation for extrinsic compression from adjacent structures (i.e. May-Thurner)
- Improved sensitivity to intra-luminal pathologies such as venous webs / synechiae

Discussion

The benefits of IVUS usage in various endovascular procedures performed by interventional radiologists are illustrated in this pictorial review. IVUS provides insights into anatomy and physiology regarding arterial, aortic and venous conditions which is not readily discernable on conventional angiogram or cross-sectional imaging.

Clinical efficacy and safety of the procedures may potentially be enhanced with the additional information derived from IVUS, as well as the general benefits of reduced contrast usage and radiation exposure of the patient.

Numerous additional applications of IVUS are also well described in the literature. These include IVUS-guided bedside placement of inferior vena cava (IVC) filters for critically-ill patients not fit for transfer, and IVUS-guided re-entry techniques to gain true lumen access in challenging chronic total occlusions cases.

Apart from the radial IVUS catheters described in this article, there is also increasing interest in the use of side-firing IVUS catheters, also known as intracardiac echocardiogram (ICE), for performing various interventional radiology procedures. Salient examples include portal venous interventions such as transjugular intrahepatic portosystemic shunt (TIPS) placement or intravascular biopsy under ICE guidance.

Potential disadvantages of IVUS usage includes increased cost of the procedure. Learning curve regarding operation of the IVUS system and interpretation of the images may also lead to increased procedural time when compared to usage of conventional angiography alone. These may be mitigated after appropriate training and familiarization with the setup.

Conclusion

IVUS complements assessment of conventional angiography and provides valuable additional information that may enhance procedural efficacy and safety in arterial, aortic and venous procedures and may be an important addition to an interventional radiologist's armamentarium.

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Disclosures of conflicts of interests

The authors have no relevant financial disclosures.

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