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Ultrasound Measurement of Aortic Diameter in a National Screening Programme

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Abstract *Objective:* Currently there is no universally accepted standard for ultrasound measurement of abdominal aortic aneurysm (AAA). The aim was to investigate the reliability and reproducibility of inner to inner (ITI) versus outer to outer (OTO) ultrasound measurement of AAA diameter.
Methods: A prospective study design was used to collect 60 random images of aorta (1.4–7.1 cm). Inner and outer wall diameter measurements were then performed by 13 qualified AAA screening technicians and 11 vascular sonographers.
Results: The mean (range) diameter for all 60 aortas by ITI was 3.91 cm (1.39–6.80) and by OTO was 4.18 cm (1.63–7.09), a significant mean difference of 0.27 cm (95% CI:0.23–0.32 cm). The reproducibility coefficients for differences between technicians were 0.30 cm (95% CI:0.24–0.36) for ITI and 0.42 cm (95% CI:0.35–0.49) for OTO indicating significantly better repeatability using ITI. Finally, 15 images were measured twice in random order by all screeners and sonographers. For AAAs >5 cm, repeatability was significantly better with ITI than OTO (0.14 vs. 0.21; $p = 0.016$).
Conclusion: There was the expected difference in AAA diameter between the two methods (0.27 cm). However, ITI wall method was measurably more reproducible.

Introduction

Ultrasound is a low-cost and effective method of screening for abdominal aortic aneurysm (AAA)[1–4] and has been adopted for this purpose. The main disadvantage of ultrasound is operator dependence and variability. Aortic diameter is assessed from static ultrasound images obtained at

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ultrasonography and measured using electronic callipers. Previous studies assessed the limitations of ultrasound measurement and have demonstrated that it is most reliable at measuring the antero-posterior aortic diameter, but that it is only accurate to within 5—8 mm.[5] Systematic training can reduce this variability to 2—3 mm.[6,7]

A Department of Health funded programme to screen 65-year-old men for AAA is currently being rolled out in England. The NHS Abdominal Aortic Aneurysm Screening Programme (NAAASP)[8] is based on evidence from the Multicentre Aneurysm Screening Study (MASS), a randomized trial that demonstrated screening can reduce aneurysm-related mortality by 40% after ten years.[9] In MASS, aortic diameter was measured using callipers placed on the inner walls of the aortic image (inner to inner method, ITI)(-Fig. 1); the maximum longitudinal and transverse measure of aortic diameter was recorded. Other studies, including the UK Small Aneurysm Trial[6] used callipers placed on the outer aortic wall of the image (outer to outer method, OTO)(Fig. 1); to record the antero-posterior aneurysm diameter as the basis for surveillance and clinical management. Thapar *et al*. conducted a study suggesting that using the ITI measurement underestimates the aneurysm size by up to 6 mm and displays greater variability when compared with OTO measurement,[10] which would have significant implications for a screening programme.

The aim of this study was to investigate the reliability and reproducibility of ITI versus OTO measurement of abdominal aortic diameter to determine which should be used for this screening programme and other future studies.

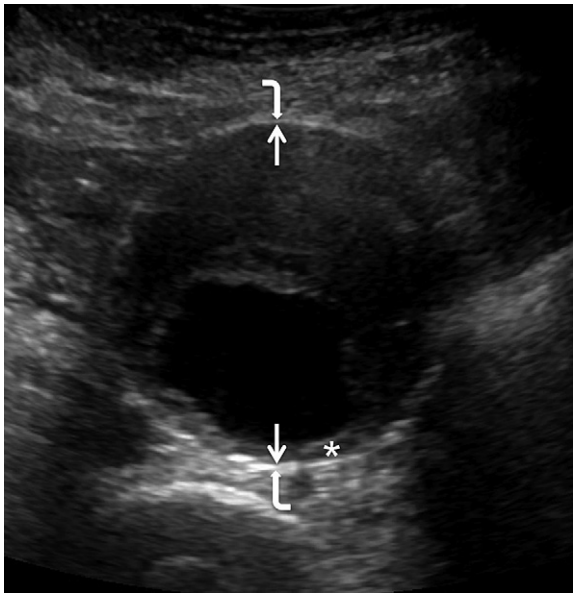

Figure 1 A transverse image of an abdominal aortic aneurysm. The aortic diameter is measured in the antero-posterior plane. The straight arrows indicate the position of the inner anterior and inner posterior wall. The angle arrows indicate the position of the outer anterior and outer posterior wall. The asterisk indicates an area of mural thrombus on the posterior wall and it is important that the posterior inner wall calliper is not placed on the inner boarder of the thrombus.

Methods

A prospective study was conducted by recruiting 13 qualified AAA screening technicians and 11 vascular sonographers. Vascular sonographers in the UK generally undertake a minimum of two years of training in peripheral vascular imaging and should hold a recognised ultrasound qualification which includes imaging of the aorta, whereas the screening technicians are only trained to image the abdominal aorta and undertake a 3-month training program. The training of screening technicians is accredited by the NAAASP. A protocol describing measurement by ITI and OTO was distributed to each participant prior to the start of this study to ensure familiarity with each method. Formal ethics approval was not considered necessary for this study, since no patient identifiable data were used, and men in NAAASP give consent to use of their information for audit and service improvement.

Sixty images were selected randomly from the Leicestershire AAA screening programme and anonymised to protect individuals' details. The images selected included a range of aortic diameters presented in both transverse and longitudinal views as measurements are required in both these planes by the NAAASP. The images were loaded onto a laptop computer and presented on a monitor with a screen resolution of 1024 $\times$ 768, similar to a standard screening scanner. The images were saved in digital imaging and communication in medicine (DICOM) format, and a DICOM viewing program (Santesoft, Athens, Greece) was used to present the images, allowing for accurate calliper measurement of diameter in centimetres in the antero-posterior plane. A trackball system, similar to the type found on an ultrasound scanner was provided for the accurate placement of measurement callipers. Before measuring the aortas, each observer was asked to measure a 10-cm scale presented on screen six times to ensure that they were familiar with trackball use and calliper placement. All observers were able to measure the 10-cm scale with an accuracy of $\pm$0.02 cm.

The first 30 images in the series of 60 were measured by one method and the second 30 by the alternate method to prevent a training effect or bias. The 60 measurements were then repeated but the measurement method was reversed for each block of 30 images. The starting method (ITI or OTO) was alternated between each observer and the presentation order of the images was also random between each observer. Finally, 15 images were re-measured by both methods to assess intra-observer variability, namely individual repeatability.

Each measurement was recorded directly onto a data-sheet so that individual observers were blinded to any previous measurements. Comparisons of the ITI and OTO measurements were made using regression modelling with generalised estimating equations (GEE). This regression technique makes the appropriate statistical adjustment required to take account of the repeated nature of the data, namely the pairs of data readings (ITI and OTO) obtained from each individual.

Inter and intra-observer variability for ITI and OTO separately were assessed by calculating reproducibility and repeatability statistics based on the between and within-

observer standard deviations respectively. The inter-technician reproducibility coefficient was derived by calculating the overall between-observer standard deviation (sd) and then deriving the 95% threshold limit for the difference in measurements taken by any two technicians ($\sqrt{2} \times 1.96 \times$ sd). The intra-technician repeatability coefficient was derived for each technician by calculating the standard deviation of the difference in repeat measurements for each individual (first reading − second reading) and multiplying by 1.96. This statistic gives the 95% threshold limit for the difference between repeat readings.

Statistical comparisons of intra-observer repeatability between ITI and OTO, and between screeners and sonographers were made using GEE regression models using the squared differences between repeats.

Finally, the axial resolution of the transducer (curvilinear 2—5.5 MHz broadband) connected to the Logiq e ultrasound system (GE Healthcare, Bedford, UK), used to capture the images for this study was also measured[11] using a standard ultrasound test object (Gammex, Nottinghamshire, UK). The axial resolution is the minimum distance in the beam direction between two reflectors that can be identified as separate echoes. This is important in resolving different interfaces such as aortic wall and adjacent tissue.

Results

The 60 aortic images were assessed by the 13 screening technicians and the 11 vascular sonographers. Six (55%) of the sonographers had greater than 10 year's experience and only one (9%) had less than one year's experience compared to two (15%) and five (39%) respectively of the screeners. The 13 screening technicians all used ITI as their routine method, but of the 11 sonographers five used OTO and six used both methods in their routine practice.

AAA diameter using ITI and OTO

A total of 1440 measurements were performed. The mean (range) diameter for all 60 aortas by ITI was 3.91 cm (1.39—6.80) and by OTO was 4.18 cm (1.63—7.09), a significant mean difference of 0.27 cm (95% CI:0.23—0.32 cm); $p < 0.001$. Fig. 2 shows the variability for ITI and OTO measurements for the 60 images.

Inter-observer variability for ITI and OTO

The estimated inter-observer standard deviations were 0.11 cm for ITI and 0.15 cm for OTO, which corresponds to reproducibility coefficients between technicians (95% threshold limit for differences between technicians) of 0.30 cm (95% CI:0.24—0.36) for ITI and 0.42 cm(0.35—0.49) for OTO ($p < 0.05$). This indicates significantly better inter-observer variability using ITI. Restricting the analysis to the 18 participants with at least 1 year's experience produced reproducibility coefficients of 0.32 cm (0.26—0.38) for ITI and 0.38 cm (0.31—0.45) for OTO.

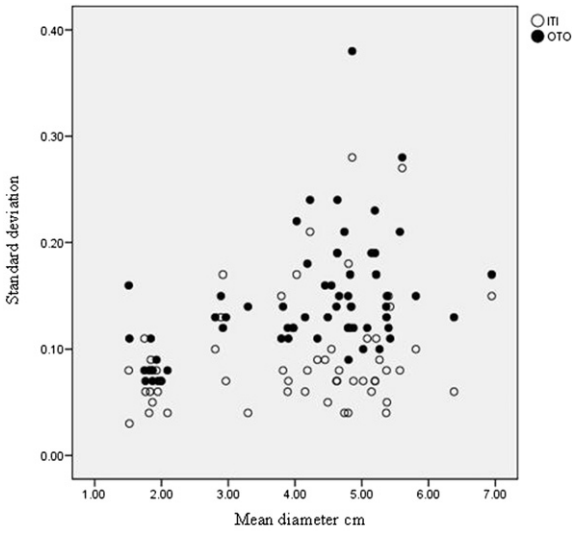

Figure 2 Variability for ITO and OTO measurements for the 60 images (each dot corresponds to the standard deviation calculated over the 24 observers).

Intra-observer variability for the ITI and OTO

Finally, 15 images were measured twice in random order by the 13 screeners and 11 sonographers; the mean repeatability within technicians was 0.16 cm for ITI (range 0.08—0.52) and 0.20 cm (range 0.05—0.61) for OTO, a non-significant difference in favour of ITI ($p = 0.22$). For aneurysms >5 cm (4 images only), repeatability was significantly better with ITI than OTO (0.14 vs. 0.21;$p = 0.016$).

In order to assess whether intra-observer variability for ITI and OTO is related to experience with the method, repeatability coefficients were calculated for screeners and sonographers separately, and their intra-observer variability compared (Table 1). Repeatability for ITI was similar between the screeners and the sonographers, but repeatability for OTO was significantly better for sonographers compared to screeners.

Comparing ITI and OTO in different aortic diameters

The 1440 measurements of the 60 aortic images were grouped into four categories to assess the impact of ITI versus OTO on the threshold for surveillance and referral for treatment. Table 2 summarises the results of this analysis which suggests that ITI method would pick up fewer aneurysms and might therefore delay referral for treatment in some patients. As the sampling in this study was random and did not include a consecutive series of patients from a screening programme, it is difficult to estimate the impact of this on a screening programme.

Axial resolution of the ultrasound system

It was not possible to resolve the two nylon lines spaced 1 mm apart as separate reflectors. The lines spaced at

Table 1 Repeatability coefficients for screeners and sonographers.

	Mean (range) repeatability		*p*-value (GEE model on repeat readings)
	Screeners ($n = 13$)	Sonographers ($n = 11$)	
ITI	0.17 (0.08—0.52)	0.14 (0.09—0.24)	$P = 0.27$
OTO	0.25(0.11—0.61)	0.14 (0.06—0.26)	$P = 0.037$

2 mm could be resolved indicating that the axial resolution of the ultrasound system at typical scanning depths for the aorta is between 1 and 2 mm.

Discussion

Ultrasound has become the accepted modality for AAA screening, since these instruments are now portable, reliable and cost-effective. Ellis *et al*. looked at the repeatability, observer bias and instrument bias of ultrasound and found that repeatability was much better for antero-posterior than tranverse aortic diameter measurements.[5] They also found that a single trained observer using the same ultrasound equipment could provide aortic diameter measurements accurate to within 5 mm. Grimshaw and Docker in 1992 demonstrated that ultrasound was accurate when compared with computed tomography (CT) in assessing AAA size and that repeatability measurements with a trained observer were approximately 3 mm.[1] Similar accuracy was obtained for trained screeners in the UK Small Aneurysm Trial and other screening studies.[4,6,12] Although there are many studies looking at the use of ultrasound in assessing aortic size, there is not much literature on the methodology used in performing the maximum diameter measurement. The debate around OTO versus ITI has arisen following adoption of the ITI method by the NHS AAA Screening Programme.[10]

Our results show that ITI is more reproducible than OTO particularly in the assessment of large AAA. This is contrary to the findings of Thapar *et al*. who found ITI measurement to exhibit greater variability.[10] However, their study had a number of factors which may have affected their findings. The measurements were performed by only two sonographers who had not received NAAASP-accredited training in ITI wall measurement. The method used by the sonographers in their usual practice was not stated and this may have introduced bias. The strength of the present study lies in the fact that we have used measurements from 24 observers including 13 screening technicians accredited by the NAAASP. It is also important to consider key elements of a screening programme such as accuracy, repeatability and quality control. Although there was the anticipated difference of approximately 3 mm between ITI and OTO methods, it could be argued that this was offset by the improved reproducibility of ITI. In the context of a national programme reproducibility is important in respect of the method employed.

Thapar *et al*. found a 6—7 mm discrepancy between ITI and OTO and expressed concerns regarding delayed diagnosis and referral for treatment that could impact on the effectiveness of the current screening programme.[10] Using the MASS/NAAASP method for aortic assessment means that 65-year-old men with an initial aortic diameter just below 3 cm on ITI (approximately 4% of the sample in our study) will not be offered surveillance, which would likely have occurred if the OTO method was used. However, as mentioned previously, our study did not recruit consecutive patients and it would be difficult to estimate the impact of these findings on a screening programme. Similarly, men under surveillance with an AAA just below 5.5 cm will continue regular imaging in the present Programme, whereas they would be likely to have been referred for consideration of AAA repair had the OTO method been used. Monitoring of the latter group will be done using data within NAAASP, and if it becomes obvious that there is a risk of rupture at this stage, it should be possible to alter referral guidelines. The fate of men with an aortic diameter just below 3 cm on initial scan remains an issue that is being investigated in a number of research projects to determine whether it might be cost-effective to include them in the screening programme.

It is also important to consider the technical aspects of ultrasound equipment. Studies conducted using magnetic resonance angiography and intravascular ultrasound indicate that the aortic wall was about 2 mm thick[13—15] which would

Table 2 An assessment of the impact of ITI versus OTO on the threshold for surveillance and referral for treatment (using 1440 measurements in our study).

	Size categories using OTO			
Size categories using ITI	<3 cm (Normal)	3—<4.5 cm (Small)[a]	4.5—<5.5 cm (Medium)[b]	≥5.5 cm (Large)[c]
<3 cm (Normal)	348 (24%)	60 (4%)	0 (0%)	0 (0%)
3—<4.5 cm (Small)[a]	0 (0%)	262 (18%)	124 (9%)	0 (0%)
4.5—<5.5 cm (Medium)[b]	0 (0%)	1 (0.1%)	418 (29%)	138 (10%)
≥5.5 cm (Large)[c]	0 (0%)	0 (0%)	1 (0.1%)	88 (6%)

[a] Yearly assessments.
[b] Three-monthly assessments.
[c] Immediate surgery.

suggest that the difference between inner wall and outer wall boundaries should be generally no more than 4 mm in normal subjects. The axial resolution of the ultrasound system used to capture the images for this study at a typical scanning depth for the abdominal aorta (8—10 cm) was found to be between 1 and 2 mm. This means that boundaries less than 2 mm apart may not have a clear image resolution. In particular the resolution of the outermost boundary of the posterior aortic wall from surrounding tissue is often poor which can lead to uncertainty over placement of the deeper calliper. The inner posterior wall provides a much stronger reflective boundary for calliper placement due to the higher amplitude reflection coefficient[16] and impedance mismatch between the blood and tissue. This is one possible reason why the ITI method was found to be more reproducible, especially for the screening technicians who have limited ultrasound expertise compared to experienced sonographers. In Scandinavia, their standard aortic measurement is from outer anterior wall to inner posterior wall (leading edge to leading edge); repeating our study using this method might add valuable data.

One of the limitations of our study is the use of static images and it is likely that there will be greater inter and intra variability with live images. However, it is anticipated that differences between ITI and OTO will remain similar, as in our study, it is the perceived position of the ultrasound boundaries that has been identified by the observers for placement of the measurement callipers and these boundaries are clearly evident when scanning patients.

In conclusion, the aorta can be measured accurately using both ITI and OTO methods, with repeatability in the range of 2 mm, similar to the difference in the two techniques. For NAAASP, where trained screeners will undertake the bulk of aneurysm screening, better reproducibility was obtained using the ITI method. It is probably more important to ensure good reproducibility in a screening programme, since as long as everyone is screening to the same standard, the indications for surveillance and intervention can be reconsidered.

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Conflict of interest

None.

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