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ULTRASOUND

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Imaging of aortic abnormalities with contrast-enhanced ultrasound. A pictorial comparison with CT

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Abstract Aortic abnormalities are commonly encountered and may represent a diagnostic challenge in patients with acute or chronic clinical symptoms. Contrast-enhanced ultrasound (CEUS) with low mechanical index (low MI) is a new promising method in the diagnosis and follow-up of pathological aortic lesions. CEUS with SonoVue allows a more rapid and noninvasive diagnosis, especially in critical patients because of its bedside availability. This review compares CEUS findings with those documented on computed tomography angiography (CTA), allowing the reader to appreciate the usefulness of CEUS in this clinical situation.

Keywords Contrast-enhanced ultrasound · Aortic lesions · CT angiography

Introduction

Owing to its availability, safety and low cost, conventional ultrasound is the most widely used imaging modality in routine clinical practice worldwide. Its limitations, however, in the detection of aortic lesions versus CTA are well recognized [1, 2].

Direct comparison of unenhanced ultrasound with contrast-enhanced CTA is probably inappropriate given the fact that without contrast enhancement the performance of CT may well be equal or even inferior to that of ultrasound. The introduction of microbubble ultrasound contrast might be a way of bridging the gap between these modalities.

Recent articles have described the use of contrast-enhanced ultrasound (CEUS) for endoleak detection after aortic stent graft repair [3–5] and for diagnosis of ruptured abdominal aortic aneurysm [6].

Rapid advances in imaging techniques combined with the development of a new generation of contrast agents have improved the clinical applications of ultrasound. CEUS is a relatively new, accurate, time- and cost-effective and minimally invasive tool for the detection of aortic lesions such as ruptured aortic aneurysms. It overcomes most limitations of conventional ultrasound and shows good correlation with CTA.

Abdominal aortic abnormalities may present acutely with pain and signs of hemorrhage including hypotension, tachycardia, cold extremities, hematemesis, hematochezia or melena. Initial presentation however can vary from mild discomfort to hypotensive shock. The term acute aortal disorder includes aneurysm rupture, dissection, acute occlusion, traumatic injury, postoperative complications and aortocaval fistula. Understanding the scope of acute abdominal aortic pathology helps to expedite the rapid-imaging evaluation and diagnosis of these frequently lifethreatening conditions. We describe in this pictorial review aspects of aortic pathology encountered in clinical practice and compare CEUS assessment with CTA in order to demonstrate the usefulness of CEUS.

CEUS technique

Technical developments over the past decade have focused on different microbubble consistencies and effective methods of detection of their nonlinear signals. The low mechanical index (MI, 0.15–0.19) allows production of real-time gray-scale images [7]. Contrast-specific techniques use a low applied acoustic pressure to produce images based on nonlinear acoustic interaction between the ultrasound system and stabilized microbubbles. These microbubbles oscillate and resonate, giving continuous contrast enhancement to gray-scale images [7, 8].

A recent advance in improved contrast imaging is the Cadence™ contrast pulse sequencing (CPS) technology on the Siemens ACUSON (Mountain View, CA) Sequoia™ 512. The detection technique harnesses nonlinear microbubble energy discovered within the same fundamental frequency band as the transmitted pulses of sound and thus offers improved sensitivity. Furthermore this technology supports more effective high-frequency imaging and a colorized differentiation of micro- and macrovasculature [9, 10].

SonoVue (Bracco, Milan) is a second-generation contrast agent consisting of stabilized microbubbles of sulfur hexafluoride gas, which is eliminated through the respiratory system. It is of low solubility, innocuous, isotonic with human plasma, and devoid of antigenic potential, as it does not contain any proteinaceous material [11]. The required dose of the contrast agent is still not well defined. The recommended dose for a single injection is 1.6–2.4 ml to improve the detection ability of contrast enhancement [5, 11]. In our series, no side effects related to SonoVue were observed.

Abdominal aortic aneurysm (AAA)

An abdominal aortic aneurysm (AAA) is defined as a focal, irreversible dilatation of the abdominal aorta greater than 3 cm (Fig. 1) [12]. Ruptured AAAs are the tenth leading cause of death in men over 55 years of age [13].

Rupture of an abdominal aneurysm requires immediate recognition and prompt treatment. Untreated patients have a fatal outcome, whereas patients with surgical repair recover in 30–65% of cases [14, 15]. Stable patients may deteriorate rapidly and delayed surgery carries lower survival [15]. Therefore minimizing the time spent on preoperative investigation is crucial. Most authors agree that subjects with typical symptoms should not undergo prolonged investigation and that emergency US should be the initial diagnostic step [6, 15, 16]. Worldwide, US is used for primary screening of abdominal aortic aneurysm and blunt abdominal trauma [17]. Stable patients with questionable, possibly contained ruptures are usually imaged with contrast-enhanced CTA [6]. Sonography has been proven to be an accurate and consistent method of ruling out aneurysm, with a sensitivity of 95–98% [12, 18–20].

Some authors have suggested that a proper clinical setting (hypotension, back or abdominal pain and pulsatile mass) and a 1-min sonography examination in the emergency department will allow the recognition of an aneurysm in 97% of the patients and is enough to bring the patient to the operating theater [20].

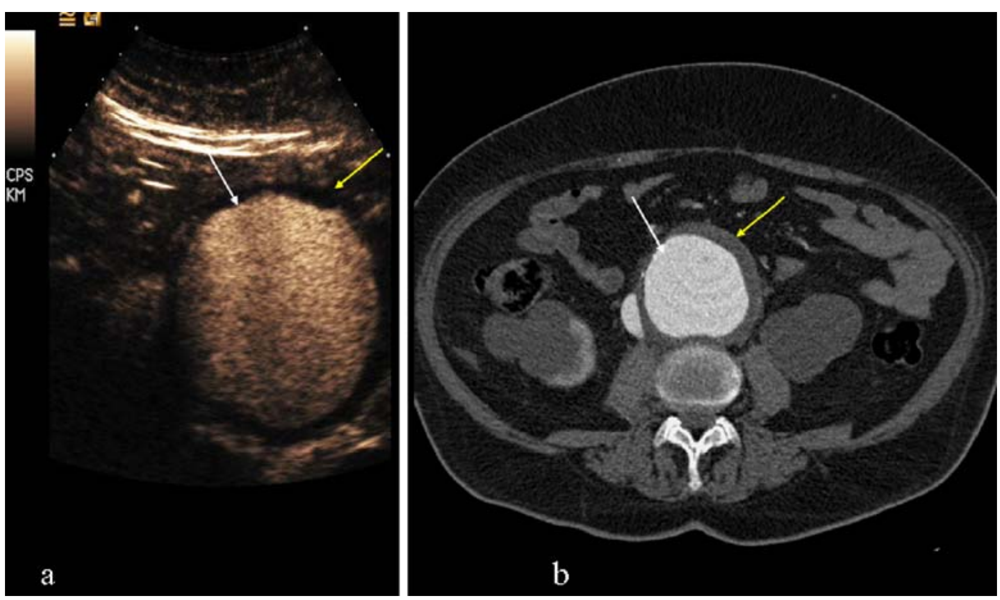

Fig. 1 Aortic aneurysm visualized by CEUS (**a**) and CTA (**b**). Perfused lumen (*white arrow*) framed by thrombotic material (*yellow arrow*)

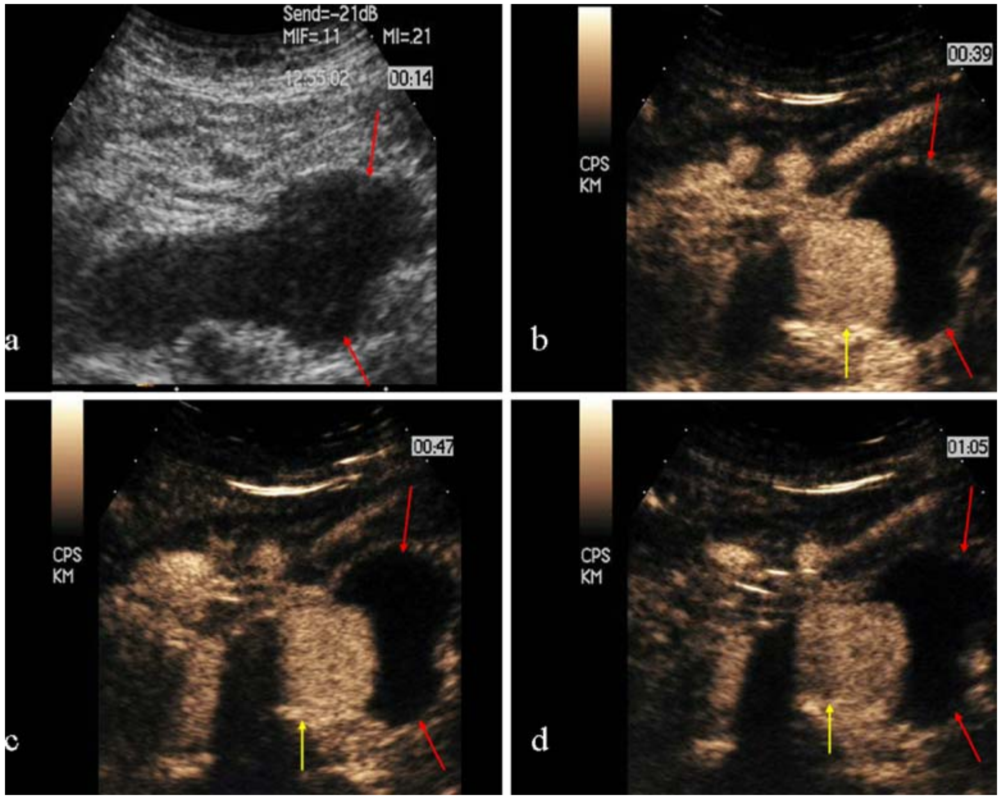

Fig. 2 B-scan imaging (**a**) of a covered abdominal aortic rupture (*yellow arrows*) with periaortic hematoma (*red arrows*). CEUS showed no contrast extravasation over more than 30 s (**b**–**d**)

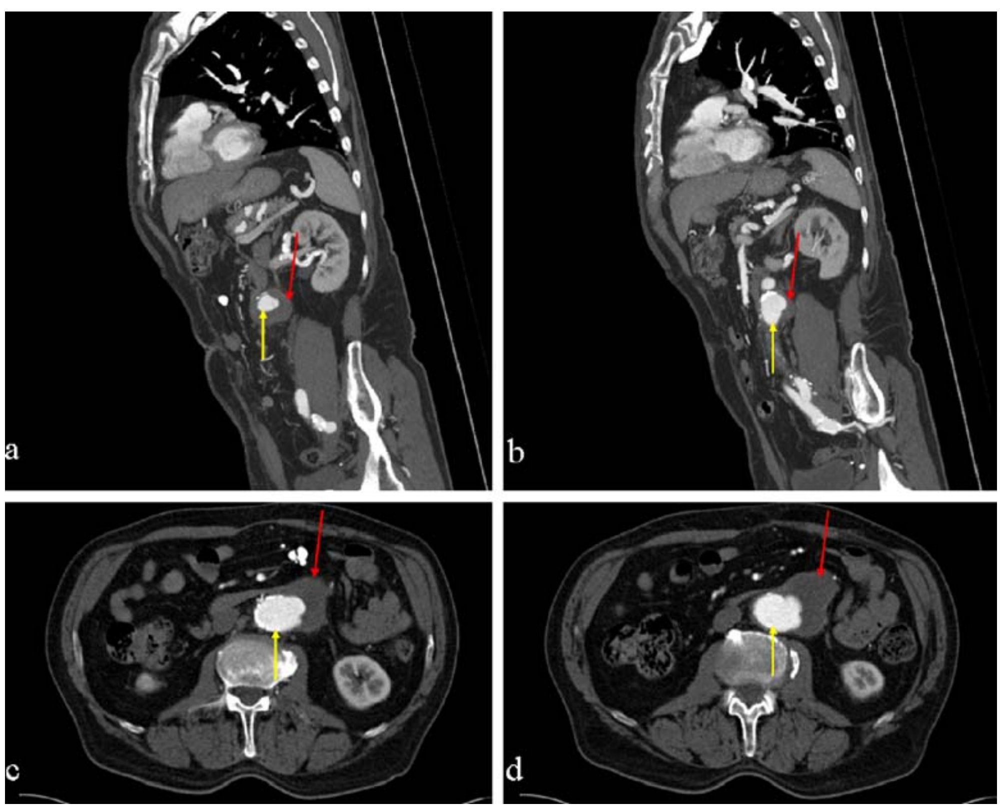

Fig. 3 Same patient as Fig. 2. CTA in sagittal (**a**, **b**) and axial (**c**, **d**) planes demonstrating a covered abdominal aortic rupture (*yellow arrows*) with periaortic hematoma (*red arrows*). No contrast extravasation could be detected

However, conventional US has some limitations in imaging patients with ruptured abdominal aneurysm because, e.g., retroperitoneal hematomas are not always detected and there is no direct feature of rupture itself [20].

Contrast-enhanced sonography can overcome some of these limitations. CEUS can detect several signs of rupture including delayed lumen wash-in and wash-out, enhancement of the aneurysmal wall and contrast extravasation (Figs. 2 and 3) [6]. Catalano et al. reported identifying specific features of ruptured aortic aneurysms without causing any delay in surgery. The technique might be as effective as CTA, and allows a more rapid and noninvasive diagnosis because of its bedside availability [6].

Aorto-caval fistulas

Aorto-caval fistulas are a rare complication of infrarenal aortic aneurysms having a frequency of less than 1% of all abdominal aortic aneurysms [21, 22]. Spontaneous rupture into the inferior vena cava (IVC) has an overall prevalence of 3–6% [23–25]. Especially infrarenal aortic aneurysms with the involvement of the right iliac artery seem to be associated with a higher risk for perforation into the inferior cava vein. Preoperative recognition is of importance because heart failure from over-transfusion, inadequate or misplaced incisions, major blood loss and pulmonary embolization of aneurismal debris through the fistula can occur. Typical clinical symptoms of aorta-caval fistulas are acute abdominal pain, rapid cardiac decompensation with dyspnea and an audible machinery-like bruit. In addition tachycardia, peripheral edema, constricted renal function and hematurea can be present [26, 27]. However in stable circulation with a small fistula volume, clinical symptoms might be marginal.

Syme et al. was the first to report an aorto-caval fistula in combination with an abdominal aortic aneurysm in 1831 [28]. Over 90% of aorto-caval fistulas are associated with atherosclerotic abdominal aortic aneurysms in western Europe. Iatrogenic aorto-caval fistulas are not that common with a prevalence of 2–5%.

Untreated aorto-caval fistulas can cause rapid cardiopulmonary decompensation depending on the fistula's volume [21, 24, 26].

Perioperative mortality of patients with abdominal aortal aneurysms with the presence of aorto-caval fistulas undergoing open surgery is up to 20–60% [22, 23]. Additional retroperitoneal rupture of the aneurysm considerably increases the mortality.

The diagnosis is usually made by noninvasive testing, such as US scanning, including CEUS (Fig. 4). The gold standard for detecting and characterizing an aorto-caval fistula today is CTA (Fig. 5). The precise site of the fistula, loss of the fat plane and direct inflow of contrast material from the aorta into the infrarenal inferior vena cava can be identified [29].

Aortic dissections

Isolated abdominal aortic dissections are rare and are much less common than abdominal dissection associated

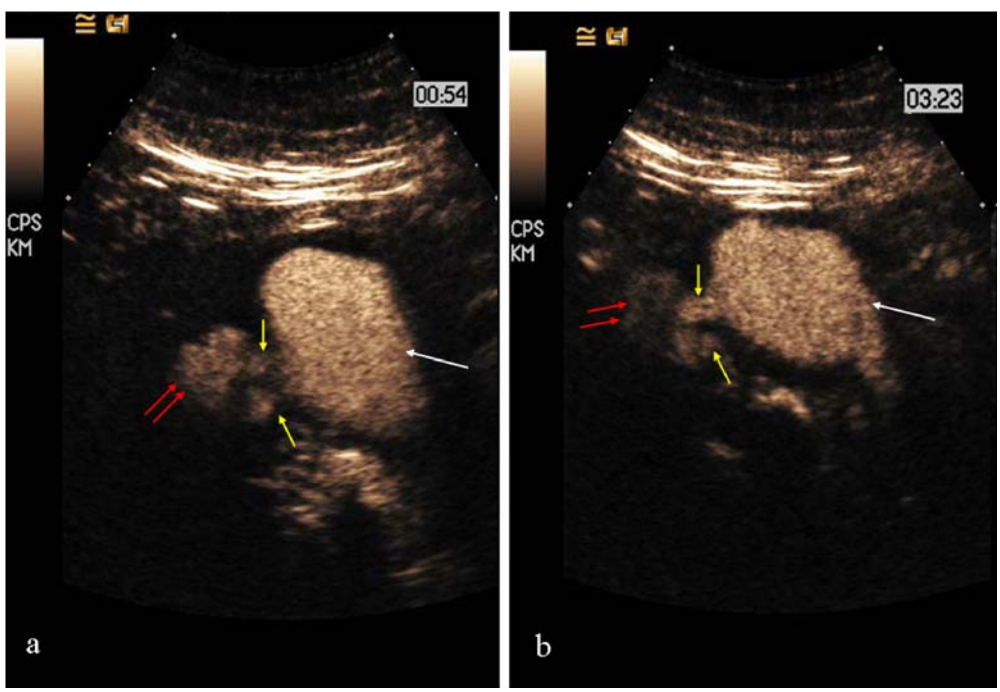

Fig. 4 Aortocaval fistula depicted by CEUS, showing the aortic lumen (*white arrows*), the inferior cava vein (*red arrows*) and two different perfused fistula "canals" (*yellow arrows*)

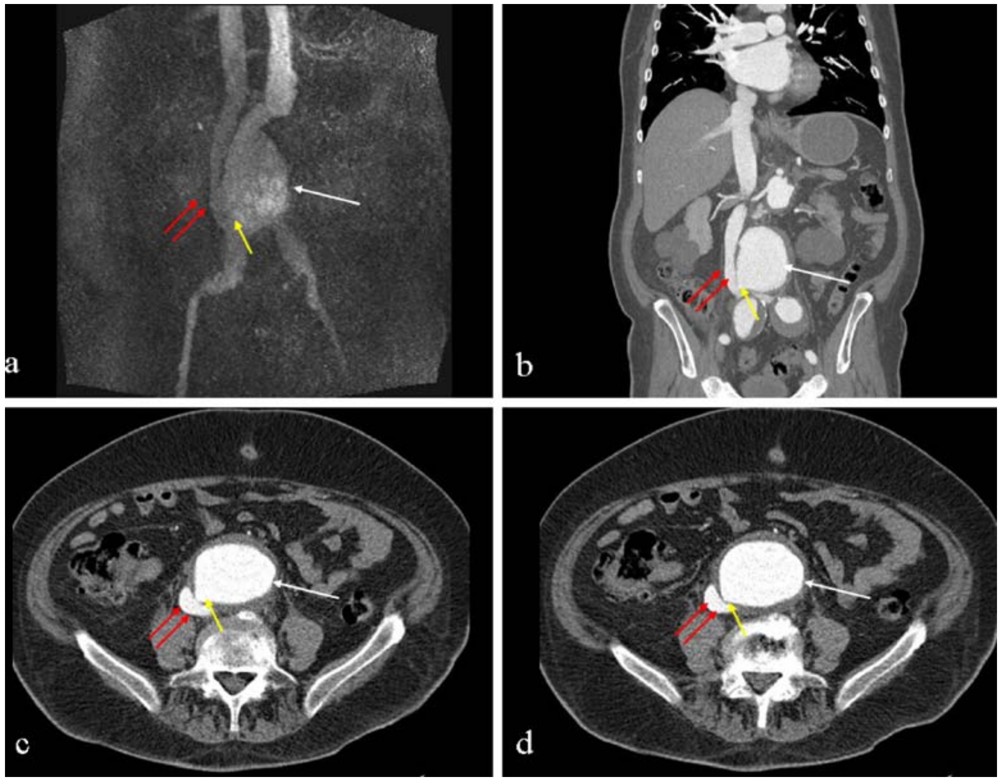

Fig. 5 CTA in sagittal (**a**, **b**) and axial (**c**, **d**) planes demonstrating the aortocaval fistula. Only one perfused fistula canal could be detected (*yellow arrow*) between the aorta (*white arrows*) and inferior vena cava (*red arrows*)

with thoracic aortic dissection [30]. As with AAA, hypertension is believed to be a major risk factor for aortic dissection [31]. Cystic medial necrosis, associated with Marfan syndrome, is another important etiology of aortic dissections. Up to 5% of aortic dissections are caused by intravascular catheterization and are usually

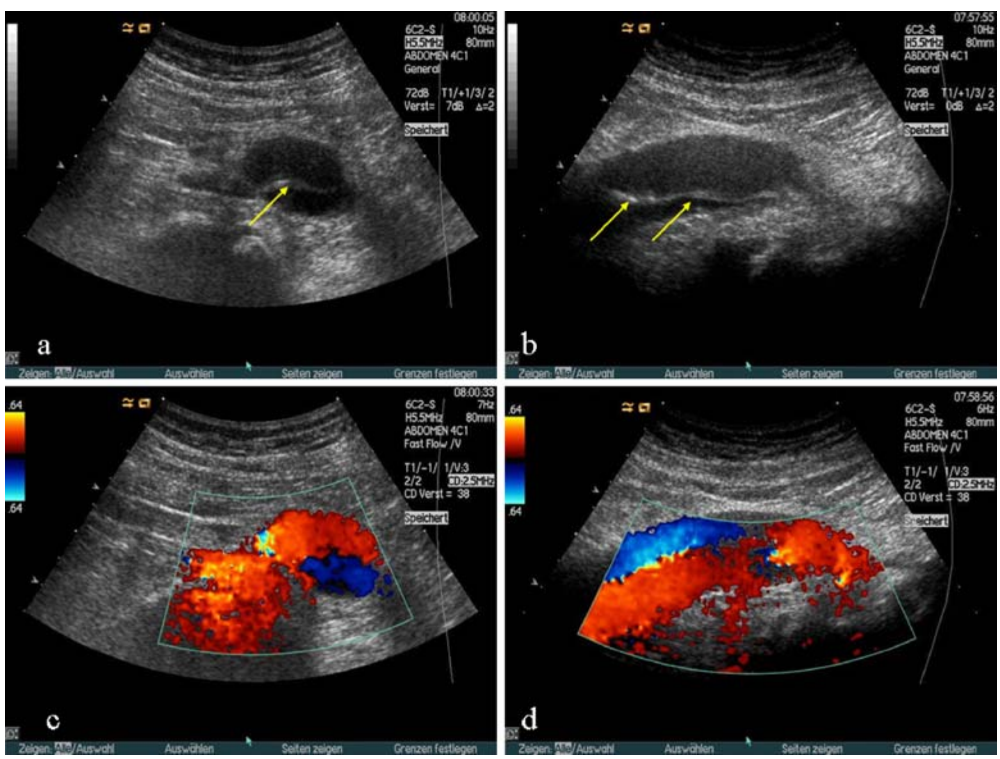

Fig. 6 B-scan, aortic dissection axial (**a**) and sagittal (**b**) plane with pulsating membrane (*yellow arrow*). Color Doppler perfusion of both lumens. Differentiation between true and false lumen was not possible (**c**, **d**)

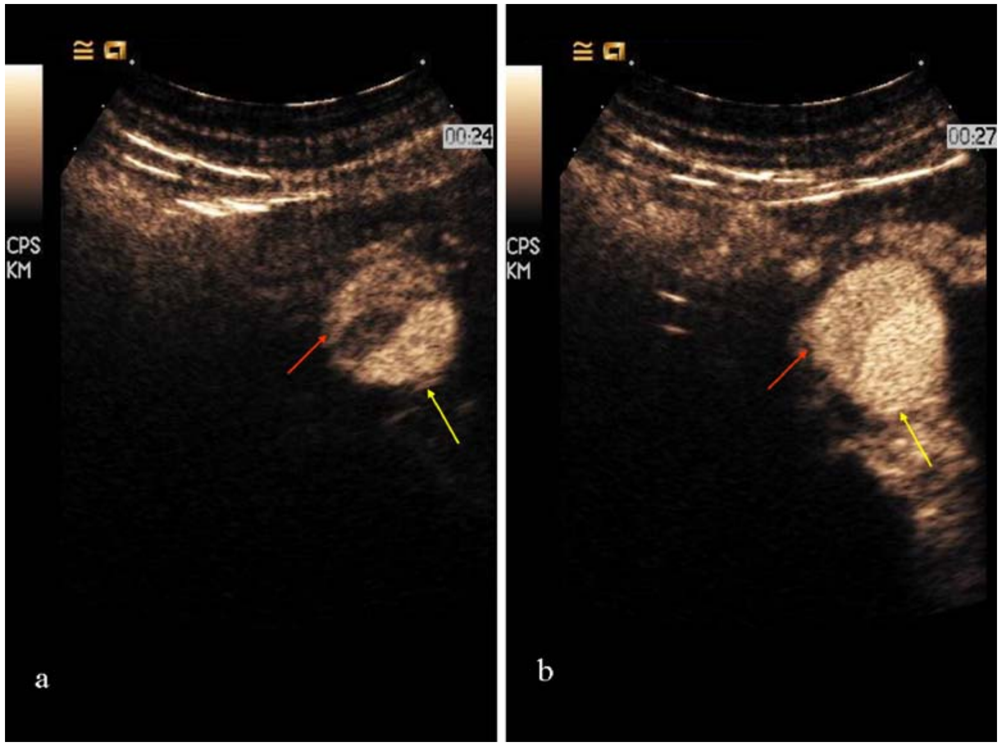

Fig. 7 CEUS axial plane, demonstrating perfusion of true (*yellow arrow*) and false (*red arrow*) lumen (**a**, **b**). Early contrast enhancement of true lumen after 24 s (**a**)

located in the abdominal and descending thoracic aorta [32].

Symptoms such as chest or abdominal pain, asymmetric blood pressure and signs of branch vessel occlusion (i.e., mesenteric ischemia, renal symptoms), paraplegia or hemiplegia are not universally present, and the clinical manifestations may often overlap with other diseases that patients bring to an emergency department [31, 33]. Clinical suspicion is important because up to 38% of aortic dissections are missed on initial examination and up to 28% of aortic dissections remain undetected until autopsy [31, 33, 34].

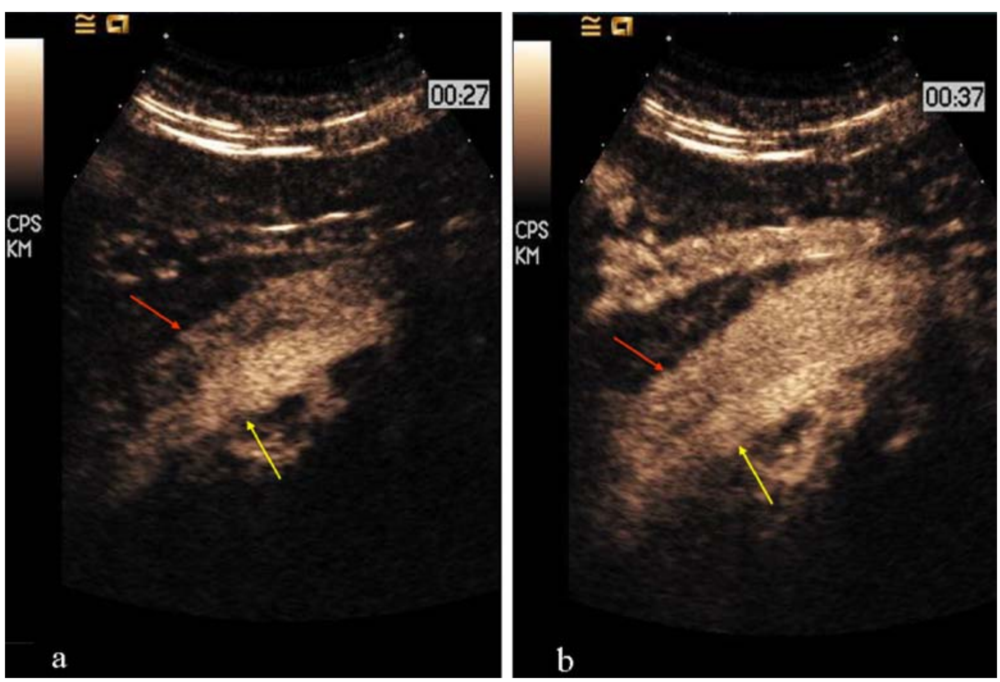

Fig. 8 CEUS sagittal plane, demonstrating perfusion of true (*yellow arrow*) and false (*red arrow*) lumen (**a**, **b**). Early contrast enhancement of true lumen after 27 s (**a**)

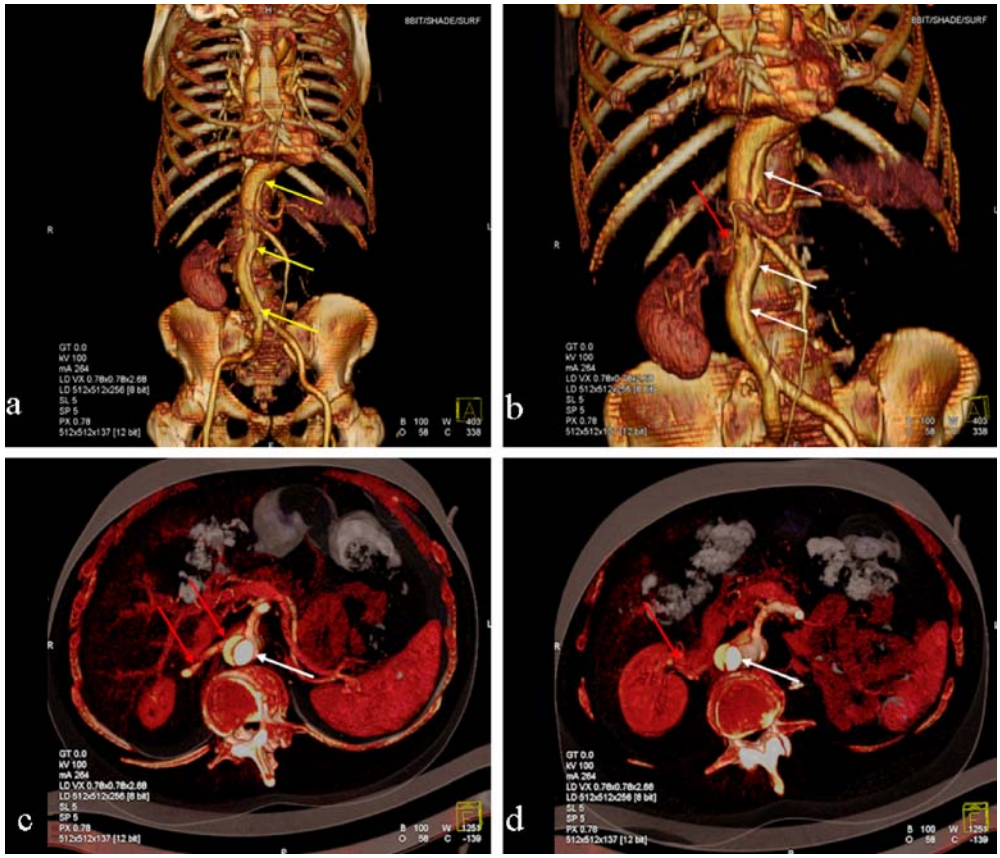

Fig. 9 Same patient as Figs. 6, 7 and 8. CTA in 3D reconstructions (**a**, **b**) showing a long aortic dissection (*yellow arrows*). CTA in axial plane (**c**, **d**) showing the right renal artery perfused from the false lumen (*red arrows*) and the true (*white arrows*) and false lumen of the aorta

With CEUS the true and false lumen can be clearly distinguished, because both early (true lumen) and late (false lumen) contrast flow can be detected. In addition the pulsating membrane and re-entry of the dissection membrane can be recognized. Even small membranes can easily be detected (Figs. 6, 7, 8 and 9).

Endoleaks

Endoleaks represent the main complication after endovascular aortic aneurysm repair (EVAR). They occur in up to 45% of the cases. Presence of an endoleak can cause aneurysm enlargement and increased pressurization of the thrombosed sac, which requires treatment to reduce the risk of rupture [35, 36].

Over the years endoleak classification has changed. Current classification describes endoleaks resulting from incomplete sealing of the stent graft to the attachment sites as type I endoleaks. Type II endoleaks are determined by retrograde flow from aortic collateral vessels (usually a vertebral artery). Type III endoleaks are caused by graft disruption. Type IV endoleaks occur due to an abnormal porosity of the graft structure [37, 38].

The most widely accepted imaging modality for follow-up of patients after EVAR is biphasic CTA (Fig. 10) [39, 40]. However, CTA does not allow detection of some types of endoleaks [39]. Several authors have pointed out the usefulness of US because it seems to allow better identification and characterization of endoleaks, with analysis of velocity and flow direction [41–43]. US contrast agents seem to increase US diagnostic accuracy

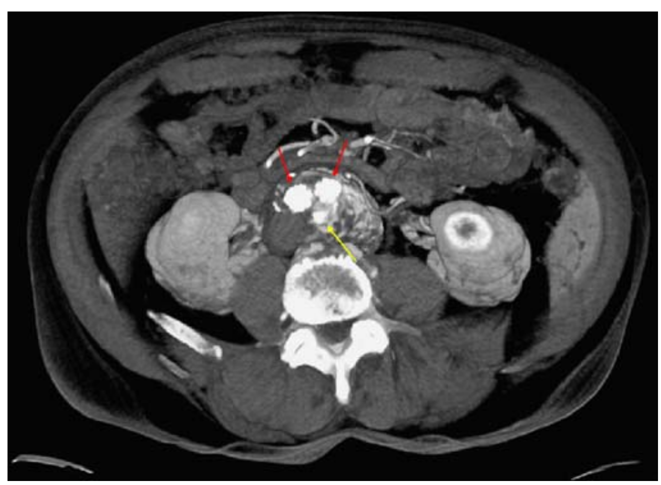

Fig. 10 CTA axial plane demonstrating the right and left iliac segment of the stent graft (*red arrows*) and the type III endoleak (*yellow arrow*)

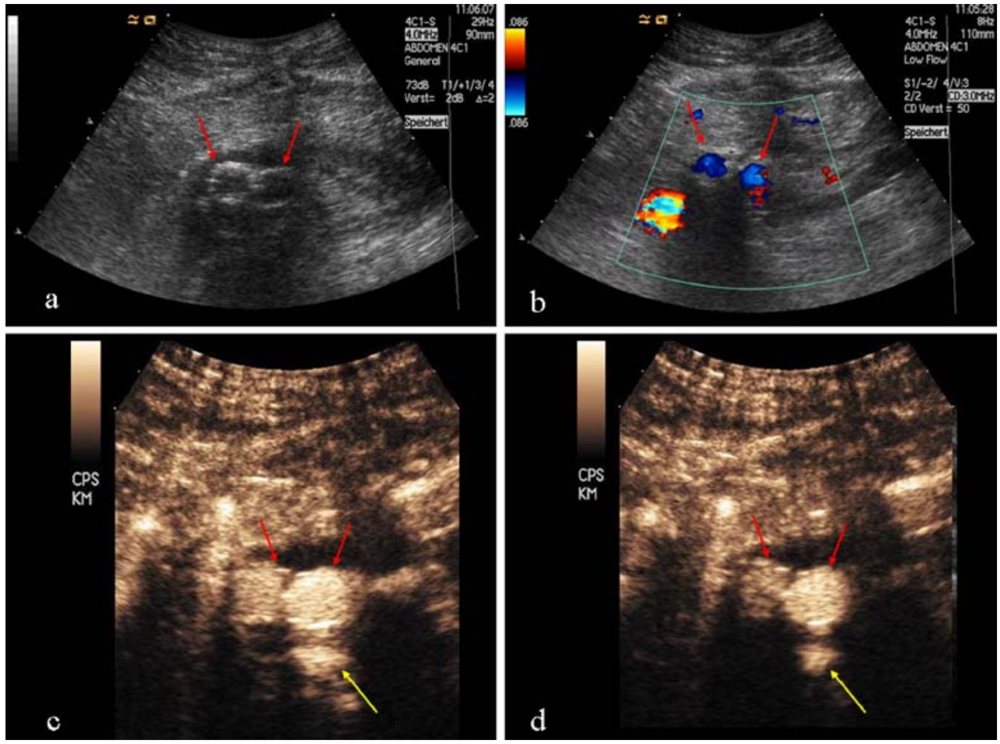

Fig. 11 Same patient as Fig. 10. B-scan (**a**) and color Doppler (**b**) imaging demonstrating both iliac segments of the stent graft (*red arrows*). CEUS images in axial sections (**c**, **d**) showing right and left iliac segments of the stent graft (*red arrows*) and a type III endoleak (*yellow arrow*)

substantially and have recently been applied in several fields (Fig. 11). Their effectiveness in aiding in the detection of endoleaks has recently been investigated, too [3, 4].

Discussion

Compared to CTA, vascular ultrasound is often regarded as a second-choice modality for detecting vascular disorders such as dissection or arteriovenous fistulas. Nowadays, however, ultrasound technology offers promising developments such as CEUS. CEUS represents a noninvasive, fast, well-tolerated, reproducible, and apparently very sensitive imaging modality [4, 44]. In our experience the use of sonographic contrast agent tends to increase the sensitivity of the ultrasound examination, overcoming some of its limitations and improving the detectability of blood flow within the vessels, with no need for complex maneuvers and no discomfort for the patient.

Nonetheless, CEUS has some limitations. Obesity and bowel gas can interfere with US scanning, and patient compliance is always required. The equipment, including the contrast agent, is highly specific, not yet widely available, and expensive. The examination is operator-dependent and requires specific skills and training. Finally, CEUS may seem very sensitive in the depiction of per-graft flow but is not appropriate for the evaluation of other factors such as graft anchorage and integrity and changes in aneurysm morphology, for which CTA is the modality of choice [2, 39, 45]. However, CTA has some limitations, such as potential contrast-agent allergy and nephrotoxicity, radiation exposure and cost. One disadvantage of all ultrasound methods is that they cannot cover all areas, such as the thoracic aorta or intracranial area and thus, for example, the true extent of dissection may be underestimated.

Conclusion

Contrast-enhanced ultrasound with SonoVue enables the detection and evaluation of aortic disorders. The main advantage is its bedside availability. Additional information such as perfusion from the true to the false lumen can be obtained. In hemodynamically compromised patients in particular, the bedside examination that is possible with CEUS provides a good alternative to CTA.

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