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Comparison of Doppler ultrasonography and computed tomography angiography for endoleak diagnosis after endovascular treatment of abdominal aortic aneurysm

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ABSTRACT

Objectives: This study aims to compare the utility of Doppler ultrasound (DUS) versus computed tomography angiography (CTA) in the diagnosis of endoleaks.

Patients and methods: Between October 2008 and December 2010, a total of 30 patients (27 males, 3 females; mean age: 70.1±12 years, range: 52 to 85 years) with abdominal aortic aneurysms (AAAs) who underwent endovascular aneurysm repair (EVAR) were retrospectively analyzed. All patients were followed at 1, 6, and 12 months after EVAR with both DUS and CTA.

Results: Stents grafts were patent in all patients. Endoleak was detected with CTA in six patients. Four patients had type I endoleak and two had type 2 endoleak. On CTA, two patients with type 2 endoleaks were unable to be detected with DUS. Considering CTA as the gold standard, DUS had a sensitivity and specificity of 75% and 100%, respectively. For detecting type 1 endoleak, DUS demonstrated a sensitivity and specificity of 100% and 100%, respectively. For detecting type 2 endoleak, DUS had a sensitivity of 50% and specificity of 100%.

Conclusion: Our study results suggest that DUS is reliable method for detecting endoleak and measuring diameter of aneurysm during follow-up after EVAR. It may be possible to use DUS as an alternative to CTA in routine follow-up of the patients.

Keywords: Aneurysm, computed tomography angiography, Doppler ultrasound, endoleaks, endovascular aneurysm repair.

Abdominal aortic aneurysm (AAA) is pathological dilation of the abdominal aorta which is susceptible for rupture and ranks the 13th leading cause of death in the United States.[1,2] Major risk factors for aneurysm rupture are female sex, aneurysm diameter, growth rate (more than 1 cm per year), chronic obstructive pulmonary disease, low forced expiratory volume in 1 sec (FEV1), current smoking status, family history, connective tissue disease, and elevated mean arterial pressure.[3,4]

Ultrasound (US) and Doppler US (DUS) are used to show the diameter of the aneurysm, its longitudinal size, its relationship with the renal artery, the presence of mural thrombus, and its extension to the iliac arteries.[5,6] If surgery is planned, computed tomography (CT), computed tomography angiography (CTA), magnetic resonance imaging (MRI), magnetic resonance angiography (MRA), digital subtraction angiography are the choices.[7]

Apart from non-operative follow-up, there are two options for elective repair of AAA: open surgical treatment (OST) and repair with endovascular aneurysm repair (EVAR) to prevent rupture.[8] Surgery should be performed in low medical risk, active life of patients with aneurysm diameter greater than 5.5 cm, or symptomatic and rapidly growing aneurysms (0.5 cm within six months, over 1 cm in a year), regardless of diameter or diameter of ≥6 cm.[9] Compared to conventional surgery, EVAR has many advantages such as shorter procedure time, low morbidity, mortality

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and paraplegia rates, short intensive care unit duration, and lower rates of renal, cerebral and respiratory complications.[2,10,11] On the other hand, OST has lower rates of re-operation with lower long-term mortality rates.[12]

Contrast medium reaction, contrast medium-induced renal insufficiency, colonic ischemia, wound complications, renal failure, myocardial infarction, pneumonia and death are perioperative complications of EVAR.[2,10,13,14] Long-term complications of the technique are endoleaks, graft infection, aortoenteric fistula, buttock claudication, limb occlusion, and sexual dysfunction.[2,10] The most common complication of EVAR is endoleaks, which is the leakage of blood between the graft and the aneurysm sac and is asymptomatic until aneurysm sac ruptures occur.[13]

Currently, CTA is the most commonly used gold-standard imaging modality in the diagnosis of endoleaks and in post-repair follow-up with EVAR. In the present study, we aimed to investigate the diagnostic accuracy of DUS versus CTA for the detection of endoleaks after EVAR in the early follow-up period.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Izmir Katip Çelebi University, Faculty of Medicine, Department of Cardiovascular Surgery between October 2008 and December 2010. Patients who were diagnosed with AAA and underwent endovascular stent graft application were screened using the hospital database. Patients with ruptured AAAs, previous open abdominal vascular surgery history, AAAs extending above the renal arteries, and those who were not eligible for endovascular intervention were excluded. Finally, a total of 30 patients (27 males, 3 females; mean age: 70.1±12 years, range: 52 to 85 years) who were followed with both DUS and CTA after treatment were included. A written informed consent was obtained from each patient. The study protocol was approved by the Izmir Katip Çelebi University, Faculty of Medicine Ethics Committee (Date/no: 2021/0019). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Endovascular stent graft placement was performed under local anesthesia in 16 patients, general anesthesia in 11 patients, and epidural anesthesia in the remaining three patients. Femoral access was used in all patients and self-expandable monotype graft was preferred. An aorto-uni-iliac stent graft was placed in four patients, contralateral iliac artery was occluded, and femoro-femoral bypass was applied in these patients. An aorto-bi-iliac stent graft was placed in the other 26 patients. Approximately 10 to 20% oversizing was applied to preoperative calculated size of proximal and distal landing zones. An interventional radiologist and vascular surgeon performed the procedures simultaneously. The patients were followed at 1, 6, and 12 months after EVAR with both DUS and CTA.

Computed tomography angiography technique

All patients underwent CTA examination with an aneurysm protocol on a four-detector CTA device (Toshiba Corp., Tokyo, Japan). Contrast material was administered through the antecubital route with an automatic injector. Axial sections in the arterial phase were obtained from the diaphragm level to the iliac bifurcation after an average of 100 mL of non-ionic contrast material administration at a rate of 3 mL/s with the bolus tracking technique. Sagittal and coronal images were reconstructed from axial images. Aneurysm diameter measurement was performed on these reconstructed reformat images. Considering the course of the aorta, transverse diameter was measured from the widest part of the aneurysm. In the captured CTA protocol, the slice thickness was 3 mm, pitch: 1, rotation time 0.5 sec, kV: 120, mA: 250. Images were sent to Picture Archiving and Communication System (PACS) and workstation after shooting. Evaluation was made at workstations and all images were archived in the PACS (Figure 1).

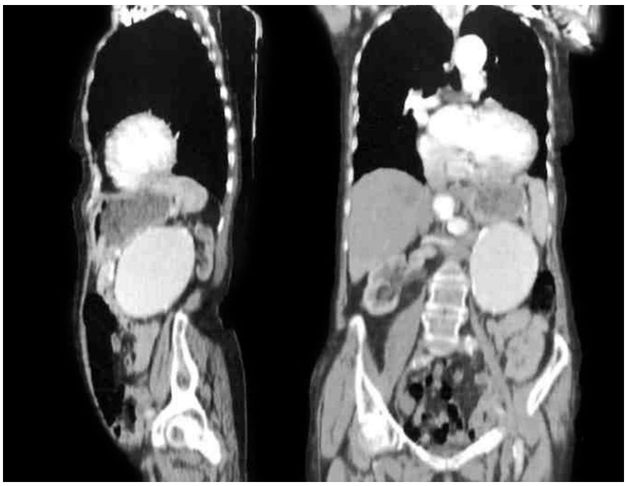

Figure 1. Computed tomography angiography of sagittal and coronal reformat images.

Doppler ultrasound technique

Doppler US examination of the abdominal aorta and its branches was performed in all patients in the supine position, with breath holding or during shallow breathing in patients who could not hold their breath. Investigations were performed using a 3 to 5 MHz multifrequency probe on a Logiq™ P6 device (General Electric Co., NY, USA). The images obtained after the examination were archived. All DUS examinations were performed by a radiologist experienced in DUS. Aneurysm and stent graft were examined in axial and longitudinal planes with B-mode and DUS. The transverse diameter of the aneurysm, perpendicular to the course of the vessel, was measured at the widest part of the aneurysm (Figure 2). The presence of flow in the lumen of the aneurysm other than the lumen of the stent, the presence of color coding in DUS, whether this flow is related to the aortic branches and the patency of the graft lumens were investigated in cases with flow outside the stent lumen.

Routine CTA and DUS results were compared considering the presence of endoleak, aneurysm diameter, and stent patency. This comparison was made by two separate radiologists who evaluated routine CTA scans and performed DUS examination.

Statistical analysis

Statistical analysis was performed using the SPSS version 15.0 software (SPSS Inc., Chicago, IL, USA). Descriptive data were expressed in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. One sample t-test was used to analyze variables, while the Kappa agreement analysis and receiver operating characteristics (ROC) curve analysis were used for the agreement on endoleaks detection between DUS and CTA. The Pearson correlation analysis was used to evaluate the correlation between the variables. The difference between DUS and CTA diameter measurements was examined using the Student's t-test. The sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of DUS for endoleak detection were calculated by accepting CTA as the gold standard. A p value of <0.05 was considered statistically significant.

RESULTS

Demographic characteristics of the patients included in the study are summarized in Table 1. The mean follow-up period was 8.6±3 months. In all of our patients, the first CTA and DUS examinations were performed within the first week before discharge. Eighteen (60%) patients were further evaluated with CTA and DUS at both 6 and 12 months of the follow-up, eight (26.67%) patients were evaluated with CTA and DUS at six months, and four (13.33%) patients were evaluated with CTA and DUS at 12 months. The stent graft was patent in all patients. Endoleak was detected in six patients (20%) on CTA examination.

Three patients diagnosed with type 1A endoleak on DUS were also diagnosed with type 1A endoleak

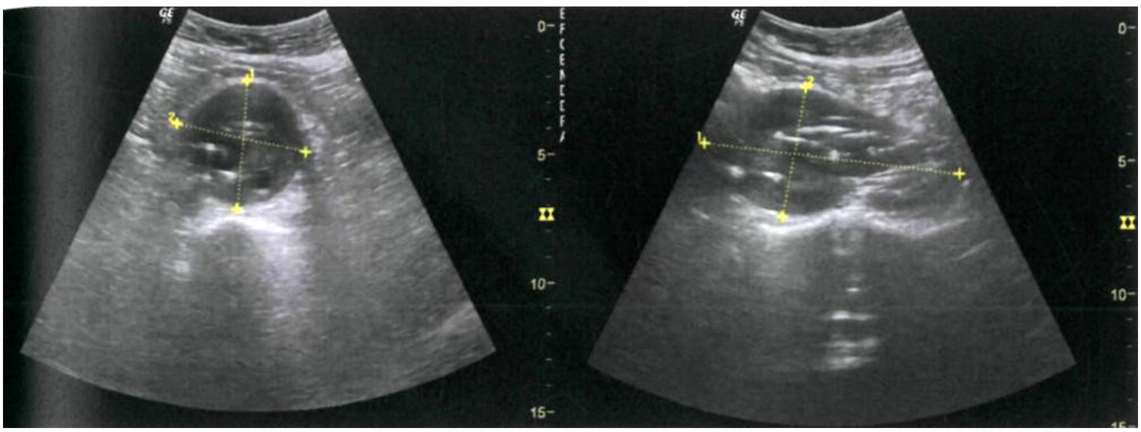

Figure 2. Size measurements of the aneurysm sac in images perpendicular and parallel to the long axis, respectively with DUS.

DUS: Doppler ultrasonography.

Table 1
Demographic characteristics of patients

No	Age	Sex	Comorbidity	Operation	Aneurysm diameter (CTA) (mm)	Aneurysm diameter (DUS) (mm)
1	59	M	HT, DM, COPD	-	64	6
2	76	M	CAD, PAH, HT	CABG	74	69
3	71	M	PAH, HT	-	65	65
4	71	M	HT, CAD	CABG	56	50
5	78	M	CAD, HT, COPD	CABG	63	60
6	85	M	CAD, HT	-	100	93
7	81	M	DM, HT	-	60	63
8	58	M	HT, CAD	CABG	55	52
9	54	M	HT, Ehler Danlos	-	92	90
10	82	M	DM, HT, CAD	CABG	62	60
11	80	M	COPD, HT	-	58	55
12	67	M	HT, CAD	CABG	98	96
13	82	F	HT	-	55	52
14	54	M	HT, Crohn	-	60	57
15	72	M	HT, COPD	-	60	58
16	80	M	HT	-	65	62
17	79	M	HT	-	54	50
18	72	F	-	-	70	66
19	52	M	-	-	93	89
20	63	M	CAD, COPD	-	75	72
21	71	M	HT	-	60	58
22	62	M	HT, PAH		52	51
23	60	M	DM, HT	-	56	52
24	62	M	HT, CAD	CABG	79	80
25	80	M	HT	-	45	45
26	82	M	-		53	50
27	75	M	CAD, PAH	CABG	67	66
28	84	M	COPD	-	57	53
29	84	F	-	-	65	67
30	76	M	DM, HT	-	66	64

CTA: Computed tomography; DUS: Doppler ultrasound; HT: Hypertension; DM: Diabetes mellitus; COPD: Chronic obstructive pulmonary disease; CAD: Coronary artery disease; PAH: Pulmonary artery hypertension; CABG: Coronary artery bypass graft.

on CTA and 27 patients who were thought not having type 1A endoleak on DUS were not type 1A endoleaks on CTA, either (Table 2). The Kappa coefficient calculated for the positive and negative values for the diagnosis of type 1A endoleak was found to be 1,000 (p=0.000), and a perfect agreement was observed between DUS and CTA results which were statistically significant according to the ROC curve analysis (p<0.001) (Figure 3, Table 3).

One patient who was diagnosed with type 1B endoleak on DUS was also diagnosed with type 1B endoleak on CTA. Again, all 29 cases who were thought to be negative for type 1B endoleak on DUS were also negative on CTA for type 1B endoleaks,

Table 2
Diagnosis of endoleak type according to imaging procedures

	CTA (+)	CTA (-)
Type 1A endoleak		
DUS (+)	3	0
DUS (-)	0	27
Type 1B endoleak		
DUS (+)	1	0
DUS (-)	0	29
Type 2 endoleak		
DUS (+)	2	0
DUS (-)	2	26

CTA: Computed tomography angiography; US: Ultrasonography.

either (Table 2). The Kappa coefficient calculated for the positive and negative values for the diagnosis of type 1B endoleak was found to be 1,000 (p<0.001), and a perfect agreement was observed between DUS and CTA results which were again statistically significant according to ROC curve analysis (p<0.001) (Figure 3, Table 3).

Two patients who were diagnosed with type 2 endoleak on DUS were also diagnosed with type 2 endoleak on CTA. On the other hand, two of 28 cases who were not thought to have type 2 endoleak on DUS were defined as type 2 endoleak on CTA (Table 2). The Kappa coefficient calculated for the positive and negative values for the diagnosis of type 2 endoleak was found to be 0.634 (p<0.001), and there was a significant agreement between DUS and CTA results, indicating a statistical significance according to the ROC curve analysis (p<0.001) (Figure 3, Table 3).

The largest transverse diameter was measured from outer side to outer side in both DUS and CTA. There was a positive and very strong linear relationship between the two measurements (r=0.988 p=0.001) (Figure 4). The mean difference between the measurements of DUS and CTA was found to be 2.47±2.16 mm which was statistically significant

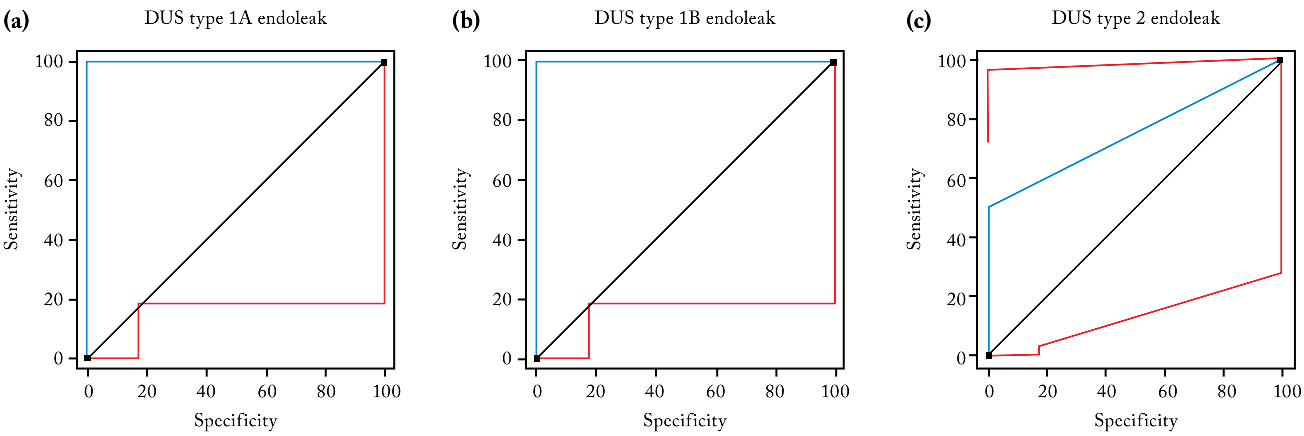

Figure 3. ROC curve analyses of DUS diagnosis according to endoleak subtypes. **(a)** Type 1A endoleak diagnosis ROC curve area under curve was calculated as 1,000 (95% CI: 0.884-1,000). **(b)** Type 1B endoleak diagnosis ROC curve area under curve was calculated as 1,000 (95% CI: 0.884-1,000). **(c)** Type 2 endoleak diagnosis the area under the ROC curve was calculated as 0.750 (95% CI: 0.559-0.889).

ROC: Receiver operating characteristics; DUS: Doppler ultrasonography; CI: Confidence interval.

Table 3
Statistical analysis of DUS according to endoleak subtype diagnosis

	Type 1A endoleak	Type 1B endoleak	Type 2 endoleak
Sensitivity	100.0	100.0	50.0
Specificity	100.0	100.0	100.0

DUS: Doppler ultrasonography.

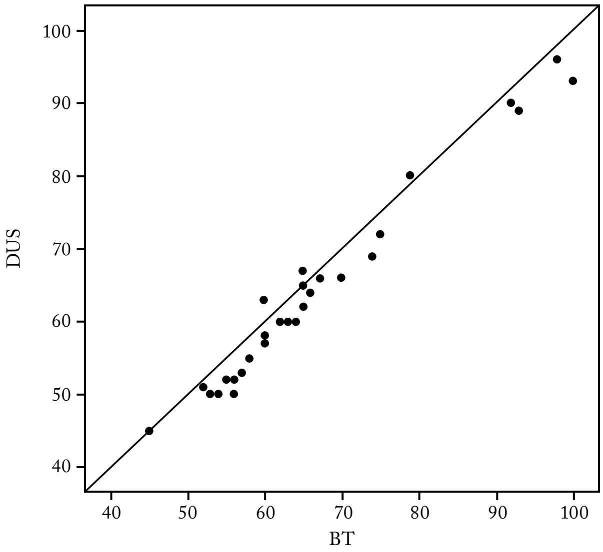

Figure 4. Comparison of aneurysm transverse diameters measured in DUS and CTA.

DUS: Doppler ultrasonography; CTA: Computed tomography angiography; CTA: Computed tomography angiography.

(p=0.001). The lower limit of the 95% confidence interval (CI) for the difference of the two measurements was 1.66 mm and the upper limit as 3.27 mm.

The endoleak types detected in the study and the secondary interventions applied after the diagnosis are summarized in Table 4. In two patients, an endoleak developed from the proximal end of the stent in the early postoperative period (Figure 5). After an additional stent replacement proximal to the stent, no endoleak was detected during follow-up. In another patient, at 12 months of the operation, symptoms developed and DUS detected a leak at the proximal end of the stent and CTA proved the leakage. An additional stent was placed at the proximal end of the stent; however, the leak continued and the patient was switched to open surgery (Figure 6). Two patients (No. 4 and No. 5) had type 2 endoleak, which was detected to originate from the lumbar arteries at the first month of control. No additional intervention was considered

Table 4
Endoleak subtypes and further interventions

Patient	Age	Sex	Endoleak subtype	Secondary intervention
1	78	M	Type 1A	An extension was placed proximal to the stent.
2	85	M	Type 1A	An extension was placed proximal to the stent.
3	76	M	Type 1A	An extension was placed proximal to the stent. Open surgery was performed after the leakage.
4	80	M	Type 2	-
5	62	M	Type 2	-
6	82	F	Type 1B	-

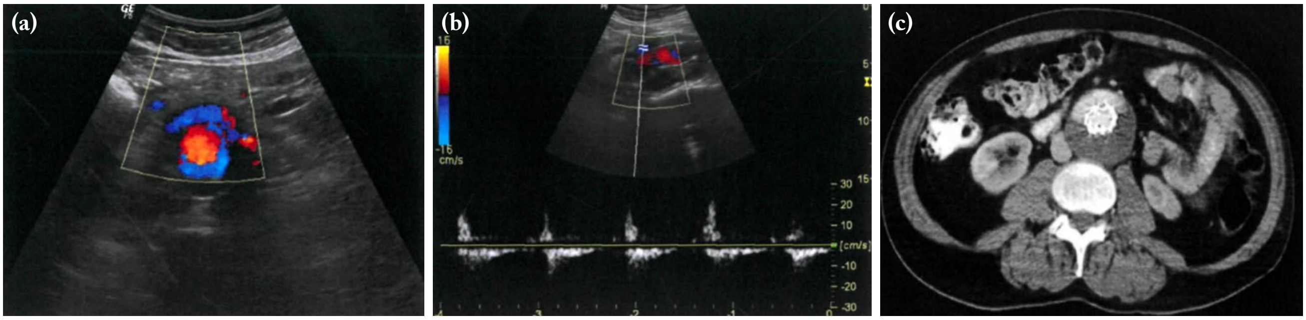

Figure 5. A 78-year-old male patient (No. 1) with endoleak development after operation. **(a)** Transverse plane DUS demonstrates type 1A endoleak on the proximal end of the graft with perigraft flow. **(b)** Arterial flow samples were detected with spectral analysis of perigraft flow. **(c)** In axial CTA images abnormal contrast filling is monitored anterior of the graft compatible with type 1A endoleak.

DUS: Doppler ultrasonography; CTA: Computed tomography angiography.

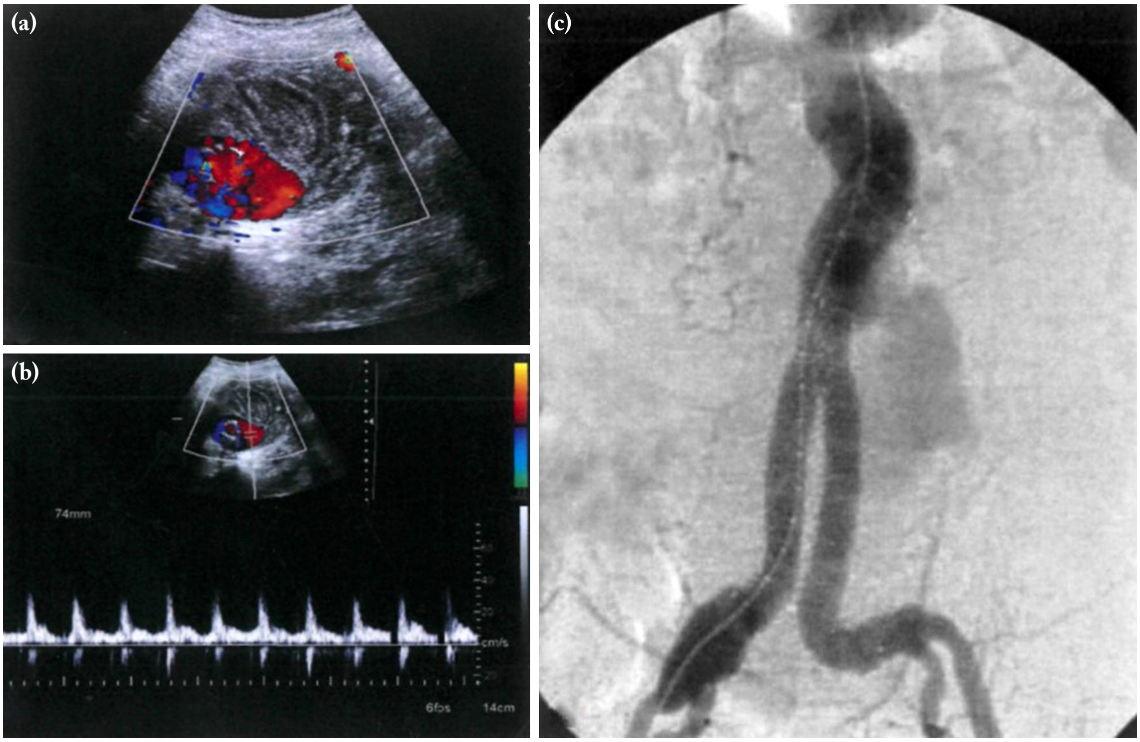

Figure 6. A 76-year-old male patient (No. 3) with type 1A endoleak development after surgery **(a)** Axial plane DUS showed color coding on proximal attachment side of graft towards to the sac. **(b)** Arterial flow pattern was detected in spectral analysis. **(c)** Preoperative CTA image showing contrast filling excess in the left proximal part of graft extending into the sac.

DUS: Doppler ultrasonography; CTA: Computed tomography angiography.

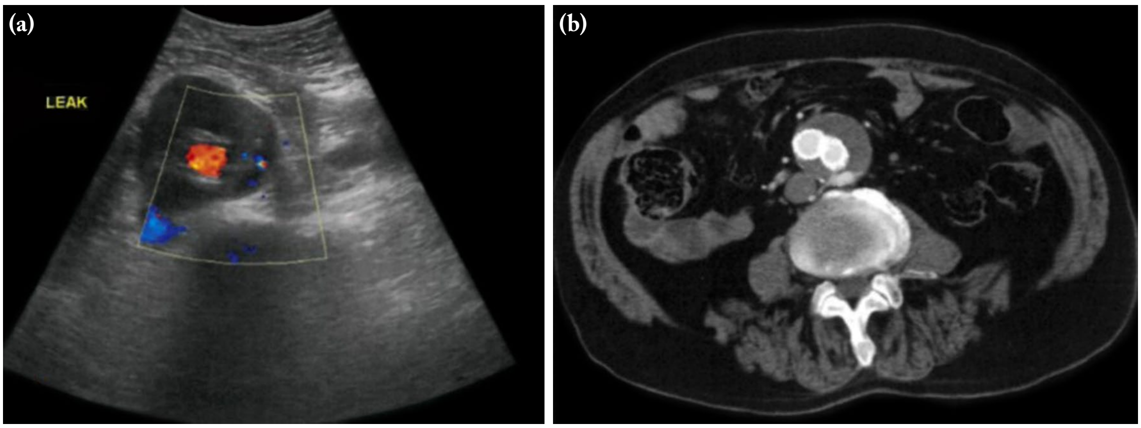

Figure 7. A 80-year-old male patient with type 2 endoleak (No. 4). **(a)** Axial DUS image demonstrating color coding at the posterior periphery of the sac. **(b)** Axial CTA image showing contrast filling compatible with type 2 endoleak from the lumbar artery.

DUS: Doppler ultrasonography; CTA: Computed tomography angiography.

in these two cases in whom shrinkage was detected in the aneurysm sac and persistence of the endoleak during follow-up (Figure 7). In another case (No. 6), the presence of flow from the graft distal attachment region into the pouch was detected consistent with type 1b endoleak at the first month of follow-up (Figure 8). Follow-up examinations showed that the leak persisted. In this case, no additional

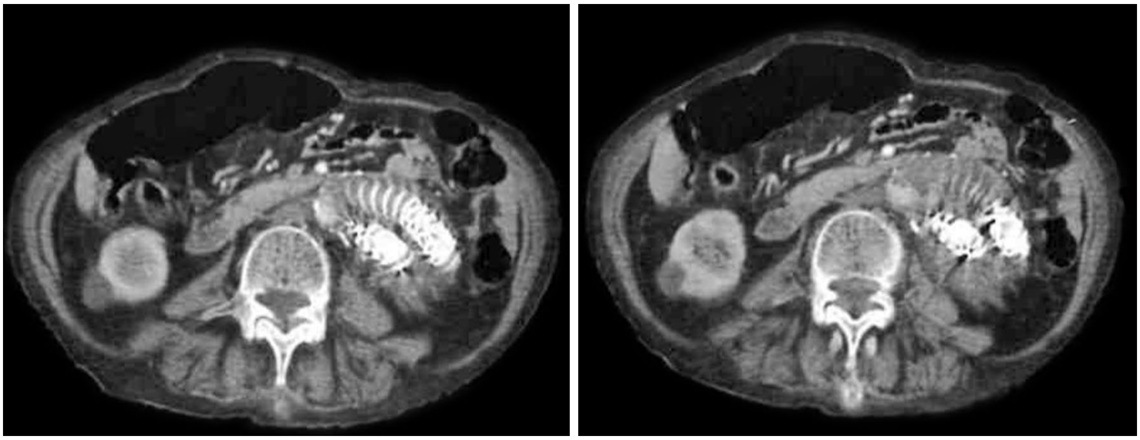

Figure 8. Sequential CTA images obtained in the axial plane showing contrast filling close to the distal part of graft consistent with type 1B endoleak (No. 6).
CTA: Computed tomography angiography.

intervention was performed due to the detection of reduction in the sac diameter, either.

DISCUSSION

Considering CTA as the gold standard, DUS was found to have a sensitivity and specificity of 75% and 100%, respectively for endoleak detection in the current study. For detecting type 1 endoleak, DUS demonstrated a sensitivity and specificity of 100% and 100%, respectively and it had a sensitivity of 50% and specificity of 100% for type 2 endoleak detection.

Persistent type 1 and 3 endoleaks may cause an increase in the pressure in the aneurysm sac, leading to enlargement of the aneurysm; therefore, rupture and death may occur. Type 2 endoleak occurs as a result of retrograde flow from patent side branches to the aneurysm sac and is considered as a low pressure endoleak.[15] Therefore, after repair with EVAR, follow-up should be done at 1, 6, and 12 months and annually thereafter up to five years according to risk status of endoleaks.[16] The CTA is the gold-standard imaging method with a short examination duration, minimal patient dependence, and three-dimensional reformat image advantages. However, it requires ionizing radiation and potentially nephrotoxic and allergic contrast agents.[17] Doppler US is a potentially alternative imaging modality to CTA. It has advantages such as not having ionizing radiation, not requiring the use of nephrotoxic and allergic contrast agents, being relatively inexpensive, non-invasive, and reproducible. However, it is a user-dependent method and has technical limitations in cases with obesity and meteorism.[18]

Studies comparing CTA and DUS in the diagnosis of post-repair endoleak with EVAR demonstrated the sensitivity of DUS to be between 25 and 100%.[16] The effectiveness of DUS varies according to the device, user experience, and endoleak types detected in the study groups. In our study, CTA was superior to DUS in the detection of type 2 endoleaks. On the other hand, no superiority was demonstrated in the detection of type 1 endoleaks. Overall, specificity of DUS to detect all subtypes of endoleaks was found to be 100%, sensitivity for type 1A and type 1B were 100%, sensitivity for type 2 was 50% in the current study. A previous study showed that DUS had a sensitivity and specificity of 74% and 94%, respectively in which they concluded that DUS could detect type 1 and 3 endoleak after EVAR.[19] In our study, the sensitivity was relatively low and the specificity was higher, considering the high level of the devices we used, indicating that it is needed to gain experience in detecting type 2 endoleaks.

The effectiveness of DUS varies according to the endoleak types detected in the study groups with different results. A study showed a sensitivity and specificity of 100% for endoleak detection with DUS, while DUS was concluded to even be superior to CTA in endoleak detection.[20] On the other hand, AbuRahma et al.[17] reported that DUS is more sensitive in detecting type 1 endoleaks than type 2 endoleaks (88% and 50%, respectively) and that DUS had a low sensitivity, particularly in detecting type 2 endoleaks and should not be used alone. However, they also mentioned that most of the type 2 endoleaks regressed spontaneously and the intervention decisions of these patients should be determined according to the aneurysm diameter increase. In our study, the presence of type 2 endoleak, which could not be detected in DUS in two cases, was revealed by CTA. No progression or spontaneous thrombosis was detected in these patients, and after the endoleak detection, DUS follow-up was appropriate and performing CTA did not have any additional contribution. Doppler US can be used in follow-up owing to its high sensitivity and NPV compared to CTA; however, more aggressive invasive diagnostic methods can be applied when endoleak is suspected. Furthermore, low sensitivity of DUS for detecting type 2 endoleaks is acceptable, since undetected endoleaks are clinically insignificant.[21]

The increase in the aneurysm diameter is critical for intervention decision in cases with type 2 endoleak. Doppler US is a method that can be used in aneurysm diameter follow-up. Raman et al.[22] reported that CTA and DUS showed a high correlation for aneurysm diameter follow-up. Besides, it has been proposed that, although DUS is a method that can be used in the diagnosis of endoleak thanks to its high sensitivity and specificity, it gives very different results with CTA in the follow-up of aneurysm diameter.[23] Ultrasound may underestimate aortic size compared to CTA with the inner-to-inner measurement method.[24] In our study, anteroposterior and transverse diameters were measured at the widest level of the aneurysm which showed a correlation between the two measurements. However, the aneurysm diameter was measured smaller with DUS than with CTA. This difference should be kept in mind while using DUS for aneurysm diameter monitoring. In the current study, CTA measurements were made on reformat images, taking into account the tortuosity of the aorta, in the transverse plane, at its widest point, and from outer to outer.

AbuRahma et al.[17] reported that, apart from the known limitations of DUS, it was not exactly known how the stent graft could affect the sound conduction as a factor that might cause errors in the detection of endoleaks. The decrease in the transmission of sound waves by the stent may cause the sensitivity of DUS to decrease in endoleak detection. In our study, color artifacts behind the graft during DUS examination were also problematic. Similar to mirror artifact behind the stent, pulsating artifacts such as color coding of the flow in the stent may occur. To distinguish it from true endoleak, it was examined from different angles. The location of the true endoleak remains constant, while the artifacts change their location and are always seen behind the stent, enabling the distinction between endoleak and artifact.

In their study, Berdejo et al.[25] reported that DUS might be an effective technique for the postoperative evaluation of patients treated with endovascular grafts and might be the main diagnostic method in the post-intervention follow-up in the near future. According to their own experience, false negative results depended on suboptimal examinations or the examination technique. They also emphasized that it was necessary to know the underlying pathology and the details of the procedure performed in each patient. Bargellini et al.[26] compared the results of CTA and DUS in 196 patients after EVAR and showed that DUS was a method that could be used alone after the first-year follow-up after repair with EVAR, bearing in mind the low diagnostic value in aneurysm diameter measurements, and CTA should be used in cases with persistent diameter increase. In our study, CTA and DUS results were correlated, suggesting that DUS is an alternative method to CTA in the diagnosis of endoleak. Unlike the previous study, the current study demonstrates that DUS can be a method that can be used in the aneurysm diameter follow-up.

Through the evaluation of the hemodynamics of the artery with pulse wave DUS, waveforms or measuring current velocities for type 2 endoleak persistency can be detected.[27] Therefore, it can be speculated that DUS, with the help of hemodynamic parameters, can contribute to the determination of the prognosis and prevention of more serious complications. In our study, the possibility of thrombosis was not evaluated by comparing intra-endoleak flow velocity measurements or evaluating waveforms. The presence of arterial flow in the aneurysm was investigated and after the endoleak was detected, the vascular structure that could be the source was determined.

Several studies have also been conducted on the use of contrast media in post-repair ultrasonographic examination with EVAR. While there are studies that argue that contrast-enhanced US is not a reliable method in the follow-up after repair with EVAR, there are also studies suggesting that it can detect endoleaks even that CTA cannot detect.[28] In the current study, unfortunately, we were unable to use contrast agents during DUS and could not compare the further results.

The main limitations of the present study include its single-center, retrospective design with a relatively small sample size. In addition, follow-up period was short and optimal time point for follow-up could not be achieved, and pulse wave measurements were not available.

In conclusion, DUS is potentially an alternative imaging modality to CTA, although it has low sensitivity for detecting type 2 endoleaks during post-repair follow-up after EVAR. It has many advantages over CTA during routine follow-up. It may be appropriate to evaluate with CTA when an increase in the aneurysm diameter, graft migration or rupture is suspected. It is important to strictly adhere to the DUS examination protocol and evaluation criteria to minimize false-positive or false-negative results. As the number of cases and experience increase, it may be possible to use DUS as an alternative to CTA in the routine follow-up of all patients.

Declaration of conflicting interests

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