Color Doppler ultrasound for surveillance following EVAR as the primary tool

HAKKI ISCAN[1], Ertekin Unal[1], Boğaçhan Akkaya[1], Mustafa Daglı[1], Mehmet Karahan[2], İsa Civelek[1], Mehmet Hamdi Ozbek[1], and rıza okten[3]

[1]Turkey Yuksek Ihtisas Hospital
[2]Turkiye Yuksek Ihtisas Hastanesi
[3]TURKIYE YUKSEK IHTISAS HASTANESI

September 28, 2020

Abstract

Objective.As aneurysm related events and rupture is not eliminated, postoperative lifelong surveillance is mandatory after endovascular aneurysm repair(EVAR).For surveillance colored Doppler ultrasound(CDUS) is a standard method of noninvasive evaluation having the advantages of availability, cost-effectiveness and lack of nephrotoxicity and radiation.We evaluated CDUS for primary surveillance tool after elective EVAR by comparing with computerized tomography. Methods.Between 2018-2020, 84 consecutive post-EVAR patients were evaluated.Firstly, CDUS was performed by two Doppler operators from the Radiology and computed tomographic angiography (CTA) was performed.A reporting protocol was organized for endoleak detection and largest aneurysm diameter. Results.Among 84 patients, there were 11 detected endoleaks(13,1%) with CTA and 7 of them was detected with CDUS (r=0,884,p<0.001).There is an insufficiency in detecting low flow by CDUS.Eliminating this frailty, there was a strong correlation of aneurysm sac diameter measurement between CTA and CDUS (r=0,777,p<0,001).The sensitivity and specificity of CDUS was 63,6% and 100% respectively.The accuracy was 95,2%.Positive and negative predictive values were 100% and 94,8%.Bland-Altman analysis and linear regression analysis showed no proportional bias (mean difference of 1.5±2.2mm,p=0.233). Conclusions.CDUS promises accurate results without missing any potential complication requiring intervention as Type I or III endoleak.Lack of detecting type II endoleaks may be negligible as sac enlargement was the key for reintervention in this situation and CDUS has a remarkably high correlation with CTA in sac diameter measurement. CDUS may be a primary surveillance tool for EVAR and CTA will be reserved in case of aneurysm sac enlargement,detection of an endoleak,inadequate CDUS or in case of unexplained abdominal symptomatology

Introduction

The noninvasive nature of endovascular procedures and successful early results were the main reasons of endovascular popularity all around the world (1-3). As the endovascular procedures has potential device related complications and aneurysm related events has not completely vanished, lifelong surveillance is mandatory. The follow up protocols should diagnose complications requiring reintervention, earlier enough to have time for elective treatment. Increasing awareness of the risks and costs of a lifelong computed tomographic angiography (CTA) surveillance, led to find out convenient follow up modalities offering non-invasiveness, cost saving, safety, availability and accuracy.

CTA still is the gold standard as a diagnostic tool and preoperative measurements in aortic aneurysms for endovascular abdominal aortic aneurysm repair (EVAR), however since potential malignancy risk is not zero and there is risk of nephrotoxicity (7-12%)(4-8), as it may not be a suitable follow-up modality. Also regarding health economics, almost one third of the EVAR cost can be attributed to post-EVAR radiologic imaging (9-12). The Markov model base-case analysis results show that annual follow-up with Color Doppler

Ultrasonography (CDUS) only is the strategy with the lowest cost (12). There are conflicting conclusions among the studies about CDUS as a surveillance modality after EVAR, maybe because of the heterogeneity of study designs, equipment, techniques, or training (9,10,13-26). The findings of the nine systematic reviews of diagnostic accuracy show that for CDUS the pooled sensitivity for detection of all types of endoleaks ranged from 65 to 96% and the pooled specificity ranged from 90 to 97% (12). Anyway, current guidelines suggest CTA and CDUS as follow up modalities in case of different scenarios (4,5).

Eventhough life-long surveillance after EVAR is universally accepted, there are currently no ideal frequency or standart regimen for imaging protocols. Because of this heterogeneity, almost every clinic has its own protocol. Modified surveillance protocols have been proposed to eliminate repetitive CTA examinations. In this study, we evaluated CDUS as the primary follow-up modality for post-EVAR patients by comparing the results with CTA.

Patients and Methods

Between January 2018 and March 2020, we organized a follow-up protocol between Department of Radiology and Department of Cardiovascular Surgery. Consecutive 84 patients who experienced elective and standard EVAR procedure for infrarenal abdominal aortic aneurysm, were evaluated in the outpatient clinic. The mean age of the patients was 68.5±7.8 years (61-89 years). Patient demographics are given in table 1. Hybrid operations, complex EVAR procedures (chimney, snorkel) and emergency cases were excluded. Two operators were performing all the CDUS from the Radiology Department. CDUS operators were blind of any CTA reports as CDUS was carried out first. The time between two modalities was 7 days in average. The reporting protocol was organized as the detection of an endoleak and sac measurements. Caliper placements for measurement of aortic diameter were put into a consensus as outer to outer manner. All reports were recorded to patient's charts.

Commercially available devices were used during the study, including Medtronic Endurant II, Endologix AFX, Gore Excluder, Jotec and Lifetech Ankura. Endoskeletons were nitinol except Endologix AFX (cobalt chromium) and graft material was Dacron or PTFE.

This study follows the Declaration of Helsinki and ethical approval was granted by the local institutional ethical board. In addition, informed consent was obtained from all the patients.

CDUS. All CDUS was performed by using a GE Logiq S7 Expert R3 (General Electric Company, Millwakuee, WI) equipped with C1-6 Mhz curvilinear broadband transducer probe. Aorta was scanned from the diaphragm to the iliac vessels by transverse and longitudinal planes, the aortic diameter was measured outer to outer manner always. Multiple transverse and anteroposterior measurements were obtained, and maximum measurements were recorded. All patients were asked to fast up to 6-8 hours. All patients were scanned in the supine position in a dark out-patient clinic room according to the organized protocol. The endograft and the aneurysm sac were assessed using B-mode, color flow and spectral Doppler to rule out any endoleak. Doppler scan with color flow was confirmed with spectral analysis and mapping of blood flow pattern. Contrast was not used in any patient.

CTA. The CTA protocol consisted of a set of an arterial scan phase followed by a single venous scan phase. All of the CT angiograms were obtained with a 512 - slice CT scanner (Revolution CT, GE Healthcare, Waukesha, Wisconsin, US). Patients were examined in the supine position. After localizer scans were obtained and 90 mL of nonionic iodinated contrast material (Iohexol, Omnipaque 350 mg of iodine per milliliter; GE Healthcare) was injected at a flow rate of 4 mL/sec through an 18-gauge antecubital intravenous line, the CT angiography series was started with bolus-tracking measurement in the abdominal aorta at a threshold of 170 HU. The arterial phase of the series was followed by venous phase scanning that covered the entire abdominal aorta, with a delay of 80 seconds after completion of the first scan

Statistical analysis

All statistical analyses were carried out using SPSS for Windows 15.0 (SPSS Inc., Chicago, IL, USA). Continuous variables with normal distribution were expressed as mean ± standard deviation (SD), and categorical variables were expressed as number and percentage. Sensitivity and specificity values, accuracy, positive and negative predictive values were analyzed by the contingency table and calculated for CDUS CTA as the gold standard method. Bland-Altman plot was generated to evaluate agreement between two measurements of sac diameter (CDUS and CTA) by constructing limits of agreement. These limits are calculated by using the mean and standard deviation of the differences between two measurements. At least 95% of paired measurements were expected to lie within ± 2 SD of the mean difference. Linear regression analysis was conducted to assess proportional bias. Type-I error of 0.05 was set as statistically significant.

Results

Technically there was no inadequate CDUS examination. There were 11 detected endoleaks (13.1%) with CTA and 7 with CDUS (8.3%). There was one type IA, three type IB, two type III and five type II endoleaks detected with CTA (Table 2). CDUS was not able to detect four type II endoleaks, however, all type I and III endoleaks were detected. Figure 1-4 demonstrate the type I and III endoleaks in Blood flow image(BFi) and Color Doppler modes. Among the modes of CDUS, eventhough BFi was much more demonstrable, there was no superiority or sensitivity difference. There were no leaks missed on CDUS requiring intervention however, there was an insufficiency of CDUS in detecting low flow. Eliminating this frailty, there was a very high correlation of aneurysm sac diameter measurement between CTA and CDUS. For CDUS average aneurysm sac diameter was 57.1±14.5 mm, for CTA 58.7±15.0 mm. There was a very strong correlation of CTA and CDUS for diameter measurement and endoleaks ($r = 0.884$ and $r = 0.777$ respectively, $p < 0.001$ for both).

The mean difference from Bland-Altman analysis (Figure 5) was 1.5 ± 2.2 mm and limits of agreement were -2.85 mm (lower limit) and 5.93 mm (upper limit). A small percentage of measurements were outside of the ± 2 SD ranges. The direction and magnitude of the mean differences were similar between the two methods of measurement (CDUS and BTA). Linear regression analysis represented no proportional bias (p=0.233).

The sensitivity and specificity of CDUS was 63.6% and 100% respectively. The accuracy was 95.2%. Positive and negative predictive values were 100% and 94.8% respectively. The missed type II endoleaks were not considered to be clinically significant. They are still under follow up for sac enlargement. The detected type II endoleak was written as "suspected endoleak" because of a mobile thrombus seen inside the aneurysm sac.

Discussion

The frequent use of CTA scanning has raised concerns related to the added cost, as well as cumulative radiation exposure and the use of nephrotoxic agents (6-10,27,28). The Society for Vascular Surgery practice guidelines scaled back and currently recommend contrast-enhanced CT scanning at 1 and 12 months during the first year after EVAR and adds if neither endoleak nor aneurysm expansion is detected subsequent duplex follow up may be a reasonable alternative (4). All the guidelines suggest that type I and III endoleaks should be treated immediately with a strong recommendation (4,5). For type II endoleaks aneurysm expansion should be surveilled. Expansion of sac diameter [?] 1 cm detected during the follow up after EVAR using the same modality and measurement method may be considered as a reasonable threshold for significant growth (4,5).

Surveillance after EVAR is universally accepted eventhough there are currently no ideal frequency or standart regimen. Compliance of patients to surveillance after EVAR is around 60% in the literature (29). As a vascular surgeon we must improve patient compliance for EVAR surveillance without any adverse consequences in the long term. Besides distant homeland of the patient, the awareness of the risks of CT surveillance is a critical issue on this topic. A noninvasive, easy to apply and repeatable tool will be pleased by the patients also.

CDUS does not carry associated radiation exposure and nephrotoxicity risk as well as the obvious advantage of being readily available and non-invasive manner. These specifications make it a more desirable imaging modality for long term surveillance. However, it is definitely operator dependent and the quality of the images can be adversely affected by obesity or excess bowel gas. Concerns have been raised in the past regarding its variable sensitivity in detecting endoleaks almost always because of type II endoleaks (10, 13, 16, 30, 31). Based on recent reports, some investigators have proposed that follow up with duplex ultrasound as the sole imaging modality is proper (9, 10, 16). CDU sensitivity for type I and III is excellent. CDUS has the advantage of identifying the flow direction of endoleaks over CT.

Sensitivity refers to the ability of a test to detect a positive finding; a highly sensitive test will detect most real problems but may return some false positives. In contrast, a highly specific test will be very trustworthy when it is positive, though it will not necessarily detect all true positives. Accuracy refers to the overall rate of true test results. In literature, there are many diverse reports about sensitivity and specificity concerning the endoleak detection of CDUS. These conflicts may be due to heterogeneity of study designs, lack of standardized protocols, equipment, techniques, or training. Notably some rigorous CDUS reporting 90-minute search for endoleaks or some CT protocols did not include delayed phase images (19, 25, 32). In our study, the CDUS examination took approximately 10 to 20 minutes depending on the patient's status, bowel gas or obesity. Raman et al, one of the largest studies, reports 43% sensitivity may have been a consequence of older equipment and shorter scan times (23). Elkouri declaring CDUS sensitivity of only 25% may be because of the lack of a standardized technique and protocol (24). Nagre et al reported a very low overall sensitivity of 35% however in each case requiring reintervention, CDUS detected the endoleak on subsequent visit or detected a significant increase in aneurysm sac (33). In our study, the sensitivity and specificity of CDUS was 63,6% and 100% respectively. The accuracy was 95,2%. Positive and negative predictive values were 100% and 94,8%. According to our findings, CDUS is highly sensitive and capable of diagnosing Type I and III endoleaks which require reintervention. There was no endoleak which were detected on CT and missed on CDUS requiring reintervention. Lack of detecting type II endoleaks may be negligible as sac enlargement was the key for reintervention in this situation and CDUS has a remarkably high correlation with CTA in sac diameter measurement.

Our results showed strong correlation among CDUS and CTA in measuring the sac diameter, as it is in the literature (23,24,34,35). The correlation of CTA and CDUS for diameter measurement and endoleaks were remarkably strong with statistical significance ($r = 0{,}884$ and $r = 0{,}777$ respectively, $p < 0{,}001$). These results are comparable with Gray ($r=0{,}96$) (10) and Arko ($r=0{,}93$) (15) to the degree of correlation. There is also a consistent observation that CDUS underestimates size compared to CTA (23, 24, 34). This diameter follow-up issue is very important for Type II endoleak surveillance and endotension. Follow up of sac diameter with the same modality will be of foremost importance for successful CDUS surveillance.

In literature there is inconclusive CDUS results of 6-25% possibly due to techniques, experience or how you define the technical adequacy and factors concerning the patient (10, 19, 21, 24). In our experience, we do not have an inconclusive CDUS result. We always inform patients about fasting for 6-8 hours and all examinations were performed in the morning session. To our knowledge, only examinations soon after implantation, may be inadequate because of inflammation, or air captured inside the deployment devices. Our ultrasound scan almost always took 10-20 minutes of search of the aneurysm sac.

There are studies concerning the contrast enhanced doppler ultrasound (CEUS) concluding superior sensitivity and accuracy over CDUS and also CTA (12,31,36-39). Contrast enhancement will increase the sensitivity also with the cost, iv administration, risk of allergy and longer time duration. We do not used and/or needed any contrast in our study, undoubtedly cost of surveillance will increase by CEUS and studies confirm the only cost-effective modality is CDUS (12) .

The frequency, length of follow-up, imaging protocols are very heterogenous, almost every clinic has its own protocol. Our clinical approach for surveillance after EVAR begins with baseline CTA for all patients as a reference point. It should be performed with in the first three months after the procedure, according to the patient's renal status, aneurysm anatomy and risk of graft related complications. Component overlap, sealing zones, positioning and endoleaks are evaluated at this reference CTA, and the images are kept for every patient in order to compare and comment for possible future complications. After that, our follow up modality is CDUS for every 6 months in the absence of an endoleak or aneurysm sac enlargement. If there is a type II endoleak in the CTA, we again follow the patient with CDUS with concern to the sac enlargement every 6 months. We use CDUS as a primary surveillance tool for EVAR, we reserve CTA scan, in case of aneurysm sac enlargement, detection of an endoleak, inadequate CDUS or in case of unexplained abdominal symptomatology. By this way we not only avoid ionizing radiation or nephrotoxic agents, but achieve cost saving issue also.

Limitation of CDUS is the detection of structural deformities. However, if there is no endoleak or aneurysm sac enlargement we follow those patients so it is not important issue. In complicated cases Type Ib and Type III endoleaks may resemble each other however as this situation should be confirmed with CTA, there will be no missed patients requiring reintervention. The limitations of CDUS must be weighted with its benefits. Limitation of our study is its single center, cross-sectional structure. Patients are from various stages of follow-up and different commercial endografts.

What must be the goal of the post-EVAR surveillance test? Not to miss a diagnosis or not to miss an essential reintervention. For a vascular surgeon, proper physical examination, symptomatology of the patient is also of significant importance. Most reinterventions occur in symptomatic patients and only 1.4 – 9 % of patients require reintervention as a result of detected abnormalities (27,28,40-42). Safety concerns, availability and inexpensive non-invasive manner make it a more desirable imaging modality for long term surveillance.

CDUS is a convenient modality for monitoring the evolution of the aneurysm sac and sufficient to identify complications requiring reintervention. Also, CDUS better provides the characterization of the endoleak by flow direction. Therefore, we perform CDUS for post-EVAR patients as the primary diagnostic test, reserving CT for consulting the reintervention strategy. It may easily be repeated without any safety concerns. Modern equipment and highly experienced Doppler operators remain crucial requirements for CDUS surveillance. Randomized clinical trials should target if CDUS surveillance is satisfactory for all patient group.

References

1. EVAR Trial participants. Endovascular aneurysm repair in patients with abdominal aortic aneurysm. Lancet 2005; 365: 2179-2186.

2. JT. Powell, MJ. Sweeting, P Ulug, JD. Blankensteijn, FA. Lederle, JP. Becqueminand R. M. Greenhalgh. Meta-analysis of individual-patient data from EVAR-1, DREAM, OVER and ACE trials comparing outcomes of endovascular or open repair for abdominal aortic aneurysm over 5 years. BJS 2017; 104: 166–178

3. HZ İşcan, EU Ünal, Sarıcaoğlu MC, Aytekin B, Türkcan B, BB Akkaya, G Yiğit, HM Özbek, İ Civelek, U Tütün, CL Birincioğlu. Our clinical approach to the last five year elective infrarenal abdominal aortic aneurysm: Short term results. J VascSurg 2018;27(1):1-7.

4. The Society for Vascular Surgery practice guidelines on the care of patients with an abdominal aortic aneurysm. Elliot L. Chaikof, Ronald L. Dalman, Mark K. Eskandari, Benjamin M. Jackson, W. Anthony Lee, M. Ashraf Mansour, Tara M. Mastracci, Matthew Mell, M. Hassan Murad, Louis L. Nguyen, Gustavo S. Oderich, Madhukar S. Patel, Marc L. Schermerhornand Benjamin W. Starnes. J VascSurg 2018; 67:2-77.

5. Editor's Choice: European Society for Vascular Surgery (ESVS) 2019 Clinical Practice Guidelines on the Management of Abdomin l Aorto-iliac Artery Aneurysms

Anders Wanhainen, Fabio Verzini, Isabelle Van Herzeele, Eric Allaire, Matthew Bown, Tina Cohnert, Florian Dick, Joostvan Herwaarden, Christos Karkos, Mark Koelemay, Tilo Kölbel, Ian Loftus, Kevin Mani, Germano Melissano, Janet Powell, Zoltán Szeberin. Eur J Vasc Endovasc Surg 2019; 57: 8-93.

6. Brenner DJ, Hall EJ. Computed tomography–an increasing source of radiation exposure. N Engl J Med. 2007; 357 (22) : 2277–2284.

7. Walsh SR, Tang TY, Boyle JR. Renal consequences of EVAR. J EndovascTher 2008;15(1):73-82.

8. White HA, McDonald S. Estimating risk associated with radiation exposure during follow-up after EVAR. J Cardiovasc Surg (Torino) 2010;51(1):95-104.

9. Beeman BR, Doctor LM, Doerr K, Mc Afee-Bennett S, Dougherty MJ, Calligaro KD. Duplex ultrasound imaging alone is sufficient for midterm EVAR surveillance: a cost analysis study and prospective comparison with CT scan. J Vasc Surg 2009 ; 50 (5): 1019-1024.

10. Gray C, Goodman P, Herron CC, Lawler LP, O'Malley MK, O'Donohoe MK, McDonnell CO. Use of CDUS as a first line surveillance tool following EVAR is associated with a reduction in cost without compromising accuracy. Eur J Vasc Endovasc Surg 2012(44):145-150.

11. Noll R, Tonnessen BH, Mannava K, Money SR, Sternbergh WC. Long term placement cost after endovascular aneurysm repair. J Vasc Surg 2007; 46 (1): 9-15.

12. Brazelli M, Hernandez R, Sharma P, Robertson C, Shimonovich M, Mc Lennan G, Fraiser C, Jamieson R and Vallabhaneni SR. CEUS and/or CDUS for surveillance after EVAR: a systematic review and economic evaluation. Health Tech Assessment 2018 (Dec); Vol 22 (72):1-220.

13. Karanikola E, Dalainas I, Karaolanis G, Zografos G, Filis K. Duplex ultrasound versus computed tomography for the postoperative follow-up of endovascular abdominal aortic aneurysm repair. Where do we stand now? Int J Angiol 2014; 23(3) :155–64.

14. Collins JT, Boros MJ, Combs K. Ultrasound surveillance of endovascular aneurysm repair: a safe modality versus computed tomography. Ann Vasc Surg 2007;21:671–5.

15. Arko FR, Filis KA, Heikkinen MA, Johnson BL, Zarins CK. Duplex scanning after EVAR: an alternative to CT. Semin VascSurg 2004; 17(2): 161-5.

16. Chaer RA, Gushchin A, Rhee R, Marone L, Cho JS, Leers S, Makaroun MS. Duplex ultrasound as the sole long-term surveillance method post-endovascular aneurysm repair: a safe alternative for stable aneurysms. J Vasc Surg 2009;49:845–9.

17. Harrison GJ, Oshin OA, Vallabhaneni SR, Brennan JA, Fisher RK, McWilliams RG. Surveillance after EVAR based on duplex ultrasound and abdominal radiography. Eur J Vasc Endovasc Surg 2011;42:187–92.

18. Manning BJ, O'Neill SM, Haider SN, Colgan MP, Madhavan P, Moore DJ. Duplex ultrasound in aneurysm surveillance following endovascular aneurysm repair: a comparison with computed tomography aortography. J Vasc Surg 2009; 49: 60–65.

19. Sato DT, Goff CD, Gregory RT, Robinson KD, Carter KA, Herts BR, et al. Endoleak after aortic stent graft repair: diagnosis by color duplex ultrasound scan versus computed tomography scan. J Vasc Surg 1998;28:657–63.

20. Sandford RM, Bown MJ, Fishwick G, Murphy F, Naylor M, Sensier Y, et al. Duplex ultrasound scanning is reliable in the detection of endoleak following endovascular aneurysm repair. Eur J Vasc Endovasc Surg 2006;32:537–41.

21. Wolf YG, Johnson BL, Hill BB, Rubin GD, Fogarty TJ, Zarins CK. Duplex ultrasound scanning versus computed tomographic angiography for postoperative evaluation of endovascular abdominal aortic aneurysm repair. J Vasc Surg 2000;32:1142–8.

22. Ashoke R, Brown LC, Rodway A, Choke E, Thompson MM, Greenhalgh RM, Powell JT. Color duplex ultrasonography is insensitive for the detection of endoleak after aortic endografting: a systematic review. J Endovasc Ther 2005; 12: 297–305.

23. Raman KG, Missig-Carroll N, Richardson T, Muluk SC, Makaroun MS. Color-flow duplex ultrasound scan versus computed tomographic scan in the surveillance of endovascular aneurysm repair. J Vasc Surg 2003;38(4):645–651

24. Elkouri S, Panneton JM, Andrews JC, et al. Computed tomography and ultrasound in follow-up of patients after endovascular repair of abdominal aortic aneurysm. Ann Vasc Surg 2004;18(3): 271–279

25. Bakken AM, Illig KA. Long term follow up after endovascular aneurysm repair: Is ultrasound alone enough? Perspectives in Vasc Surg Endovasc Therapy 2010; 22(3): 145-151.

26. E Jean-Baptiste, P Feugier, C Cruzel, G Sarlon-Bartoli, T Reix, E Steinmetz et al. Computed Tomography-Aortography Versus Color-Duplex Ultrasound for Surveillance of Endovascular Abdominal Aortic Aneurysm Repair: A Prospective Multicenter Diagnostic-Accuracy Study (The ESSEA Trial). Circ Cardiovasc Imaging 2020 Jun;13(6):e009886.

27.Black SA, Carrell TW, Bell RE, Waltham M, Reidy J, Taylor PR. Long-term surveillance with computed tomography after endovascular aneurysm repair may not be justified. Br J Surg 2009;96:1280–3.

28. Dias NV, Riva L, Ivancev K, Resch T, Sonesson B, Malina M. Is there a benefit of frequent CT follow-up after EVAR? Eur J Vasc Endovasc Surg 2009;37:425–30.

29. MJ Grima, M Boufia, M Lawd, D Jacksond, K Stenson, B Patterson, I Loftus, M Thompson, A Karthikesalingama, P Holt. Editor's Choice – The Implications of Non-compliance to Endovascular Aneurysm Repair Surveillance: A Systematic Review and Meta-analysis. Eur J Vasc Endovasc Surg 2018 April; 55(4): 492–502.

30. Schmieder GC, Stout CL, Stokes GK, Parent FN, Panneton JM. Endoleak after endovascular aneurysm repair: duplex ultrasound imaging is better than computed tomography at determining the need for intervention. J Vasc Surg 2009;50(5):1012–1017, discussion 1017–1018

31. Henao EA, Hogde MD, Felkal DD, McCollum CH, Noon GP, Lin PH. CEUS duplex surveillance after EVAR: Improved efficacy using a continuous infusion technique. J Vasc Surg 2006; 43(2): 259-264.

32. Parent FN, Meier GH, Godziachvili V et al. The incidence and natural history of type I and II endoleak: a 5 year follow up assessment with CDUS. J Vasc Surg 2002; 35(3):474-81.

33. Nagre SB, Taylor SM, Passman MA, et al. Evaluating outcomes of endoleak discrepancies between computed tomography scan and ultrasound imaging after endovascular abdominal aneurysm repair. Ann Vasc Surg 2011;25(1):94–100.

34. AbuRahma AF, Welch CA, Mullins BB, Dyer B. Computed tomography versus color duplex ultrasound for surveillance of abdominal aortic stent-grafts. J Endovasc Ther 2005;12(5):568–573.

35. AbuRahma AF. Fate of endoleaks detected by CTA and missed by CDUS in EVAR for iAAA. J Endovasc Ther 2006;13: 490-95.

36. Cantisani V, ricci P, Grazhdani H, Napoli A, Fanelli F, Catalano C. prospective comparative analysis of CDUS,CEUS,CT and MR in detecting endoleak after EVAR. Eur J Vasc Endovasc Surg 2011;41(2): 186-92.

37. Cantisani V, Grazhdani H, Clevert DA, Iezzi R, Aiani L, Martegani A, et al. EVAR: benefits of CEUS for monitoring stent–graft status. Eur J Radiol 2015;84:1658–65.

38. Iezzi R, Basilico R, Giancristofaro D, Pascali D, Cotroneo AR, Storto ML. Contrast-enhanced ultrasound vs CDUS imaging in the follow-up of patients after EVAR. J VascSurg 2009;49(3):552-560.

39. Mirza TA, Karthikesalingam A, Jackson D, Walsh SR, Holt PJ, Hayes PD, Boyle JR. Duplex ultrasound and contrast-enhanced ultrasound versus computed tomography for the detection of endoleak after EVAR: systematic review and bivariate meta-analysis. Eur J Vasc Endovasc Surg 2010;39:418–28.

40. Tse DM, Tapping CR, Patel R, Morgan R, Bratby MJ, Anthony S, Uberoi R. Surveillance after endovascular abdominal aortic aneurysm repair. Cardiovasc Intervent Radiol 2014;37:875–88.

41. Nordon IM, Karthikesalingam A, Hinchliffe RJ, Holt PJ, Loftus IM, Thompson MM. Secondary interventions following endovascular aneurysm repair (EVAR) and the enduring value of graft surveillance. Eur J Vasc Endovasc Surg 2010;39:547–54.

42. Karthikesalingam A, Holt PJ, Hinchliffe RJ, Nordon IM, Loftus IM, Thompson MM. Risk of reintervention after endovascular aortic aneurysm repair. Br J Surg 2010;97:657–63.

Figure legends

Figure 1. A. Post-EVAR infrarenal abdominal aorta. B. Type I endoleak filling the aneurysm sac. While examination with CDUS, the flow leads the direction facilitating to detect the endoleak type.

Figure 2. Type Ib endoleak demonstrated with blood flow image mode (axial section)

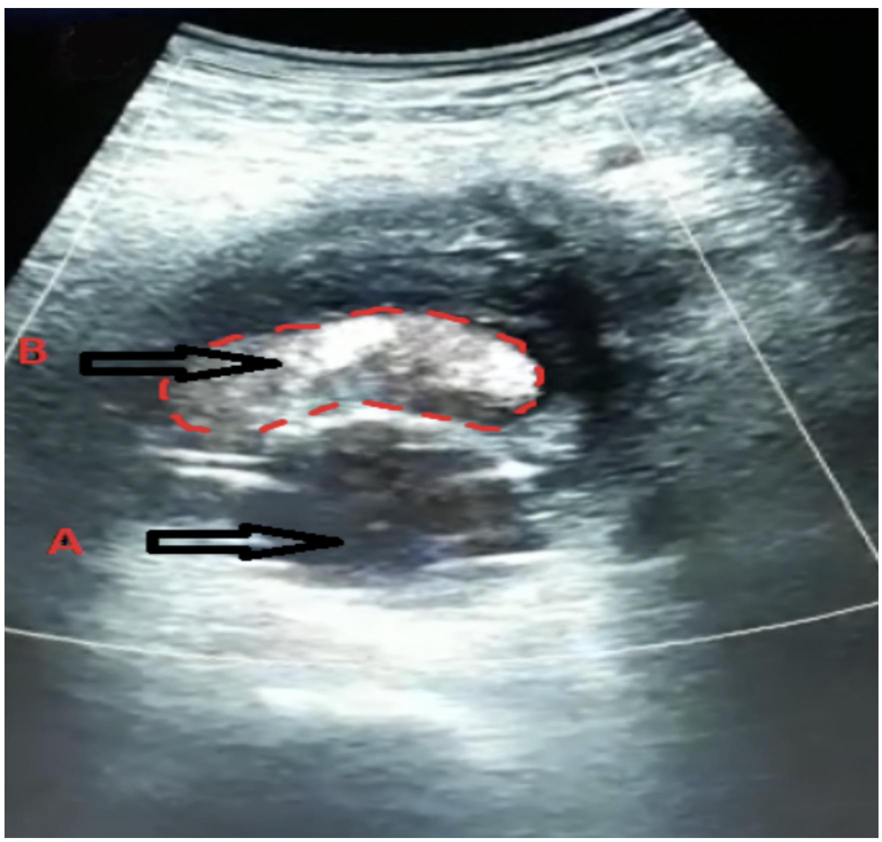
Figure 3. Type III endoleak demonstrated with color Doppler mode.

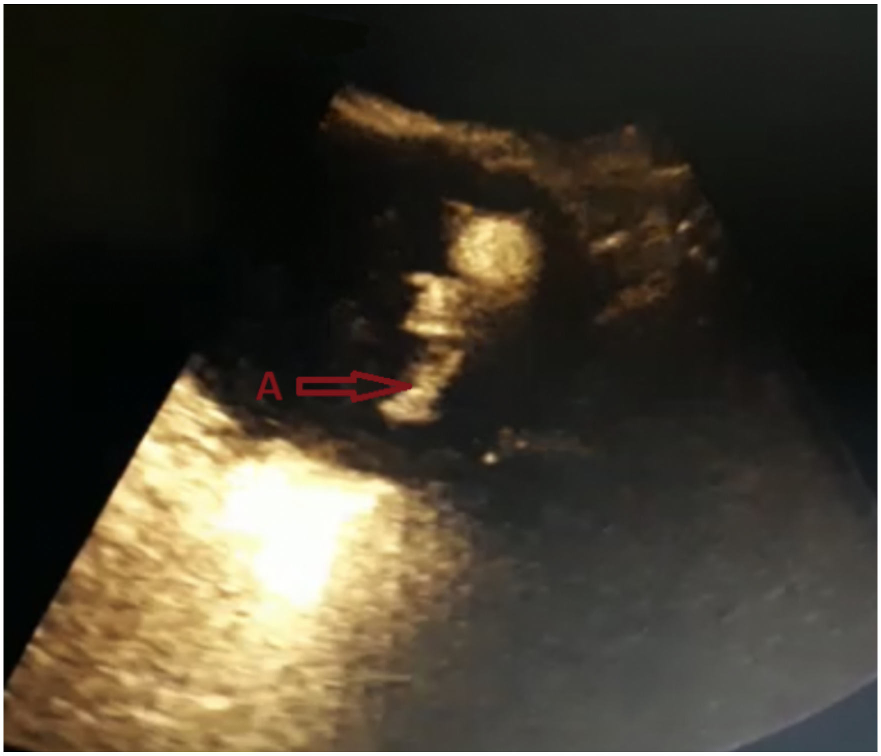
Figure 4. Type III endoleak demonstrated with blood flow image mode (sagittal section)

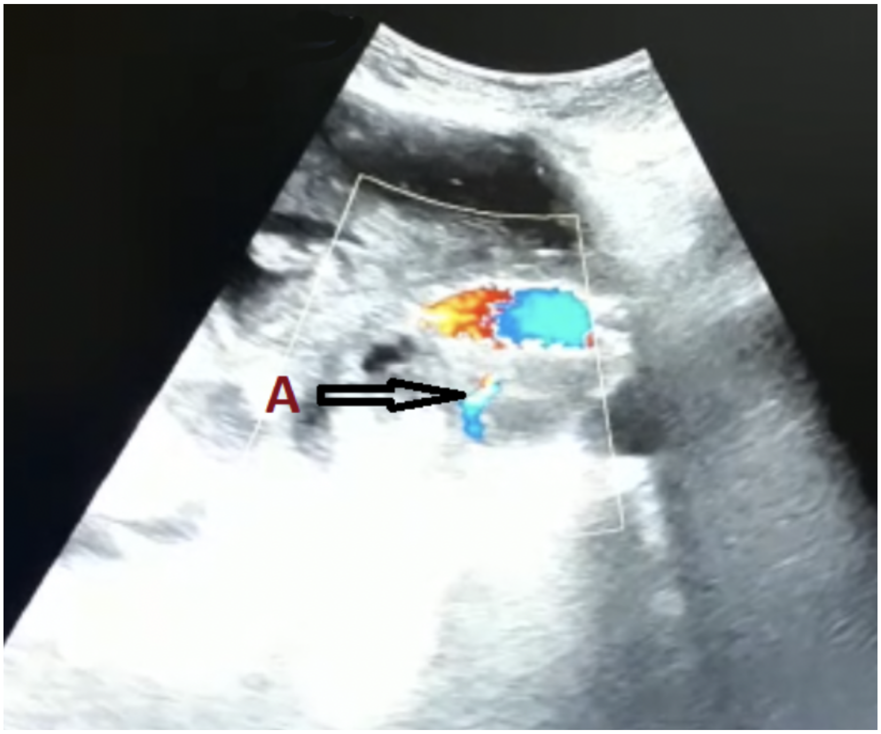
Figure 5. Bland-Altman plot of difference in diameter of sac against the avarage that shows a bias of 1.5 mm and limits of agreement spanning from -2.9 mm to 5.9 mm. The center solid line indicates the mean difference. The lower and upper lines stand for the mean difference ± 2 standard deviations.

Hosted file

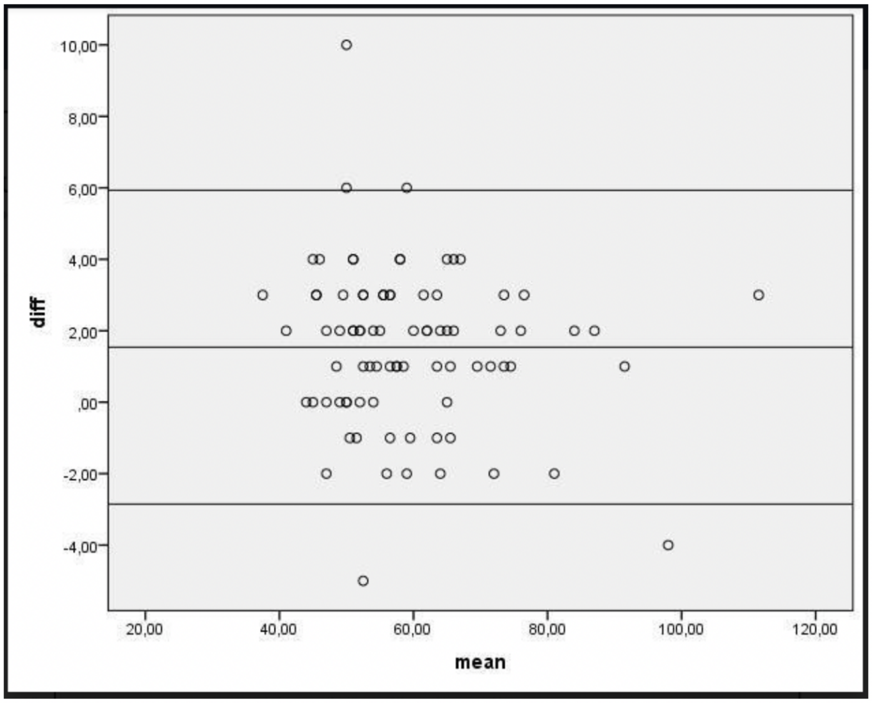
`Tables.pdf` available at https://authorea.com/users/362364/articles/483538-color-doppler-ultrasound-for-surveillance-following-evar-as-the-primary-tool




A


A


A


10,00
8,00
6,00
4,00
2,00
,00
-2,00
-4,00
diff
20,00
40,00
60,00
80,00
100,00
120,00
mean