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Intravascular ultrasound (IVUS) in endovascular abdominal aortic aneurysm repair — an adjunctive imaging tool or even less invasive self-guidance method?

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Abstract

Endovascular aneurysm repair (EVAR) is a minimally invasive technique alternative to conventional open surgical aneurysm repair. Nowadays, the majority of abdominal aortic aneurysms (AAAs) with suitable anatomy are primarily treated using EVAR; however, conventional EVAR procedure is associated with the necessity of contrast agent administration and exposure to ionizing radiation, which carries a risk not only for patients but also for the surgical team. Furthermore, the EVAR procedure may be unfeasible for patients with renal insufficiency and other contraindications to intravascular contrast agent administration, i.e. contrast allergy. An even less invasive guidance method for EVAR procedures seems to be intravascular ultrasound (IVUS), which may abolish the risk associated with contrast media usage and radiation exposure. The literature review concerns the latest research about IVUS guidance during EVAR to establish the current application of this imaging modality in daily clinical practice, its efficiency, advantages and drawbacks.

Keywords: intravascular ultrasound; aneurysm; EVAR; abdominal aortic aneurysm; stent-graft

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Introduction

Currently, endovascular aneurysm repair (EVAR) appears as a standard of care for patients with abdominal aortic aneurysm (AAA), requiring surgical intervention [1]. In the United States, approximately 80% of patients with AAA are primarily treated using EVAR [2]. Although the endovascular approach is considered a minimally invasive alternative to conventional open surgical aneurysm repair, the procedure is

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associated with a risk of radiation exposure that may be potentially harmful not only to patients but also to the surgical team [3–6]. Ruz et al. (2016) revealed that total fluoroscopy time during EVAR depends on the skills of the surgeon and the graft configuration, indicating a crucial role of the surgeon's efficiency and facility with EVAR procedure in reducing fluoroscopy duration [6]. The conventional endovascular procedure requires also iodine contrast medium administration and carries a risk of acute renal injury and general allergic reactions [7–9]. Furthermore, conventional EVAR may be also unfeasible for patients with renal insufficiency and other contraindications to contrast media administration [10, 11]. As a response to the limitations of the classical EVAR appears to be an intravascular ultrasound (IVUS) — guided EVAR [11, 12].

IVUS is an imaging modality increasingly used in interventional radiology, especially during the treatment of coronary artery disease. It allows for imaging morphology of the vessel wall, measurement of the vessel size, and assessment of other vessel and blood parameters [13, 14]. Studies have revealed the utility of IVUS guidance during coronary balloon angioplasty and endovascular stenting in many locations, considering coronary, renal, iliac, femoral or subclavian arteries [13, 15]. IVUS has also appeared as a useful tool in the case of percutaneous treatment of aortic dissection, placement of vena cava filters, or deep venous angioplasty [13, 16–19].

The usefulness of intravascular ultrasound in the case of aortic stent-graft placement has been reported for various applications, including both preintervention and intraoperative assessment [13, 20–21]. However, in the literature, it frequently emerged as an additional tool to angiography during EVAR, but unwarranted for routine use [13].

Taalab et al. (2023) in their prospective study comparing intraoperative IVUS measurements and those obtained during preoperative computed tomography angiography (CTA) in sizing of AAA and EVAR planning, revealed that measurements were comparable, whereas CTA was associated with better neck thrombus detection and IVUS more accurately depicted calcifications. Authors concluded that despite CTA, requiring intravenous contrast agent administration remains the gold standard for preoperative sizing and planning of the EVAR, IVUS may be also favourable in this process and it may be infallibly exploited along with supplementary non-contrast imaging modalities in patients with contrast allergy or increased risk of contrast-induced nephropathy [22].

The following study aims to review the latest literature regarding intravascular ultrasound appliances during endovascular repair of the AAAs and to try to answer the question of whether IVUS may be used as a self-guidance method in daily EVAR procedures, or as an adjunctive imaging modality only. The literature review was performed using the PubMed database and studies published between 2000 and 2023 were explored, according to the following medical subject headings (MeSH) terms: intravascular ultrasound, aneurysm, EVAR, abdominal aortic aneurysm, stent-graft.

IVUS — assisted EVAR in patients with renal failure and other contraindications to contrast media administration

The prevalence of chronic kidney disease is estimated at 13.4% worldwide. Roughly 4 to 7 million patients with end-stage kidney disease require renal replacement therapy [23, 24]. The aforementioned group of patients needs an especially cautious approach in contrast-enhanced procedures; however, the risk of contrast-induced acute kidney injury in patients with baseline kidney dysfunction seems to be overestimated [25].

Bush et al. (2002) described 20 of 297 patients undergoing EVAR of the infrarenal AAA who had either renal insufficiency or severe iodinated contrast allergy. 13 of these 20 patients had IVUS-guided stent-graft deployment, supplemented finally by post-implantation gadolinium aortography. Authors demonstrated that using the IVUS system both renal and internal iliac arteries ostia may be depicted and the size of the proximal and distal fixation sites of the endografts could be measured. Among all of the patients, endovascular stent-graft deployment was successful and no intraoperative deaths were reported. Based on the Society for Vascular Surgery/International Society for Cardiovascular Surgery standards, the 30-day technical success rate was 84%, with 3 (16%) endoleaks depicted by duplex ultrasound. Two patients revealed spontaneous endoleak sealing during 6-month and 12-month follow-up. The third endoleak also remained stable, but the patient died 1 year after endograft implantation due to unknown causes. None of the patients needed perioperative haemodialysis and there was no clinically significant elevation in creatinine from baseline.

This research led to the conclusion that IVUS-assisted EVAR is safe and feasible for patients with renal impairment or severe contrast allergy. Furthermore, the authors indicated that duplex ultrasound scanning can be used for postoperative endoleak surveillance, while IVUS can be used for intraoperative imaging to reduce the risk of iodinated contrast exposure [11, 26–27].

Hoshina et al. (2010) conducted a retrospective analysis investigating IVUS usefulness and limitations in EVAR procedure, in which out of 112 patients who underwent EVAR for the treatment of AAA, 33 were established to the IVUS group due anatomical difficulties, renal dysfunction or allergy to contrast medium. The remaining 79 patients received conventional EVAR with intra-arterial contrast agent administration. Compared to both IVUS and non-IVUS groups, patients in the IVUS group required significantly less intra-arterial contrast agent administration (67 ± 34 mL vs. 123 ± 50 mL; $p < 0.01$). Operation time and blood loss were comparable in both groups. There were no deaths in the 30 days after the procedure. During the follow-up period, two patients underwent re-interventions and these patients belonged to the IVUS group. Three significant renal complications appeared in the non-IVUS group and, overall, renal function collapse was observed in the non-IVUS group.

It was revealed that IVUS diminishes contrast agent usage and saves the time and labour needed to rotate the C-arm, reducing radiation exposure among both patients and surgeons. Due to the above-mentioned facts, authors recommended routine use of IVUS during EVAR; however, they mentioned that sole use of IVUS may increase the risk of complications because of the inability to evaluate endoleaks and stent alignment [28].

A case of IVUS-guided EVAR, supplemented by carbon dioxide angiography for inflammatory AAA in patients with contrast allergy was demonstrated by Morito et al. (2012). The authors described a 59-year-old male patient with infrarenal inflammatory AAA and a history of severe allergic reaction to iodinated contrast medium, who moreover had unsuitable anatomy (conical aneurysmal neck and short landing zone) for EVAR performing. IVUS images were used to confirm the location of the lower renal artery, size of devices and optimal fixation sites. Aortic branch orifices were carefully detected for precise stent-graft placement. CO_2 completion angiography confirmed proper flow inside the grafts and no primary endoleak. There were no postoperative complications, and 18 months after surgery aneurysm size diminished from 86 to 60 mm [29].

Interestingly, Guntani et al. (2012) in their study investigating the impact of contrast agent usage during EVAR for deterioration of renal function in patients with pre-existing chronic kidney disease without haemodialysis, revealed no creatinine serum level accretion in all investigated groups. Researchers concluded that despite renal insufficiency contrast-enhanced EVAR may be performed safely. In the study, however, in 4 of 46 cases of severe renal impairment, IVUS was used to minimize the volume of intravascular contrast medium usage during arteriography [30].

IVUS — assisted EVAR as an elective approach in all patients (not only with contraindications to contrast media administration)

The research conducted by Illuminati et al. (2022) showed that fully ultrasound-guided EVAR (IVUS and contrast-enhanced ultrasonography (CEUS)) makes the exclusion of an infrarenal aortic aneurysms efficient, durable and safe. The authors proved that there is no need for iodine contrast administration during EVAR, and drew attention to minimising the radiation exposure for patients and surgeons. The study investigated 27 patients, 81% men, qualified for a standard endovascular aneurysm exclusion via an aortobi-iliac graft with sufficient infrarenal neck and normal common iliac arteries at their bifurcation. The mean aneurysm diameter was 62 ± 12 mm. There was no observed postoperative morbidity or mortality, and there was no necessity for reintervention [31].

Illuminati et al. (2020) in their pilot study conducted among 173 consecutive patients undergoing EVAR of the infrarenal AAA (out of them, 69 patients had IVUS-assisted EVAR with X-ray angiography limited to the last control phase of the operation) revealed that IVUS-assisted procedure is associated with a significant reduction in renal load with contrast agents, radiation dose and fluoroscopy time while stent-graft deployment efficiency is maintained [32].

Similarly, Pecoraro et al. (2019) demonstrated that IVUS-assisted EVAR procedures in patients presenting infrarenal abdominal aortic aneurysm significantly lowered the quantity of contrast medium usage and radiation exposure compared to conventional EVAR. The research included 52 patients (26 cases with IVUS-assisted EVAR and 26 cases with conventional EVAR). There were no differences between both groups in baseline characteristics, including perioperative mortality and morbidity, endoleaks or other complications. Analyses indicate also that there were no significant differences in operation time and blood loss between patients in the IVUS and non-IVUS groups [33].

The Lausanne experience already from 2005 provided congruous results, in which 88 patients with infrarenal aneurysms had implantation of endoprostheses, using exclusively IVUS and fluoroscopy. There was no contrast usage. IVUS identified the target site of deployment in all cases, and the 360° cross-sectional view ensured proper visualization of incomplete expansion in some endoprostheses. Endovascular aneurysm repair using IVUS has been approved as a reliable alternative method [34].

Regarding accepted rules, the European Society for Vascular Surgery Guidelines indicate that for an unstable patient in an emergency of rupture of infrarenal AAA, it is possible to obtain necessary measurements intra-operative during EVAR either via IVUS or fluoroscopically, instead of preoperative CT scan, but first, intraoperative aortogram should be performed to determine EVAR eligibility and to select suitable device [35].

Pros and cons of IVUS-guidance during EVAR of the AAA

IVUS is useful in assessing the distal and proximal stent-graft landing zones. It enables 360° visualization of the arterial wall and distinguishes the plaque nature (lipid core or calcium) [12]. Another relevant use of IVUS is measuring the distance between aortic branches [28]. The use of IVUS in the aortic district characterizes anatomic details of vessels and branches, particularly for aneurysms, dissections, or penetrating aortic ulcers [12]. It supplies data on diagnosis in real-time, it may help in final graft selection through reliable intraoperative diameter and length measurements, and it helps in accurate graft deployment [36]. EVAR with IVUS has been described to be more efficient than conventional EVAR with angiography in locating the ostia of the hypogastric arteries, removing the problem of parallax in an anteroposterior view of angiography [32, 37–39]. In many cases of AAA, during angiography with intra-arterial contrast agents, iliac arteries overlapped with the ostium of the hypogastric artery. The swing of the C-arm at exaggerated angles, which were difficult for operators to achieve and maintain, is needed to obtain images that show a clear separation of the branches. Then the exposure to intraoperative ionizing radiation increases for both patients and operators. Therefore, using IVUS decreases energy and time, and makes the work environment safer [28].

Regarding branched and fenestrated EVAR (B-FEVAR) procedure that is usually more difficult than infrarenal aneurysm exclusion, Gennai et al. (2021) revealed in their single-centre cohort study that IVUS is also safe as an adjunctive completion imaging tool for B-FEVAR; however, authors indicated the necessity of further research in this field. The technical success defined as IVUS assessment in each target visceral vessel (TVV) was reached in all investigated cases, considering 33 TTVs. Furthermore, intraoperative IVUS guidance allowed the detection of complications such as branch instability that had not been identified at the completion of angiography (they were missed by angiography). IVUS revealed TTV stenoses, kinking, or distal maladaptation between the renal artery and bridging stent. In some cases, TTV stenosis was difficult to assess during preoperative CT owing to the presence of vessel calcifications (concerning patients with secondary intervention, included also in the study); however, IVUS accurately depicted and confirmed possible CT image stenoses. In the aforementioned study, IVUS guidance has appeared to be feasible in various types of endografts and a variety of vessels (including renal arteries, superior mesenteric artery and celiac trunk). IVUS identified intraprocedural technical issues, and the authors concluded that it might prevent accessory interventions in the future [40]. Additionally, BEVAR could require significant amounts of contrast agent and radiation exposure due to the use of intra-operative cone beam computed tomography (CBCT). It was shown that using IVUS instead of CBCT it is possible to detect geometric anomalies of the bridging grafts during BEVAR, and hence IVUS may diminish costs and risks associated with CBCT [39, 41].

The IVUS provides exact true lumen length measurements using the incorporated radiopaque markers after the identification of anatomical landmarks such as the renal arteries, aortic bifurcation, and iliac bifurcation. Moreover, it provides real-time qualitative and quantitative characteristics of the aneurysm neck (length, diameter, calcifications and plaques). All these observed parameters can be compared to the measurement from the preoperative CT, allowing changes in the operative strategy. The IVUS control following the stent-graft deployment is also helpful in verifying the correct apposition of the stent graft in relation to the aortic neck and the proper patency of visceral vessels, particularly renal arteries [33, 42].

Problems were encountered while advancing the IVUS catheter through the bridging stent graft by the preferred fenestrated EVAR (FEVAR) femoral route. Hence, the use of the IVUS technique dominates in BEVAR cases, via brachial access [39]. Furthermore, a risk of complications is indicated, because it is not possible to evaluate endoleaks and stent alignment with the exclusive use of IVUS [28].

Conclusions

According to the literature, routine IVUS employment during EVAR procedures may be associated with intra-arterial contrast medium administration at least in the final phase of the operation; however, it may ensue from surgeons' desire to check the propriety of the performed EVAR promptly and thoroughly, or from the paucity of novel surveillance equipment, inter alia, contrast-enhanced ultrasonography. There were described studies, revealing that no contrast agents might be administered during EVAR of the infrarenal AAAs, and IVUS self-guidance with minimal duration fluoroscopy allows for completely correct carrying out of the procedure. Although the scientists' opinions are divided, and there is no consensus, certainly IVUS-guidance reduces ionizing radiation exposure and volume of administered intravascular contrast medium and allows for perioperative recognition of aortic morphology and stent-graft deployment factors. The majority of studies have been concerned about infrarenal aneurysms only, hence further research is needed to evaluate and validate IVUS-guidance utility in various types of aneurysms and stent grafts.

Article information and declarations

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