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Transthoracic Ultrasound Evaluation of Arch and Descending Thoracic Aortic Pathology

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WHAT THIS PAPER ADDS

This study increases awareness about the potential use of ultrasound in patients with thoracic aortic pathologies. The study promotes the use of ultrasound as an additional tool in this cohort of patients and should therefore be considered as a valid tool in the management of these patients.

Background: Duplex ultrasonography (DUS) currently has limited applicability in the diagnosis and surveillance of thoracic aortic pathologies because of associated limitations. This study investigates the feasibility of using an optimised DUS protocol to detect descending thoracic aortic pathology.

Methods: Forty patients were scanned (20 cases and 20 controls). All patients but one had a technically adequate assessment of the thoracic aorta (at least one view of the descending thoracic aorta). Using a size threshold of 40 mm, 16 out of 19 cases and two out of 20 control patients would have been recommended for definitive imaging. Using a cutoff of 35 mm, this became 18 out of 19 cases and six of 20 controls. Sensitivity and specificity were 100% and 70% for a threshold of 35 mm, and 84% and 90% for a threshold of 40 mm.

Results: This was a prospective, case control cohort study. Patients with computed tomography (CT) confirmed thoracic aortic pathology underwent DUS of the thoracic aorta. A control group known to have no thoracic pathology also underwent DUS. The sonographer performing DUS was blinded to the CT findings, and recorded the presence of pathology or any dilated aortic segment where visualised. Diameter cutoff points of 35 mm and 40 mm were compared.

Conclusions: DUS has the potential to be used as a diagnostic modality for thoracic aortic pathology, and may have a role in surveillance for some patients for whom CT scanning is contraindicated. Further validation and refinements to this technique are required. However, this study provides proof of concept.

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INTRODUCTION

Thoracic aortic aneurysms (TAAs) and thoracic aortic dissection (TAD) are potentially life threatening conditions. Early diagnosis is desirable. However, 95% of patients are asymptomatic.[1,2] As the maximum diameter of the thoracic aorta increases, observed aortic growth and adverse event rates increase exponentially.[3,4] Diagnosis is currently reliant on imaging studies of the aorta such as computed tomography (CT), magnetic resonance (MR) angiography, and catheter angiography. Such technologies are expensive and can be associated with significant risks including radiation exposure and nephrotoxicity from contrast agents. In the case of MR imaging, access to this service remains limited in some healthcare settings. Consequently, these modalities are not ideal for screening or ongoing pre-operative or post-operative surveillance programmes.[5]

Unlike abdominal aortic aneurysms (AAAs) that are readily assessed by duplex ultrasound scan (DUS), the thoracic aorta has traditionally been excluded from assessment by DUS. This is because TAAs are more complex to evaluate using ultrasound modalities because of the anatomical location of the descending thoracic aorta within the thorax. The distance from the chest wall, surrounding bone, and the presence of intrapulmonary gas limit image acquisition via transthoracic ultrasound.[5–7] Trans-oesophageal echocardiography (TEE) can overcome many of these issues and has been shown to visualise much of the

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descending aorta with similar measurements to CT or MR angiography. However, routine use in diagnosis or surveillance is again limited due to the invasive nature of the procedure.[8,9]

Over the last few years, specific DUS techniques have been reported to allow visualisation of various parts of the thoracic aorta. TTE has been shown to effectively visualise the ascending aorta with similar accuracy to TEE using non-standard acoustic windows.[6] Further studies have also reported that cardiac ultrasound can accurately visualise more distal regions of the thoracic aorta, particularly in the parasternal long axis view.[10] Recently, few case reports have described cardiac ultrasound diagnosis of TAAs, including the descending aorta in emergency settings.[11,12] This study aimed to prospectively assess the feasibility and accuracy of DUS for the diagnosis of aneurysms of the descending thoracic aorta and to propose a functional protocol for such an assessment.

PATIENTS AND METHODS

Study design

In this prospective pilot study, 20 consecutive patients with known thoracic aortic pathology were referred to a vascular laboratory for ultrasound assessment of either the carotid arteries or the abdominal aorta between November 2014 and January 2016. All patients were previously diagnosed with a TAA by a dedicated CT angiogram, so no new findings were expected. A single vascular sonographer with experience in cardiac ultrasound performed all ultrasound measurements. Twenty patients with known AAA (but no TAAs) also underwent assessment of the descending thoracic aorta, and constituted the control group. The sonographer was blinded to the CT diagnosis, location, and extent of the aortic pathology in all patients. The metric of interest was the maximum diameter of the different areas of the descending aorta from the isthmus to the level of the diaphragm. A conservative cutoff point of 35 mm and a liberal cutoff of 40 mm were both tested.

Descending thoracic aorta ultrasound protocol

All scans were performed using a GE LOGIQ E9 using a 2 MHz phased array by a dedicated vascular sonographer with great experience of assessment of patients with aneurysmal disease. Ultrasound assessment was considered satisfactory when at least two of the three regions of the descending thoracic aorta were visualised, partially satisfactory when a single view was obtained and inconclusive when none of the three windows could be obtained (Supplementary fig. 1). A combination of different acoustic windows was used to assess the descending thoracic aorta (Fig. 1). All the aortic measurements were performed using

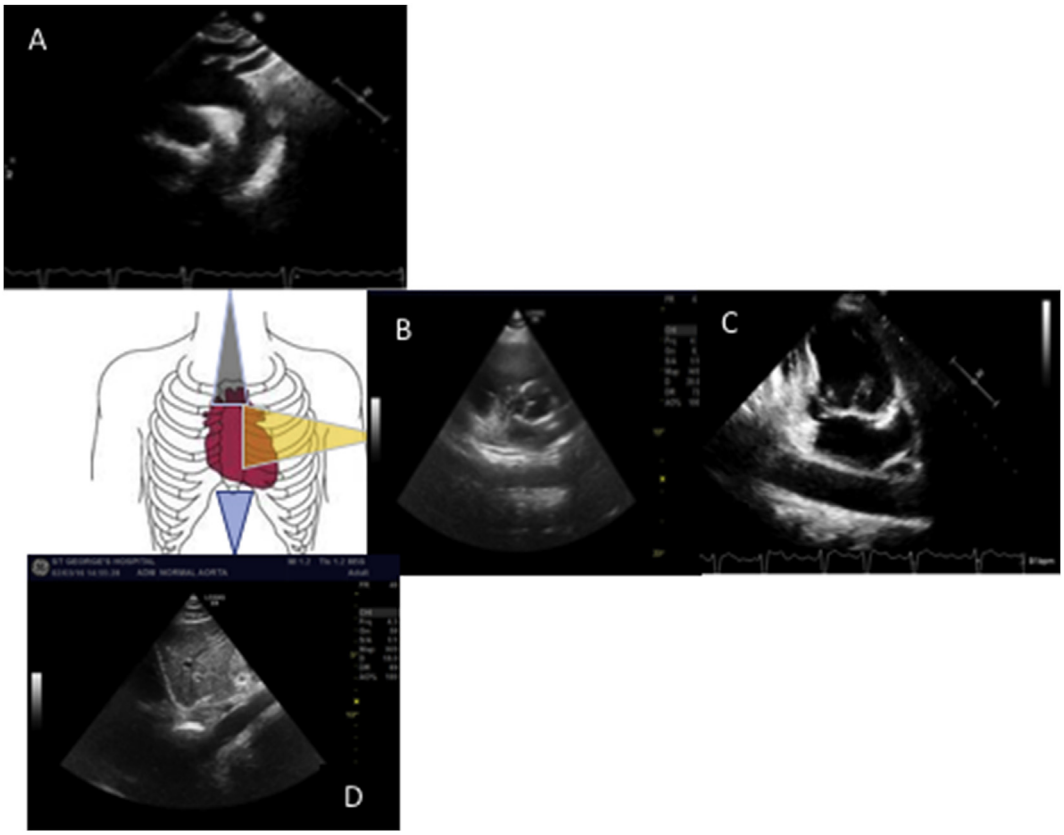

Figure 1. Main acoustic windows used in this study to assess the aortic arch and descending thoracic aorta. (A) Suprasternal window. The aortic arch and the three major supra-aortic vessels can be visualised with this window. (B) Longitudinal view of the aorta in parasternal long axis window. To obtain a longitudinal view of the mid descending thoracic aorta, modification of the standard parasternal long axis view was used; the transducer was rotated by 90°. (C) Apical two chamber views of the descending aorta (longitudinal views of the aorta). (D) Subcostal view. The distal end of the thoracic aorta and proximal segment of the abdominal aorta are visualised in this window.

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the leading edge to leading edge (LL) measurement method with electrocardiogram triggered in end diastole.[13]

Aortic root diameters were measured at the aortic annulus level only as the purpose of the study was to assess the descending thoracic aorta. The aortic root and ascending aorta were measured through a parasternal long axis view. The parasternal long axis window was optimised to visualise the ascending aorta with movement of the probe laterally, superiorly, and inferiorly to standard orientation to obtain an optimal view.[14] The aortic arch and the three major supra-aortic vessels were imaged via the suprasternal window, as was the aortic isthmus (Fig. 1A). To optimise the visualisation of the proximal descending aorta, movements of the probe laterally, superiorly and inferiorly standard orientation were used to visualise the isthmus of the descending aorta.

The mid-descending aorta was visualised using either the parasternal long axis view (Fig. 1B) or the apical two chambers view (Fig. 1C). A transverse plane of the descending aorta was seen posteriorly to the left atrium in the parasternal long axis view (Fig. 1B). To obtain a longitudinal view of the mid-descending thoracic aorta, modification of the standard apical two chambers view was used, by increasing the depth setting and moving the transducer to a higher intercostal space,[14] allowing a longer segment of the thoracic aorta to be imaged (Fig. 1B). A subcostal view was used to visualise the distal end of the thoracic aorta and proximal segment of the abdominal aorta (Fig. 1D). The diagnosis of aortic dissection was based on the demonstration, on B-mode imaging, of the presence of an intimal flap that divides the aorta into the true and false lumens. When a dissection was identified, colour flow imaging was adopted to distinguish the two lumens. The 5 MHz curvilinear transducer was also used when a poor acoustic window of the descending aorta was present. Colour Doppler and B-flow imaging where used with the curvilinear array to better define the lumen of the descending aorta when a poor acoustic window was present.

CT angiography

A vascular specialist with experience in imaging assessment of patients with thoracic aortic pathology (B.P.) reviewed the CT scans. Measurements of the aorta were taken at the same level as the ultrasound using 3mensio Vascular (Pie Medical, Maastricht, the Netherlands) to make central luminal line measurements according to a modification of a previously published protocol.[15] The aorta was measured at the following levels: distal transverse arch of the aorta, aortic isthmus, mid-descending aorta posteriorly to the left atrium, and descending aorta at the level of the diaphragm. The distal transverse arch was not included in the analysis.

Data analysis

Data were recorded and statistical analysis performed using MS Excel. Descriptive data were expressed as mean ± SD. Using cutoff points of 35 mm and 40 mm, sensitivity and specificity of ultrasound for thoracic aortic dilation and aneurysmal disease were calculated using the largest measurement on CT as the reference standard. Although there is no consensus Bland–Altman plots with 95% limits of agreement were performed to show agreement for aortic measurements (see Table 3).

Table 1. Patient demographics and aortic pathology.

Variable	Cases ($N = 19$)	Controls ($N = 20$)
Age years, mean ± SD	75 ± 7.8	77.9 ± 7.9
Male	14 (74)	19 (95)
Aortic pathology		
Thoracic aortic aneurysm[a]	16 (80)	0 (0)
Type B dissection	4 (20)	0 (0)

Note. Values are presented as *N* (%) unless stated otherwise.
[a] Two saccular aneurysms.

RESULTS

The descending thoracic aorta was assessed with ultrasound in 40 patients comprising 20 cases and 20 controls. Table 1 describes patients' demographics and types of aortic pathology. Mean maximum diameter was 47 mm (±1.35) in the TAA group by DUS and 49 mm (±1.26) ($p = .76$) by CTA. One of the cases was excluded from this analysis as they only had aneurysmal pathology of the ascending aorta. There were four cases of aortic dissection (all Debakey IIIb), two distal arch saccular aneurysms, one distal descending saccular aneurysm, and 12 fusiform aneurysms which were either isolated descending or Type II/III thoraco-abdominal aneurysms. The mean time between CT and DUS was 4.2 (range 0.2–9.2) months.

Threshold detection

With a size threshold of 35 mm, DUS screening would have triggered further imaging in all 19 TAAs case. If a threshold of 40 mm were used, this would have occurred in 16 of 19 cases. Each of these cases had a completely or partially satisfactory ultrasound assessment (Table 2). In the control cohort, one patient was unable to undergo full assessment because of inadequate ultrasonic windows. Of the remaining control patients, if a threshold of 35 mm were applied, six out of 19 would have been recommended for further

Table 2. Number of positive TAA identified with DUS among cases and controls and technical success rate of the ultrasound assessment.

Size threshold	Cases ($n = 19$)	Controls ($n = 20$)
35 mm	19/19 +TAA	6/20 +TAA
40 mm	16/19 +TAA	2/20 +TAA
Technical success of DUS		
Successful	8	10
Partial	11	9
Unsuccessful	0	1

Note. The analysis reports only 19 cases. One patient was excluded due to the location of the aneurysm (ascending aorta). Technical success of the ultrasound assessment was defined as successful (at least 2 of the 3 windows present), partial (at least 1 of the 3 windows present), and unsuccessful (none of the window visualised). DUS = duplex ultrasound scan; TAA = thoracic aortic aneurysm.

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imaging (i.e., false positives). Using a threshold of 40 mm, two of the 19 would have been referred for further imaging. This resulted in a sensitivity and specificity of 100% and 70% for a threshold of 35 mm; and 84.2% and 90% for a threshold of 40 mm.

Technical success and aneurysm location

The ultrasound assessment of the thoracic aorta was technically complete with all areas of the descending thoracic aorta seen in 18 patients (8 cases, 10 controls), partial in 20 (11 cases, 9 controls) with at least one area of the DTA seen, and inconclusive in one (0 cases, 1 control). Examples of aneurysm at different level of the descending aorta are shown in Figs 2—4. The main limitations encountered were adverse patient body habitus, and bowel and intra-pulmonary gas leading to poor visualisation.

Correlation analysis between CTA and ultrasound measurements

DUS and CTA measurements at equivalent positions in the DTA were correlated. The correlation analysis between ultrasound and CTA measurements was performed only for the descending aorta from the isthmus to the diaphragm level (Table 3). There were no statistically significant differences between CT and DUS measurements among the TAA group, but in the control group there was a difference in the measurements taken at the diaphragm with DUS slightly underestimating the diameter of the aorta in this position.

In two of four cases of aortic dissection it was possible to identify the true and false lumens using DUS (Fig. 2), but no attempt was made to further characterise thrombus or any other feature of the aneurysm in this pilot study.

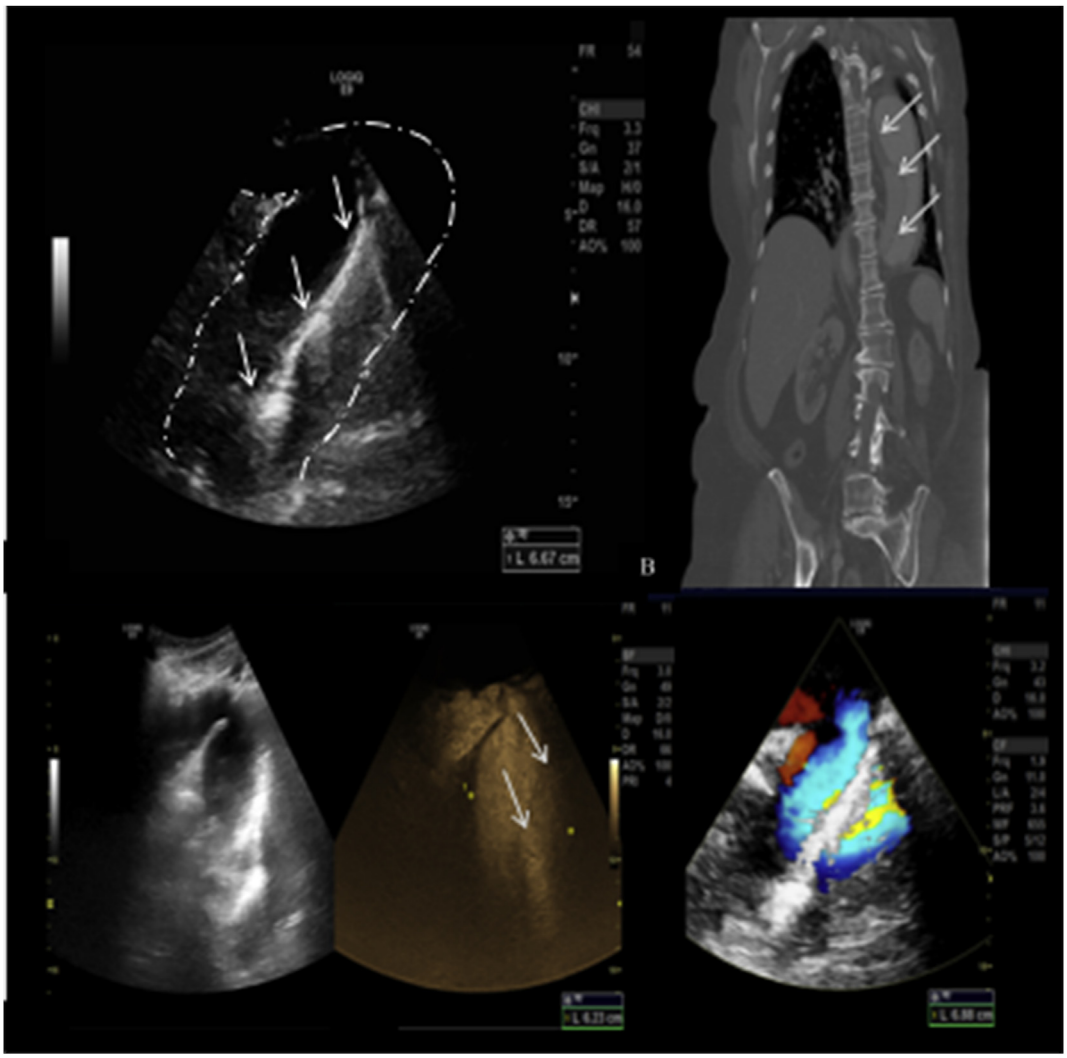

Figure 2. Aneurysms of the distal arch and proximal descending aorta. (A) Fusiform aneurysm of the proximal descending aorta with evidence of chronic dissection (white arrows) both confirmed on CT scan (B). The dissection may be easily overlooked when calcified and when mural thrombus is present, thus misleading the sonographer into thinking that the aorta is of normal calibre (dotted lines indicates the true dimensions of the aorta). In these circumstances, the aneurysm may be better visualised by using a curvilinear transducer (5 MHz) and with B-flow imaging as shown in this example (C) or by using other colour flow modalities (D). Colour Doppler imaging can also be used to better understand the distribution of the aneurysm. However, this may override the arterial borders, hence careful use with B-mode imaging is recommended.

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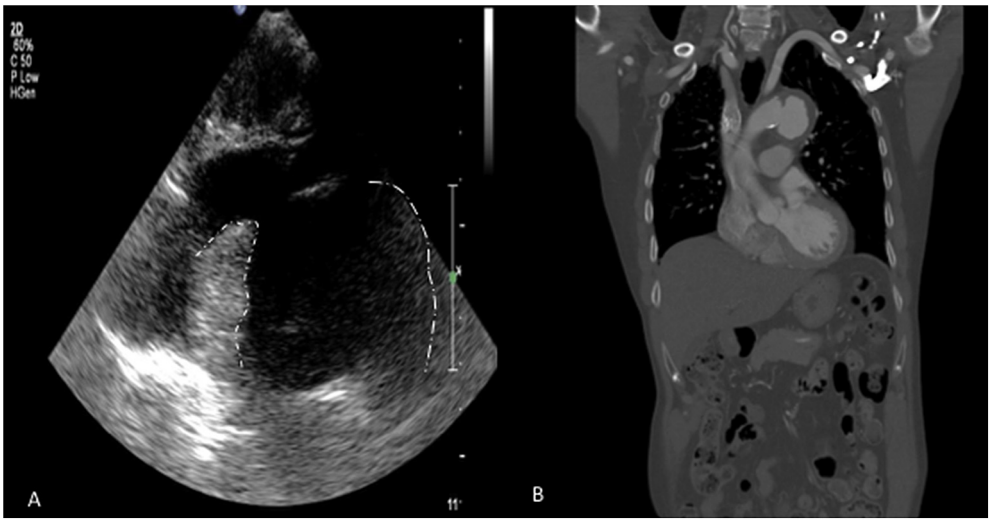

Figure 3. Saccular aneurysm of the descending aorta at the level of the isthmus. The aneurysm measured 4 cm on ultrasound (A) and 5.2 cm on CT scan (B). This discrepancy is probably due to the poor edge definition of the aortic isthmus on ultrasound due to the saccular nature of the aneurysm; however, ultrasound was discriminatory in identifying aneurysmal pathology at this level.

There were three false negative results if the 40 mm threshold was used in the TAA group. One of these was due to a focal saccular aneurysm being present in the distal descending aorta which was relatively inaccessible to ultrasound assessment. The aneurysm was 76 mm at this point but no acoustic window was obtained. The second case was an obese patient with emphysema in whom the aorta became most dilated in the mid-descending aorta, measuring 56 mm in diameter. The aorta was ectatic above this point but not aneurysmal. The final one was a distal arch aneurysm measuring 51 mm in which the ultrasound measurement underestimated the diameter. The false positive results among the control group there was a higher proportion of technically adequate scans, and if a 40 mm threshold was used there were only two false positives, both of which were caused by simple overestimation of aortic diameter. This was probably due to difficulty in obtaining a true orthogonal view of the aorta in this region where the aorta turns through three dimensions in an unpredictable fashion.

DISCUSSION

Previously, the accuracy of ultrasound in detecting pathology of the thoracic aorta has been investigated mainly in reference to the ascending aorta, and there are relatively few studies investigating this technique in the descending portion of the thoracic aorta.[11,12,16] The recently published European Society of Vascular Surgery guidelines highlight the fact that prior to this work there were no specific studies examining the role of ultrasound in diagnosing diseases of the descending thoracic aorta and the limitations of this modality when used for this purpose.[17] The largest of

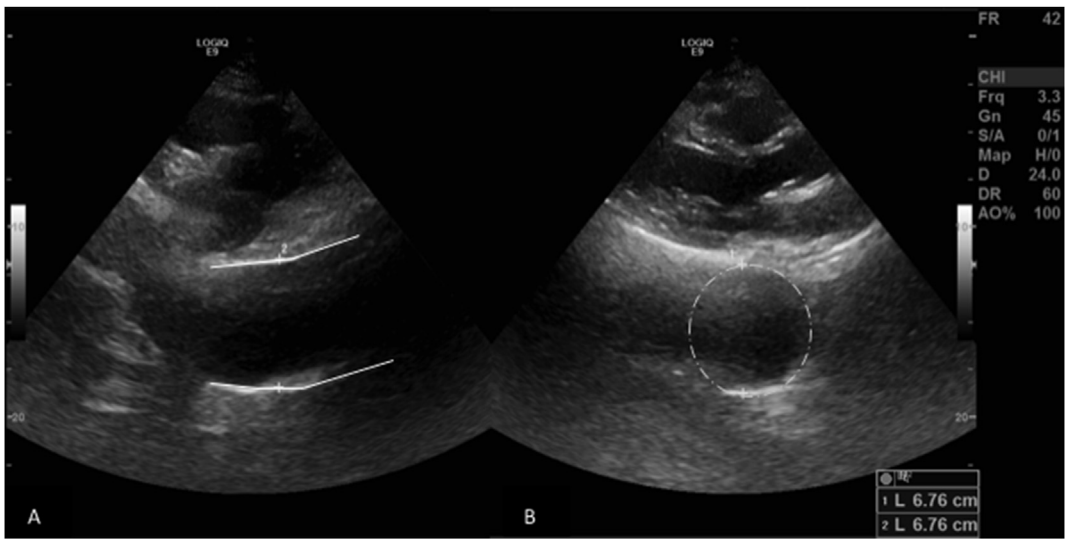

Figure 4. Longitudinal (A) and transverse (B) view of a 6.76 cm aneurysm in the mid portion of the descending aorta. This aneurysm was detected using a standard parasternal long axis view (B) and a modified parasternal long axis view (A).

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Table 3. Comparison between ultrasound measurements and CTA measurements at three different level of the descending aorta.

Level of measured aortic diameters	Case			Control group		
	DUS (mm)	CTA (mm)	*p*	DUS (mm)	CTA (mm)	*p*
Max aortic diameter	4.94 ± 1.35	4.71 ± 1.18	.76	3.22 ± 0.55	3.16 ± 0.31	.57
Aortic isthmus	4.26 ± 1.32	4.01 ± 1.18	.88	2.84 ± 0.47	2.98 ± 0.34	.41
Mid-descending aorta (posterior left atrium)	4.78 ± 1.39	4.64 ± 1.28	.70	2.78 ± 0.25	3.02 ± 0.25	.07
Descending aorta at level of diaphragmatic wall	4.35 ± 0.92	4.74 ± 7.06	.35	3.07 ± 0.44	2.72 ± 0.23	.005

Note. Values are expressed as mean ± SD. The level of statistical significance was set at $p = .05$. DUS = duplex ultrasound scan; CTA = computed tomography angiography.

these studies was a retrospective pilot study in which a comparison of measurements from 92 patients who had cardiac ultrasound was made with a corresponding CTA. The authors reported a good concordance for the detection of ascending aortic dilatation (40 mm cutoff) with a specificity of 0.95 and sensitivity of 0.77.[12] Two case reports also describe the detection of an aortic root and a descending aorta aneurysm in the emergency setting using Focused Cardiac Ultrasonography (FOCUS)[11] and diagnosis of a descending TAA with associated acute dissection.[18] Both the case studies and retrospective studies reported identifying the aneurysms via a parasternal long axis view with measurements made from outer wall to outer wall.

This proof of concept study found that descending thoracic aortic pathologies (aneurysms and dissection) could be identified using duplex ultrasound. Low false positive rates and acceptable positive diagnostic rates suggest that, with further refinement, and robust protocols for onward referral for CTA, ultrasound could become a mainstream imaging modality for screening and surveillance of the DTA. The findings are encouraging for the use of ultrasound in detecting aneurysms of the distal arch and descending thoracic aorta. The use of non-standard acoustic windows[14] allows better visualisation of the descending thoracic aorta posteriorly to the left atrium (Figs 1B,C, and 4A,B). Using this method, a longer segment of the thoracic aorta could be visualised than the standard parasternal long axis view, where the aorta is only imaged in the transverse plane. This increased the likelihood of detecting different aneurysmal regions of the aorta that may be overlooked by using standard acoustic windows.

The descending aorta at the level of the isthmus was visualised in the majority of patients. Aneurysms at this level are common and appear to be easy to visualise on ultrasound. By using non-standard acoustic windows, with a more posterior angulation of the transducer, a more extensive area of the descending thoracic aorta (DTA) at this level could be visualised and was imaged in 32 of 40 patients. Also, colour flow imaging, other non-Doppler modalities such as B-flow imaging and the use of curvilinear array may represent helpful tools in optimising the definition of the descending aorta at this level (Fig. 2C,D). In the presence of aneurysms at this level, a 5 MHz curvilinear array may be useful in better defining the edges of the DTA (Fig. 2C). In this study, the sonographer occasionally used a 5 MHz array when a complete visualisation of the aneurysm was not possible using a phased array only (Fig. 2C). More prospective studies are needed to evaluate the utility of curvilinear arrays in assessing this region of the DTA and to evaluate whether the curvilinear array should be integrated in the assessment of the descending thoracic aorta.

The region of the aorta between the isthmus and the mid-descending aorta, posterior to the left atrium, remains difficult to access and represents the main hindrance of ultrasound in the assessment of the descending thoracic aorta. The distal end of the descending aorta was mostly limited by patient body habitus and bowel gas. Despite this, it was visualised in 29 of 40 patients. Although complete assessment of the thoracic aorta was limited to only 27 of 40 patients scanned in this series, it is suggested that effective screening criteria would only need to detect a single abnormal aortic segment in order to identify patients with a high risk of having a TAA thus leading to further imaging with a second modality. Conversely, even with suboptimal views, abnormal aortic diameters were detected on 17 patients. The poor views in the remaining cases would have led to a repeat duplex on another occasion, or referral for CTA.

In this small cohort of patients there was a 45 mm eccentric saccular aneurysm of the mid-descending aorta which ultrasound failed to identify and one further saccular aneurysm of the descending aorta that was identified (Fig. 3). Owing to the nature of these aneurysms and limited acoustic windows of the mid- and distal descending aorta, ultrasound might not be sensitive in detecting these relatively unusual morphological types of focal aneurysms at these levels. More proximal saccular aneurysms may be detected if an appropriate acoustic window is present. DUS appeared to be less accurate in describing the aortic diameter in this location. The ability of 2D ultrasound imaging in identifying aortic dissections and its superiority to M-mode imaging has previously been reported.[19]

In this small cohort of patients, two out of four dissections were detected using B-mode imaging at the level of the mid-descending thoracic aorta (Fig. 2). Although this is a small number, it suggests that assessment of the thoracic aorta for dissection may be possible. The use of curvilinear array, colour Doppler and B-flow imaging also appears to be useful in better defining luminal patency and in identification of dissection. This may provide an effective modality for a radiation free, contrast free method surveillance of such patients who are currently subjected to a large number of CT scans. Frequent exposure to imaging associated radiation is not ideal considering available evidence highlighting the risk of radiation induced cancers, and contrast induced renal dysfunction.[19,20] It is not suggested that DUS becomes the

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only form of surveillance at this stage. However, the technique warrants further development in the setting of subacute and chronic Type B thoracic aortic dissections.

Development of transthoracic ultrasound techniques could provide a safe and easily available modality for emergency assessment and screening of TAAs. Transthoracic ultrasound is unlikely to provide a comprehensive view of the thoracic aorta; however, it can be used to select patients for further imaging or for simultaneous assessment of the thoracic aorta during AAA screening. The potential clinical applications of this technique depends on the sensitivity and specificity that can be achieved with further refinements to the protocol, as well as the accuracy of the measurements acquired, compared with CT angiography. If the positive predictive power is high, it is feasible that duplex ultrasonography could be used to screen for thoracic aortic pathology in high risk groups, such as those with AAAs. At present, CT scanning is the only way to do this reliably and it has many disadvantages in comparison with ultrasound based modalities. It may also be possible to survey certain patients after thoracic aortic surgery with DUS thus replacing the annual surveillance CT scans that are currently required, although, this would not be feasible in all patients given variations in body habitus and disease configuration. A further use for this technique could be in the post-operative surveillance of patients that have undergone intervention. At present this is mostly done with annual CT scanning, with the attendant cost and potential for cumulative radiation exposure over many years. During the course of the study a patient with a sac expansion and a negative CT scan underwent thoracic aortic duplex scanning, and a Type III endoleak was discovered that was later treated. The clinical application of DUS for surveillance after TEVAR would require a separate study before it could be recommended for clinical use.

Limitations

Interpretation of the results is limited by the small sample size. In 51.2% (20/39) of the patients on whom DUS of the thoracic aorta was performed, not all areas of the aorta were visible, and no thoracic aorta evaluation was possible in one patient. The mid-portion of the descending aorta was not visualised in 30.1% (12/39) patients with TAA. The accuracy of the measurements could also have been influenced by the heterogeneity of the aortic pathologies studied as well as the learning curve associated with the examinations. It was notable that the majority of visualisation failures occurred within the first 20 cases. Also, few patients in the study had straightforward distal arch or proximal descending aortic pathology, which may have been easier to detect using transthoracic duplex scanning. DUS underestimated the diameter of the distal descending thoracic aorta. This may be due to the novel nature of this protocol and observed discrepancies may lessen with increased experience and technical development.

Finally, this was a proof of concept study. Only one sonographer performed the ultrasound scans. Therefore, the inter-variability and intra-observer variability needs to be characterised, as does the applicability of the techniques to a larger cohort of patients. The role of DUS in detecting endoleaks after thoracic aortic endovascular repair is also as yet undefined.

CONCLUSION

The descending aorta can be visualised in several patients using standard and modified ultrasound windows; however the mid-segment of the descending aorta remains the main hindrance in the ultrasound assessment. Both TAAs and Type B aortic dissections could be visualised in a large percentage of patients in this study suggesting that ultrasound could play an important role in the diagnostic pathway of patients with aortic pathology and may be shown to be sensitive in detecting pathology of the thoracic aorta amongst the general population.

Larger prospective studies are needed to assess the sensitivity and specificity of ultrasound in identifying and monitoring TAAs amongst the general population, and to define a scanning protocol specific for the thoracic aorta. The implications are widespread in terms of a thoracic aortic screening programme, and the pre- and post-operative surveillance of thoracic aortic pathologies. In a parallel to Focused Assessment with Sonography for Trauma (FAST) scans, the protocol may also have a role in the acute assessment of patients with chest pain that may be due to thoracic aortic pathology.

CONFLICT OF INTEREST

None.

FUNDING

None.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ejvs.2017.12.012.

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