First experience using intraoperative contrast-enhanced ultrasound during endovascular aneurysm repair for infrarenal aortic aneurysms

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Background: **Endovascular aortic repair (EVAR) has become an additional treatment option for patients with infrarenal aortic aneurysms and suitable aortic morphology. However, endoleaks are commonly encountered and represent a relevant risk for secondary treatment failure. In addition, impaired renal function or allergic reactions to intravascular iodine application might represent exclusion criteria for conventional infrarenal endovascular aortic repair using intraoperative angiography with iodine contrast media. Real-time contrast-enhanced ultrasound (CEUS) with a low mechanical index (MI) is a promising method recently introduced for follow up after endovascular infrarenal aortic repair.**

Methods: **In this study, intraoperative CEUS using SonoVue as ultrasound contrast agent was evaluated in 17 patients for localization of the proximal infrarenal landing zone, the distal iliac fixation area, and identification of endoleaks in patients suitable for endovascular aortic repair with an infrarenal aortic neck ≥10 mm and non-aneurysmal common iliac arteries. For comparison, 20 patients were treated by conventional EVAR using intraoperative fluoroscopy and iodine contrast media.**

Results: **Intraoperative application of contrast-enhanced ultrasound (iCEUS) for identification of the infrarenal landing zone and proximal stent graft release was achieved in 14 out of 17 patients (82.4%), as verified by intraoperative angiography or postinterventional imaging. Intraoperative CEUS-assisted visualization of the distal fixation area proximal to the level of the iliac bifurcation was achieved in 89.3% (25 out of 28 iliac arteries examined) in comparison to intraoperative angiography or postinterventional CEUS, computed tomography (CT), or magnetic resonance (MR) angiography. Three selected patients having contraindications for iodine-based contrast media were treated by iCEUS-assisted EVAR without the use of any iodine contrast during fluoroscopy. Time for exposure to intraoperative radiation, volume of contrast medium used, and the number of intraoperative angiographies and postinterventional CT or MR angiographies were significantly reduced in the iCEUS-assisted EVAR group in comparison to conventional endovascular aortic treatment ($P < .002$ or less for all parameters). Intraoperative application of CEUS detected more endoleaks than conventional EVAR (8/17 vs 4/20; $P = .08$) treated by proximal stent graft extension in one symptomatic patient with a type Ia endoleak.**

Conclusions: **Intraoperative CEUS-assisted EVAR in patients with infrarenal aortic aneurysms represents a new option for intraoperative visualization of aortoiliac segments required as proximal or distal fixation zones and identification of endoleaks, especially in those patients with contraindications for usage of iodine-containing contrast agents, in association with a reduction of iodine contrast media used and radiation exposure during fluoroscopy.** **(J Vasc Surg 2010;51:1103-10.)**

Endovascular aortic repair (EVAR) of infrarenal aortic aneurysms has now become an accepted treatment option for patients with suitable aortic configuration, when performed by an experienced endovascular surgeon or interventionalist.[1,2] Although early postoperative follow-up data showed increased survival rates in patients with infrarenal aortic aneurysms after endovascular aortic repair, during long-term surveillance, the initial advantage of EVAR is lost, showing no difference between EVAR and open aortic surgery after more than 5 years.[3]

Progression of arteriosclerotic disease, with changes in aortic morphology, aneurysm progression, stent graft migration, and mechanical damage of the stent graft material might contribute to failure of endovascular treatment with the need for secondary reintervention or conversion to open surgery and an increased risk for secondary aneurysm rupture. Incomplete exclusion of the aneurysm sac after EVAR with persistent blood flow into the aneurysm is defined as an endoleak and subclassified according to the site of incomplete sealing between the stent graft and the aortic wall, the aortic branch vessel involved, possible leakage at the stent graft connection sites, or porosity of the graft material.[4] Early and sensitive detection of endoleaks, which is indeed highly desirable during the initial intervention when endovascular treatment can be administered immediately, might therefore improve long-term results of EVAR. However, magnetic resonance (MR)- and computed tomography (CT)-angiography, frequently used for

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postinterventional imaging and follow up, are associated with specific side effects and an increased risk of organ dysfunction or a relevant exposure to radiation, probably being involved in neoplastic transformation.[5,6]

In some patients, impaired renal function or a history of allergic reactions to intravascular iodine application might represent exclusion criteria for conventional infrarenal endovascular aortic repair using intraoperative fluoroscopic angiography with iodine contrast media.[7-9] Therefore, other noninvasive methods for intraoperative visualization of the proximal infrarenal aortic neck and the common iliac arteries are required for correct endovascular aneurysm exclusion with appropriate sealing between the aortoiliac vessel wall and the stent graft. Although intraoperative endoluminal vascular ultrasound or carbon dioxide angiography is used in some institutions and might represent an alternative intraoperative diagnostic approach for these patients,[10,11] these methods are not available everywhere and will not be sufficiently able to detect and subclassify endoleaks.

Clinical application of contrast-enhanced ultrasonography (CEUS) has recently been improved by the introduction of advanced contrast imaging software such as the Cadence contrast pulse sequencing (CPS) technology (Siemens Medical Systems, Forchheim, Germany) and the availability of second-generation contrast media such as SonoVue (Bracco, Milan, Italy), consisting of stabilized sulphur hexafluoride microbubbles.[12-14] CEUS has already been established in the evaluation of tumor perfusion and vascular diagnosis and has been shown to be a safe contrast agent for vascular and tissue imaging.[15,16] We have recently described our experience using CEUS for early follow up of patients after endovascular aortic repair for infrarenal aortic aneurysms.[17-19] According to our experience, CEUS shows high sensitivity and specificity for early detection of endoleaks without exposure to radiation nor to potentially nephrotoxic contrast media. In addition, we have recently described the intraoperative application of CEUS during EVAR for a patient with an infrarenal aortic aneurysm and preexisting progressive renal dysfunction for visualization of the proximal and distal aortoiliac sealing zones to prevent the application of iodine-based contrast medium during the endovascular intervention.[20]

In the present study, we have, therefore, further investigated the value of intraoperative contrast-enhanced ultrasonography (iCEUS) during endovascular aortic repair in selected patients with infrarenal aortic aneurysms suitable for EVAR for visualisation of proximal and distal aortoiliac landing zones and early detection of endoleaks. The results were compared with patients with infrarenal aortic aneurysms treated by conventional EVAR using application of iodine contrast for intraoperative angiography.

METHODS

Patients. Thirty-seven patients suitable for endovascular aortic repair (EVAR) for abdominal aortic aneurysms were included in the study between July 2007 and June 2008. Criteria for inclusion into the study were: infrarenal aortic neck ≥10 mm, absence of juxtarenal aortic thrombus, aortic angulation of less than 45 degrees, diameter of common iliac arteries less than 20 mm, and patent transfemoral access to aortoiliac vessels. Seventeen patients received iCEUS-assisted endovascular aortic repair for localization of the lowest renal artery, the iliac bifurcation on both sides, and exclusion of endoleakage following intended aneurysm exclusion. Intraoperative angiography with iodine-containing contrast fluids was also used in patients to confirm correct imaging by iCEUS or to identify intended aortoiliac landing zones in difficult anatomies, according to the judgement of the vascular surgeon or interventionalist and in the absence of contraindication for the use of iodine-based contrast agents. According to the contraindications described for the application of iodine-based contrast media, selected patients had endovascular aortic repair completely without application of iodine contrast fluid. Twenty consecutive patients fulfilling the inclusion criteria were treated for infrarenal abdominal aneurysms using conventional fluoroscopy and iodine contrast medium during endovascular aortic repair without the use of CEUS. Patients were selected for iCEUS-assisted EVAR according to the availability of intraoperative CEUS performed by an independent radiologist (C.D.A.) or the presence of contraindications for the use of iodine contrast for intraoperative angiography. All patients had at least one preoperative additional imaging procedure (CTA or MRA), including dynamic MR without contrast medium for those patients with impaired renal function or suspected allergy to iodine-based contrast.

Technique of contrast enhanced ultrasonography. Contrast-enhanced ultrasonography was performed using Cadence CPS technology with low Mechanical Index (MI: 0.15-0.19) on a Siemens ACUSON Sequoia 512 sonography unit (Siemens Medical Systems, Forchheim, Germany), as described previously.[17] This new imaging technique leads to a low applied acoustic pressure to produce images based on nonlinear acoustic interaction between ultrasound waves and stabilized microbubbles. These microbubbles oscillate and resonate, giving continuous contrast enhancement on gray-scale images. In addition, this technology supports an effective high frequency imaging and a colorized differentiation of micro- and macrovasculature. In order to avoid the loss of gray scale resolution in the contrast-enhanced imaging, we used an overlay technique with improved resolution (mixed mode) of the contrast-enhanced image and the gray-scale image. The ultrasound scans were performed by one of the authors (D.A.C.), an experienced radiologist with a special interest for abdominal in vascular ultrasound and an experience of more than 500 abdominal contrast enhanced ultrasound examinations per year.

SonoVue is a second-generation contrast agent consisting of stabilized microbubbles of sulfur hexafluoride gas, which is eliminated through the respiratory system.[16] The recommended dose for a single intravenous injection is 0.8 to 1.6 mL to obtain improved detectability of contrast enhancement. During the intraoperative application of contrast enhanced ultrasonography, the total amount of ultrasound contrast (SonoVue) used was 3.6 to 6.0 mL.

Informed consent was obtained from all patients investigated with CEUS before the intervention, and preoperative CEUS was recommended for all patients selected for the EVAR + iCEUS group.

Contraindications for the use of Sonovue were defined for patients with severe heart diseases, including instable coronary artery disease, myocardial infarction, acute cardiac failure and class III/IV cardiac failure, severe arrhythmic disorders, patients with right-to-left shunts, acute endocarditis, prosthetic valves, severe pulmonary hypertension (pulmonary artery pressure >90 mm Hg), uncontrolled systemic hypertension, and patients with adult respiratory distress syndrome.[21]

Stent-graft placement with additional intraoperative application of CEUS. Endovascular aortic repair was performed in an interventional operating room using a mobile angiography unit (Ziehm Vision R, Ziehm Imaging, Nürnberg, Germany), usually under epidural or local anesthesia. During the endovascular intervention, patients received systemic anticoagulation (5000 IU heparin). All patients were treated with an aortobiiliac bifurcated stent graft (Cook Zenith, Bjaeverskov, Denmark). In the CEUS-assisted EVAR group, the position of the lowest renal artery was visualized by CEUS prior to stent graft insertion or on the day before the intervention. During intraoperative application of CEUS, localization of the lowest renal artery was transferred to the fluoroscopy screen using the radiopaque markers of a balloon catheter (diameter: 8 mm; length: 40 mm). After partial deployment of the proximal part of the aortic stent graft, the correct infrarenal positioning and complete deployment and sealing between the infrarenal aortic neck and the implanted stent graft was confirmed by iCEUS. Distal iliac landing zones were also localized by iCEUS, showing the position of the iliac bifurcation on both sides. Iliac stent graft extensions were then released within both common iliac arteries for complete distal aneurysm exclusion. Following balloon dilatation of the proximal fixation, the overlapping zones, and the iliac landing zones, intraoperative CEUS was used to exclude any remaining perfusion of the aneurysm sac. Endoleaks identified were then further characterized according to the origin of the blood flow identified, the aortic branch vessels involved, possible leakage at stent graft connection sites, or graft porosity and classified according to the description of White et al.[4] Release of the proximal stent graft was intended just below (≤5 mm) the lowest renal artery to achieve complete aneurysm exclusion and to prevent proximal type I endoleak.

Biphasic CT or MR angiography. Biphasic enhanced CT was performed preoperatively for planning of endovascular aortic repair or done postinterventionally to confirm correct stent graft positioning or detect persistent endoleaks, using a standard protocol with a 16- or 64-slice CT scanner (Somatom Sensation 16 or 64, Siemens Medical Systems).

In selected patients with known or suspected allergy to iodine-containing contrast agents or preexisting renal insufficiency, CT or MR scans without contrast agents were performed, and CEUS was additionally used for preoperative planning.

Table I. Patient characteristics: patients treated for infrarenal aortic aneurysm by EVAR using conventional intraoperative contrast media and fluoroscopy without or with iCEUS

	Conventional EVAR	*EVAR + iCEUS*
Number of patients	20	17
Age (years; mean ± SD)	70.9 ± 7.8	71.9 ± 7.4
Gender (male/female)	17/3	14/3
Body mass index (kg/m²; range)	28.4 (25-35)	28.8 (26-35)
Emergency treatment	1	1
Aneurysm diameter (cm; mean ± SD; range)	5.7 ± 4.8 (5.4-7.5)	6.0 ± 4.9 (5.6-7.2)
Infrarenal aortic neck (mm; mean ± SD)	14.5 ± 1.2	13.9 ± 0.8
Aortobiiliac stent graft	20	17
Monoiliac stent graft	0	0

EVAR, Endovascular aneurysm repair; *iCEUS,* intraoperative contrast-enhanced ultrasonography.

Analysis of data. Reported data were prospectively collected and documented. Comparison of frequencies was performed by chi-squared analysis using Pearson's coefficient or Fisher's exact test (both two-sided), and data from non-parametric variables were evaluated using the analysis of variance test. A P value of less than 0.05 was considered to indicate a statistically significant difference. Statistical analysis was performed using SPSS statistical software (version 15.0; SPSS, Chicago, Ill).

RESULTS

Thirty-seven patients with an infrarenal aortic aneurysm suitable for endovascular aortic repair (EVAR) were treated. In 17 patients, iCEUS-assisted EVAR was used for detection of proximal or distal aortoiliac landing zone and detection or exclusion of postinterventional endoleakage. Additional application of intraoperative angiography with iodine-based contrast agents was applied according to the judgement of the endovascular surgeon or interventionalist. For comparison, 20 patients had endovascular aortic repair using conventional fluoroscopy and intraoperative aortic angiography using iodine-containing contrast fluid.

Patient characteristics were similar in both groups regarding age, gender, body mass index (BMI), aneurysm diameter, and length of infrarenal aortic neck (Table I). All patients were treated with an aortobi-iliac stent graft system. Stent graft implantation was technically successful in all patients, with no mortality in either group.

The principal steps of the described iCEUS-assisted endovascular aortic repair are shown in Figs 1 to 5. Visualization of the individual aortic morphology using contrast-enhanced ultrasonography in comparison to three-dimensional MRI reconstruction is shown in Fig 1. Identification of the proximal landing zone just below the lowest renal artery is

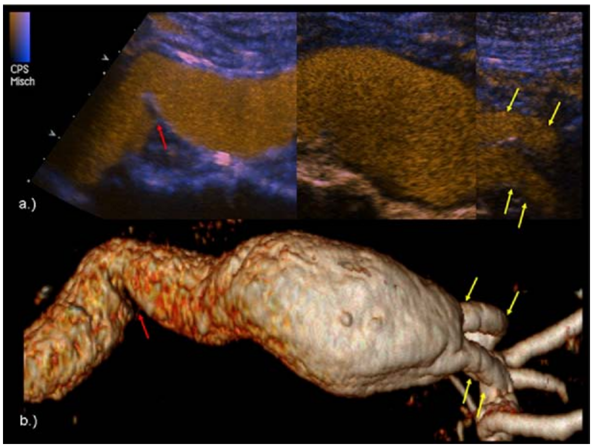

Fig 1. Intraoperative visualization of an infrarenal aortic aneurysm using contrast enhanced ultrasonography (**a**) in comparison to three-dimensional reconstruction of the magnetic resonance imaging (MRI) data obtained during MR angiography (**b**). The red arrow shows the infrarenal aortic kinking and the yellow arrows demonstrate the distal landing zone at level of the common iliac arteries.

Fig 2. Visualization of the proximal infrarenal landing zone by intraoperative contrast-enhanced ultrasound (iCEUS) using an endoluminal balloon catheter dilatation (yellow arrows), giving a contrast-sparing zone within the aortic lumen. The length of the balloon catheter is measured between the white cross markers (measured length: 4.07 cm; original length of the catheter as described by the manufacturer: 4.0 cm). The red arrow shows again the kinking of the aorta. Stent graft release was planned within the straight infrarenal aortic segment just below the zone of aortic kinking.

performed by intraoperative CEUS assistance using an endoluminal contrast-sparing balloon catheter (Fig 2) with simultaneous visualization of the radiopaque markers of the balloon catheter on the fluoroscopy screen. Following aortic stent graft implantation, intraoperative CEUS is used for confirmation of complete aneurysm exclusion at the level of the infrarenal proximal landing zone (Fig 3) and the distal

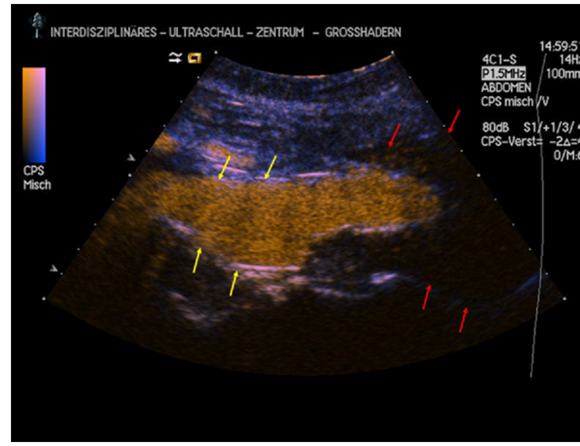

Fig 3. Intraoperative contrast-enhanced ultrasound (iCEUS): proximal infrarenal landing zone. iCEUS demonstrating complete proximal sealing of the stent graft. The yellow arrows show the sealing of the stent graft along the wall of the excluded proximal aortic segment. Proximal stent graft release is just below the aortic kinking, as intended. Red arrows show contrast air bubbles within the aneurysm sac, as expected, because distal aortic stent graft extension has not yet been performed. This picture would otherwise be identical to a distal type II or III endoleak.

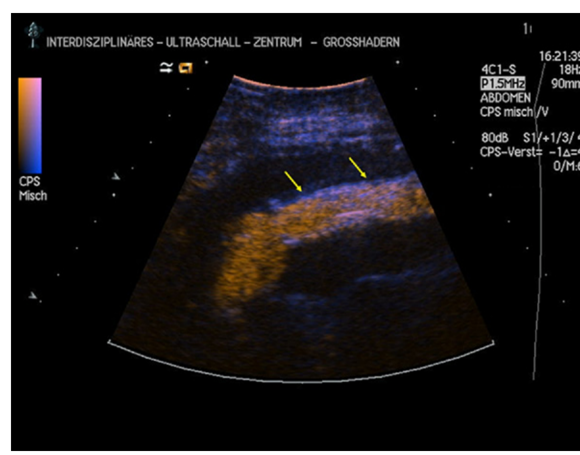

Fig 4. Intraoperative contrast-enhanced ultrasonography demonstrating the right iliac stent graft (yellow arrows) extension without a detectable endoleak.

iliac fixation segment (Fig 4). In Fig 5, a type III endoleak is shown at the connection site of the contralateral iliac extension stent graft, which was successfully treated by repeated endoluminal balloon dilatation.

Intraoperative application of CEUS during EVAR resulted in correct identification of the infrarenal landing zones and successful proximal stent graft release (≤5 mm below the lowest renal artery) in 14 out of 17 patients (82.4%), and was confirmed by at least one imaging modality: intraoperative angiography (n = 10), intraoperative CEUS (n = 17), or diagnostic or postoperative CT angiography in seven patients. Visualization of the distal fixation

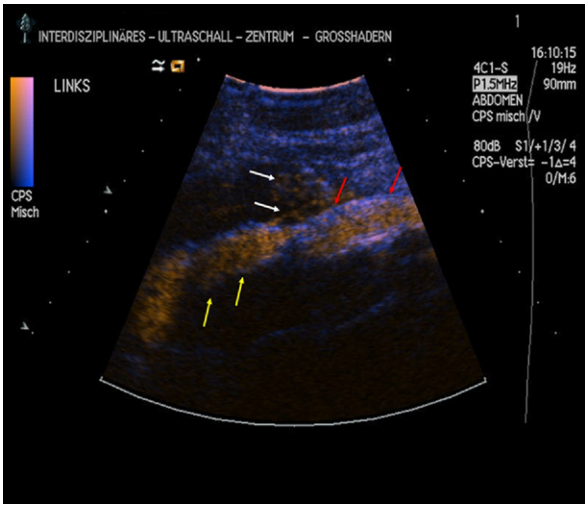

Fig 5. Postinterventional type III endoleak (white arrows) at the distal connection site of the left iliac extension (red arrows) endoleak following EVAR for an infrarenal aortic aneurysm. The type III endoleak disappeared after balloon dilatation of the left iliac stent graft connection site.

area at the level of the iliac bifurcation by CEUS in comparison to intraoperative angiography or postinterventional CEUS was successful in 25 out of 28 iliac arteries examined (89.3%; Table II). Three patients with preexisting renal insufficiency or known allergy to iodine-containing contrast agents were completely and successfully treated by iCEUS-assisted EVAR for localization of stent graft landing zones, for control of patent perfusion of renal and internal iliac arteries, and exclusion of relevant endoleaks, without the use of any iodine contrast media during fluoroscopy. Intraoperative use of CEUS-assisted EVAR identified more endoleaks in comparison to conventional EVAR using intraoperative iodine-based contrast angiography (8/17 vs 4/20; $P = .08$) and required proximal stent graft extension in one symptomatic patient with a type Ia endoleak, identified by intraoperative CEUS.

Time for endovascular intervention to exclude infrarenal aortic aneurysms was similar in both groups (Table II). However, time for intraoperative exposure to radiation and the volume of iodine-containing contrast fluid given were significantly lower in the iCEUS-assisted EVAR group (radiation time: 7.48 ± 2.2 minutes [range, 4-12 minutes] and amount of iodine-containing contrast medium: 39.1 ± 22.4 mL [range, 0-80 mL]) in comparison to the conventional EVAR group (10.7 ± 1.5 minutes [range, 8.5-14 minutes]; $P < .001$ and 97.0 ± 7.8 mL [range, 60-120 mL]; $P < .001$, respectively). Final intraoperative angiography was performed in all patients treated by conventional EVAR (20/20; 100%), but only in 8 out of 14 (57.1%; $P = .002$) patients with normal renal function treated by iCEUS-assisted EVAR. Similarly, CT or MR angiography usually performed prior to discharge was applied to all patients after conventional EVAR (20/20; 100%), but used only in 7 out of 14 patients after iCEUS-assisted EVAR (50 %; $P = .001$).

During early postoperative follow-up after 3 to 6 months, no additional endoleaks were detected in the iCEUS-assisted EVAR group in comparison to CT angiography or postinterventional CEUS, while four new endoleaks, one proximal type I and three type II endoleaks, were postoperatively detected in the conventionally-treated EVAR group by postinterventional CEUS and/or CT or MR angiography (0/9 vs 4/16; $P = .10$), initially not detected by intraoperative conventional angiography. More than half of the of the type II endoleaks initially detected in both groups by intraoperative or postinterventional CEUS (8 out of 14; 57.1%) sealed without any further intervention.

DISCUSSION

In the present study, intraoperative contrast-enhanced ultrasonography (iCEUS) was evaluated for visualization of the proximal aortic and distal iliac landing zones and for exclusion or detection of relevant endoleaks, probably requiring immediate reintervention. According to our experience, application of intraoperative contrast-enhanced ultrasonography might become an additional imaging modality, especially for patients with impaired renal function, allergy to iodine-based contrast fluids, or possible risk for iodine-induced hyperthyroidism.

Intraoperative CEUS-assisted EVAR was used for visualization of the proximal aortic and distal iliac landing zones and for detection or exclusion of relevant endoleaks, probably requiring reintervention. Identification of the lowest renal artery for correct proximal stent graft release with complete sealing at the site of the proximal infrarenal aortic neck was achieved in 14 out of 17 patients. In one patient, primary stent graft extension for a type I endoleak was required, which was identified during the endovascular intervention using iCEUS. Following identification of the lowest renal artery by CEUS localization, stent graft deployment within the intended distance of ≤5 mm below the lowest renal artery was achieved in all patients (14 out 14; 100%) using intraoperative CEUS. In three patients with a kinked aortic segment and difficult visualization of the renal arteries, conventional angiography was necessary to identify the proximal attachment site. Visualization of the iliac bifurcation was achieved in more than 80% of the iliac arteries investigated. Although relevant aneurysms of the common iliac arteries were excluded in this pilot study, three patients had at least one highly tortuous and calcified common iliac artery, with a stenosis at the site of the internal iliac artery preventing correct identification by iCEUS. According to our early results, in more demanding vascular conditions with a short and kinked infrarenal aortic neck or calcified iliac arteries, a more detailed preinterventional investigation of the aortoiliac vessels using CEUS is recommended and will improve the intraoperative accuracy of iCEUS-assisted aortoiliac procedures. Therefore, CEUS-assisted EVAR seems to be feasible for infrarenal aortic repair in selected patients with a sufficiently long infrarenal

Table II. Perioperative results following endovascular aortic repair for infrarenal aortic aneurysms using conventional fluoroscopy with iodine-containing contrast agents (n = 20) or with additional application of intraoperative contrast-enhanced ultrasonography (n = 17)

	Conventional EVAR	*EVAR + iCEUS*	P
Time for intervention (min, mean ± SD)	122 ± 19.3	134 ± 32.4	n.s.
Fluoroscopy time (min, mean ± SD)	10.7 ± 1.5	7.4 ± 2.2	<.001
Volume of contrast medium (mL, mean ± SD)	97.0 ± 7.8	39.1 ± 22.4	<.001
Intervention without iodine contrast	0	3	—
Correct visualization of stent graft fixation zone			
Lowest renal artery	18/20 (90 %)	14/17 (82.4 %)	n.s.
Distal common iliac artery	17/20 (85 %)	21/24 (89.3 %)	n.s.
Endoleaks detected	4/20 (20 %)	8/17 (47.1)	.08
Type I	0	1	
Type II	4	6	
Type III	0	1	
Immediate reintervention	2/20 (10 %)	2/17 (11.8 %)	n.s.
Balloon dilatation	2	1	
Stent graft extension	—	1	
Conversion to open surgery	0	0	
Final intraoperative angiography	20/20 (100%)	7/14 (50.0 %)	.001
Computed tomography-angiography prior discharge	20/20 (100%)	8/14 (57.1 %)	.002

EVAR, Endovascular aneurysm repair; *iCEUS,* intraoperative contrast-enhanced ultrasonography; *n.s.,* not significantly different.

aortic neck and suitable condition for abdominal ultrasonography. Based on our experience, iCEUS-assisted EVAR seems to be applicable for all types of conventionally available stent grafts and might be especially helpful for those with good visualization by ultrasonography and the possibility of a partial release mechanism. However, the applicability of iCEUS to other types of abdominal aortic stent grafts during EVAR for infrarenal aneurysms needs further evaluation.

Early detection of endoleaks, especially of type I or III endoleaks during iCEUS-assisted EVAR, might offer the possibility of early endovascular reintervention to achieve complete aneurysm exclusion with prevention of endoleak-mediated persistent systemic pressure in the aneurysm sac associated with the risk of aneurysm expansion and secondary rupture.[22-24] As shown in our study, intraoperative contrast-enhanced ultrasonography was able to identify all relevant endoleaks in contrast to intraoperative angiography or postinterventional CT angiography. In patients with evidence for a type I or type III endoleak detected intraoperatively by iCEUS, immediate reinterventions using balloon dilatation or stent graft extension were performed. These patients were then followed by CEUS and CTA or MRA. Patients with type II endoleaks and exclusion of type I or type III endoleaks underwent a check up by CEUS at the time of discharge and during early follow up for 12 months. According to this concept, the amount of iodine contrast medium used during surgery, the intraoperative time for exposure to radiation, and the number of CT angiograms usually recommended prior to discharge and during initial follow up were significantly reduced. Therefore, based on our initial experience, intraoperative CEUS seems to be remarkably sensitive and specific to identify endoleaks following EVAR in comparison to intraoperative angiography or postoperative CTA or MRA, with the immediate opportunity for early endovascular reintervention.

In selected patients with contraindications for the use of iodinated contrast fluids, the application of intraoperative CEUS has some remarkable advantages: it is noninvasive, reproducible, highly sensitive, and can be performed as a bedside procedure even in critically ill patients. Although intraoperative CEUS requires a special ultrasound system with special software for adequate contrast-enhanced imaging and an experienced investigator, it seems reasonable to perform endovascular aortic repair under control of intraoperative CEUS in selected patients to prevent major acute renal dysfunction, dialysis, and other iodine-associated side effects. In all the patients investigated by intraoperative CEUS in our center, we did not observe any systemic complications or immediate negative effects on pre-existing renal insufficiency during the early postinterventional follow up. Within the iCEUS-assisted EVAR group, one patient with preexisting renal dysfunction developed a prolonged inflammatory response syndrome over several weeks with persistent systemic inflammation, elevated temperature, increased levels of leukocytes, and inflammatory proteins. This patient's impaired renal function evolved into secondary renal insufficiency, although no alteration of renal perfusion could be detected.

Based on our experience, several conditions might make the use of iCEUS difficult: intraluminal or intra-abdominal air, severe obesity, or complex vascular anatomy. Therefore, we usually perform and strongly recommend preoperative or preinterventional CEUS before the scheduled intervention, to become familiar with the patients' individual conditions and the feasibility to perform intraoperative CEUS. According to our experience during the last 5 years with more than 250 CEUS investigations in post-EVAR patients, the feasibility of performing CEUS was >98%. Within our study, the infrarenal aortic segment could be identified in all patients investigated, although we had difficulties identifying the common iliac bifurcation in two patients (11.8%). Both of these patients had a BMI above 30 kg/m^2, and one of them was not investigated by CEUS preoperatively. However, in several other patients with a BMI above 30 kg/m^2, we were able to successfully perform intraoperative CEUS. Therefore, we would not define a certain BMI as an exclusion criteria for iCEUS during EVAR.

Contrast-enhanced ultrasonography is an advanced ultrasound technique composed of standard B-mode imaging combined with the visualization of vascular flow and parenchymal microcirculatuion using ultrasound contrast medium. In our study, iCEUS was performed by a specialized radiologist with profound experience in abdominal and especially in vascular contrast-enhanced ultrasonography. However, in our daily practice, vascular surgeons with a special interest in advanced vascular sonography also perform iCEUS, which requires a profound knowledge in abdominal ultrasonography and further training for 6 months in an experienced center with at least 100 additionally performed CEUS examinations. Therefore, the CEUS technique can also be performed by vascular surgeons with special experience and interest in advanced vascular ultrasound techniques.

Lifelong surveillance is required in patients with abdominal aortic aneurysms treated with stent grafts to detect aneurysm progression, stent graft migration, or defects in the stent graft material and structure.[23] During follow up of patients treated with EVAR for infrarenal aortic aneurysms, the technique most commonly used at present for surveillance for endoleak detection is CTA or MRA in combination with abdominal X-rays in two dimensions.[25,26] Duplex ultrasound has been investigated as an alternative to CTA for postoperative surveillance because of its noninvasive nature, its widespread availability, and its relatively inexpensive technology. However, the data reported so far have shown controversial results.[27-29] Contrast-enhanced ultrasonography was shown to overcome most limitations of conventional ultrasound and shows good correlation with CTA.[17] We have recently described our initial experience using CEUS during follow up of patients after endovascular aortic repair for infrarenal aortic aneurysms.[19] Several other recently published reports have confirmed our positive experience and support the use of CEUS for further follow up and endoleak detection after infrarenal aortic stent graft repair.[30-32]

In conclusion, intraoperative contrast-enhanced ultrasound might become an additional imaging modality in selected patients with an abdominal aortic aneurysm requiring endovascular aortic repair in association with an impaired renal function, a known allergy to iodine contrast agents, or suspected iodine-induced hyperthyroidisms. In patients with suitable aortic configurations, intraoperative CEUS enables good visualization of proximal and distal aortoiliac segments for stent graft fixation, leading to a relevant reduction of the amount of contrast medium used, the time of exposure to radiation, and the costs for surveillance during early postinterventional follow-up.

AUTHOR CONTRIBUTIONS

Conception and design: RK, DC
Analysis and interpretation: RK, DC
Data collection: RK, WZ, RW, GM, DC
Writing the article: RK, DC
Critical revision of the article: RK, WZ, RW, GM, DC
Final approval of the article: KR, DC
Statistical analysis: GM, DC
Overall responsibility: RK, DC

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