What is the most effective imaging modality to detect abdominal aortic aneurysms in a national screening programme?

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INTRODUCTION

An abdominal aortic aneurysm (AAA) is a permanent dilatation of the aorta to 1.5 times its normal size,[1] and is most commonly due to atherosclerosis of the vessel wall, as well as trauma, infection and genetic predisposition.

Risk factors for atherosclerosis

Hypercholesterolaemia	Diabetes mellitus
Hypertension	Physical inactivity
Male gender	Excess alcohol consumption
Smoking	Obesity
Increasing age	Unbalanced diet
Family history	

Aneurysms arise in the vessel wall when fibrosis and thinning of the media occurs, causing the aorta to weaken at that point. They can be true aneurysms (when the full thickness of the wall is involved) or false/pseudo aneurysms (when the weakened vessel leaks blood to form a surrounding haematoma). AAAs most commonly occur in the infra-renal segment, below the renal arteries, and affect 5% of males over the age of 60, being five times more common than in females.

Aneurysms are particularly dangerous as most are asymptomatic until complications arise; this risk explains the recent implementation of screening in the UK, with the hope of reducing the mortality rate resulting from complicated AAAs.[2] Complications that may develop include rupture and embolism formation, with ruptures accounting for approximately 6,000 male deaths in England and Wales each year.[3] If the diameter is less than 5.5cm, surgical repair is not recommended as no benefit regarding length of survival has been found, and there is no advantage over surveillance of the aneurysm.[4] However, the margin of error is very fine; therefore the imaging modality used to screen for AAAs needs to be very accurate to ensure that the appropriate treatment or monitoring is undertaken.

Aneurysms can be identified through physical examination by palpating an abdominal pulsatile mass, or detected through the use of ultrasound, plain X-ray and computed tomography (CT) scanning which can potentially prevent mortality through close monitoring and identifying the need for effective treatment. In the UK, the NHS is currently implementing a screening programme that began in 2009, which was fully implemented in England by March 2013. An ultrasound scan is offered to all males aged 65, and men over this age who have not previously been invited can refer themselves if they wish.[2] The hope is to 'reduce AAA-related mortality among men aged 65 to 74 by up to 50% through early detection, appropriate monitoring and treatment'.[2] However, this screening technique has a number of advantages and limitations affecting its accuracy in detecting aneurysms before complications arise.

This study aimed to explore the use of ultrasound in comparison to CT in screening for AAAs, to see whether ultrasound was the most effective imaging modality for this purpose. The focus of the investigation was on image quality, patient safety and acceptance, error, and also equipment, to see which device was the most effective. The two modalities were also briefly compared to the UK National Screening Committee criteria (see box below and Appendix), which every screening programme should meet before it is started.[5]

The UK National Screening Committee describes 22 criteria which need to be met by screening programmes. These relate to ethical issues, the cost-effectiveness of the screening intervention, the extent of the public health problem, etc. Criteria 5, 7, 13, 14, 15 and 16 are particularly relevant to the screening of aortic aneurysms:

- (5) – the screening test should be simple, safe, precise and validated
- (7) – the test has to be acceptable to the population
- (13) – high-quality trials must provide evidence that the screening programme is effective in reducing mortality or morbidity
- (14) – evidence must show that the screening programme is clinically, socially and ethically acceptable to the population
- (15) – the benefits of the screening programme must outweigh the risks of harm
- (16) – the opportunity cost of the screening programme should be balanced in relation to expenditure on medical care as a whole

This study has not investigated the use of plain X-ray screening and screening by abdominal palpation. Nor has it considered the cost of the respective screening methods.

Method

The sources used for this structured review include books, web pages and peer-reviewed journals, with the journals accessed using the databases: PubMed, Web of Science, MEDLINE and Wiley Online. A broad search term was entered initially and then refined using limitations.

DISCUSSION

Ultrasound is the current imaging modality used in the NHS AAA-screening programme (NAAASP) to detect aneurysms and assist in the decision to determine whether surgery is necessary. The risk of an AAA rupturing is proportional to the diameter of the vessel, with aneurysms of 5.5-6cm having an annual rupture rate of 5-15%, increasing to 20-40% for diameters of 7-7.9cm.[6] When ruptures do occur, the mortality rate is very significant, being over 80%.[6] With the 30-day mortality rate of open surgery for AAAs being 5-8%, and a significantly higher 50% for ruptured AAAs,[7] it is of paramount importance that diameter measurements taken in the screening programme are accurate, so that all patients requiring surgery are referred. If an AAA is identified through screening, as opposed to being found incidentally, the risk of mortality soon after surgery can be reduced by 50%,[8] suggesting that screening is worthwhile when performed to a high standard. Ultrasound has some advantages over CT, but it is also limited.

Advantages of using ultrasound in comparison to CT

Ultrasound has a high accuracy in detecting AAAs, with the sensitivity and specificity being 95% and almost 100%, respectively.[9] CT is also accurate in obtaining AAA measurements.[10] However, there are a number of problems which can reduce accuracy, such as overestimation of the aortic diameter.[11] When using ultrasound, the probe can be manipulated to view the aorta sagittally as well as in a transverse plane, allowing the operator to visualise the true anteroposterior and longitudinal measurements of an aneurysm, whereas CT uses only an axial plane.[12] CT can, however, produce multiplanar reconstructions to visualise a longitudinal image of the aorta, but further processing of the images during the reconstruction could reduce accuracy.[13] Moreover, 3D images can also be produced by reconstruction, but have the same disadvantage of inaccuracy and unreliability if the process is not completed properly by the operator.[13] Axial CT images alone are problematic, as the longitudinal growth of the aneurysm cannot be monitored.[12] Furthermore, if the aneurysm is tortuous, a transverse view using CT may overestimate the lumen diameter, a problem that can be alleviated when experienced operators use the ultrasound probe.[11] Figure 1 shows an aortic aneurysm as an example of how a measurement at a tortuous point in the aorta can produce a misleading result, as the cross-section will be oblique instead of perpendicular.[14]

Another concern when using CT is the use of ionising radiation to produce the image and the potential damage high doses can have on the patient when performed on multiple occasions over a long period of time. The radiation exposure of having one CT scan of the abdomen is the equivalent of having 400 plain radiographs,[15] and the repeated exposure of this has been thought to increase the risk of cancer.[16]

This increased risk is a reason why CT is not as suitable as ultrasound for periodic screening and monitoring. Furthermore, iodine-based intravenous contrasts used in CT scans to enable clearer visualisation of the interior of blood vessels can sometimes cause adverse effects such as anaphylaxis, extravasation, exacerbation of renal impairment and diarrhoea and vomiting. Ultrasound, on the other hand, is considered extremely safe for this type of investigation as it is painless and does not cause adverse side effects.

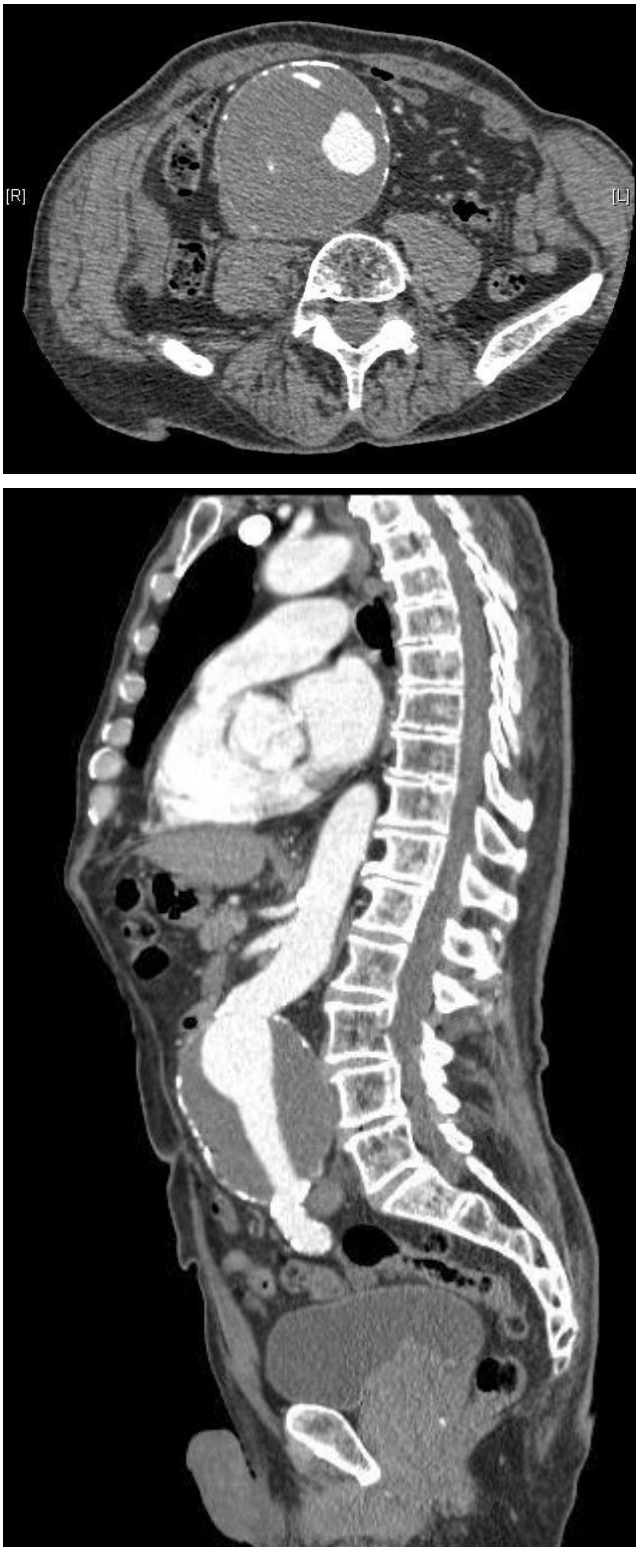

Figure 1 An axial view of an aortic aneurysm measuring 89mm, and a sagittal view of the same aneurysm which was measured as 81mm

Ultrasound is relatively easy to perform by competent operators and only requires the patient to lie flat on a bed whilst being examined. Patients undergoing a CT scan have to remain in the examination room alone and can be asked to hold their breath at intervals whilst the procedure takes place, which may be difficult and stressful. Ultrasound screening examinations can take between five and ten minutes, whereas CT scans can take up to 30 minutes depending on the size of

the area being examined, suggesting that ultrasound is generally more time efficient. From the evidence above, it can be seen that ultrasound is more representative than CT of criteria 5 of the UK National Screening Committee criteria,[5] as it is simpler to perform and has no side effects in AAA detection, whereas CT is not suitable for multiple use due to the ionising radiation.

Furthermore, a study in 2006 suggests that ultrasound is widely accepted by patients as a useful investigation, as it found the ten-year attendance rate of AAA screening to be 76.6% in one centre that screened for AAAs.[17] This may suggest that ultrasound meets criteria 7 to a greater extent than CT,[5] being more widely accepted in the population, possibly due to the issue of patient safety.

Limitations of ultrasound

The accuracy of ultrasound and whether AAAs are detected correctly is dependent on the operator and whether or not errors are minimised, with a recent study suggesting that AAAs are more accurately visualised by operators who have more than three years' experience.[18] CT results, on the other hand, are much less affected by the operator,[19] suggesting that measurements using this technique may be more reproducible. Intra-observer and inter-observer errors can reduce the reproducibility of AAA diameter measurements, which results in the concern of referring the right patients for surgery.

Inter-observer variation is defined as 'the amount of variation between the results obtained by two or more observers examining the same material'.[20] In the context of this study, it relates to different operators placing the callipers in almost the same place when measuring the diameter of the same aorta, in order to obtain a very similar result. For anteroposterior measurements, a 2002 study states that when using ultrasound 'the reported inter-observer variability is 2.2-7.5mm'.[21] It is also stated that 'the reported inter-observer variability in CT is 2.8-4.3mm'. With regards to transverse measurements, 2.8-15.5mm is the reported error for ultrasound, whereas the average error for CT is 7mm. This suggests that axial CT measurements are more reproducible than ultrasound and less affected by multiple operators scanning the same patient.

Intra-observer variation is defined as 'the amount of variation one observer experiences when observing the same material more than once'.[20] According to a 2011 study, studies have shown that the mean anteroposterior intra-observer error has ranged from 0.03-4.8mm using ultrasound, suggesting that the same operator may not be able to provide consistent results.[22] However, the intra-observer variability seems less significant than the inter-observer error, therefore a potential improvement for the future would be to minimise the number of operators screening one patient in order to decrease this variation. The highest level of inter- and intra-observer error accepted by the NAAASP Service Objectives and Quality Standards when using ultrasound is ≤3mm, with the desired achievable level of ≤2mm.[23] According to the evidence above, CT would be the optimal choice even though ultrasound is still very accurate.

Intra- and inter-observer variation can cause random errors throughout the measurement results, but the technique in which the aortic diameter is measured can also affect the reproducibility of results by introducing systematic error. If the less accurate technique is used by all operators then the results could be misleading. The current NAAASP states:[24]

> *Two anterior-posterior (AP) measurements of the maximum aortic diameter should be recorded in millimetres, measured across the lumen from/to the INSIDE of the ultrasound-detected aortic wall, one with the probe in the longitudinal plane and one with the probe in the transverse plane.*

Studies have investigated whether the internal wall diameter (IWD) or external wall diameter (EWD) should be measured, to ensure that screening programmes obtain the most accurate measurements. One study found less variability and better reproducibility measuring the IWD.[25] However, another study found EWD measurements to be more reliable, claiming that IWD measurements underestimate the size of the lumen.[26] Measurements of the IWD can be affected by the presence of a thrombus, which will cause the diameter of the lumen to be underestimated if it is not recognised and taken into account.[26] Figure 2 shows the difficulty of measuring the aortic diameter when a luminal thrombus is present.

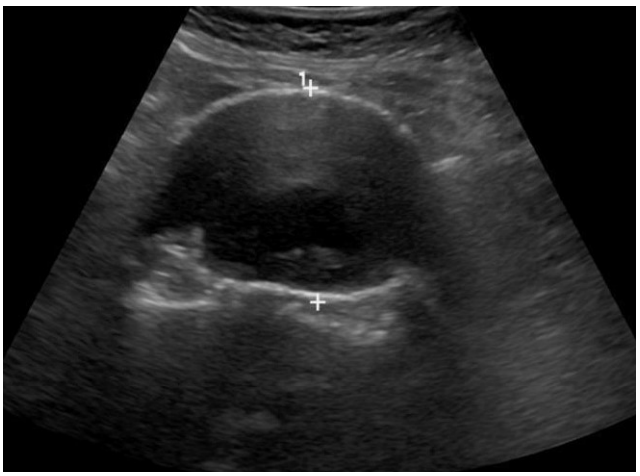

Figure 2 A transverse view of an AAA using ultrasound, with a thrombus present on the posterior wall. The central lumen measures 16mm in diameter, but the aneurysm is actually 54mm

Furthermore, image quality also poses problems when measuring AAAs. A high Body Mass Index (BMI) and/or the presence of bowel gas creates difficulty for the operator when visualising the aorta as the excess tissue and gas attenuate the sound waves from the transducer, reducing contrast and thereby distorting the image. This factor is reduced when using CT, as X-rays are used instead of sound waves to produce the image.

The equipment used when performing ultrasound can also affect the quality of the image produced. Ultrasound transducers used for medical purposes have frequencies between 2-15MHz,[27] which are selected and used for different purposes. Low frequencies are required to penetrate deeper into bodily tissues as the wavelengths are longer, making them suitable for reaching the aorta. However, these types of transducers result in a lower resolution and present difficulties with reduced contrast and a more distorted image. Higher frequency devices, on the other hand, produce more detailed and clear images as the resolution is increased; however, the shorter wavelengths are not as penetrable. For AAA detection a compromise is made so that the aorta is penetrable but the image is still clear enough to visualise aneurysms. CT is accurate in viewing the 'neck length and diameter, neck shape,

iliac vessels, as well as providing diagnostic confirmation of an AAA',[28] making it very suitable for visualising AAAs before surgery.[21]

CONCLUSION

Ultrasound and CT are useful modalities in producing images of aneurysms that can be effectively clinically interpreted. However, they both have strengths and weaknesses. Ultrasound is more operator dependent than CT,[19] and therefore affected by inter- and intra-observer error to a greater extent, which can create problems by decreasing accuracy.

Reducing the number of operators who scan the same patient during the screening process and implementing an improved operator training programme may help to reduce this variation in the future. CT is deemed to be less safe than ultrasound, due to the radiation that is used to produce the image, and the side effects caused by the contrast that is required to improve the image quality. However, it is very useful as a pre-operative tool.[21] In addition, ultrasound is more representative of the UK National Screening Criteria, being simple and safe to perform as well as accurate. Overall, ultrasound is an excellent imaging modality for AAA screening as it is safer and more practical than CT to use periodically. However, CT is more appropriate for pre-operative screening as it can produce clearer contrasted images to determine more exact anatomy for AAA repair surgery.[10]

Technological advances could possibly provide the NHS with an even more effective imaging technique in the future, but currently ultrasound is the most suitable option for the screening of abdominal aortic aneurysms.

CT *vs* ultrasound	
CT	**Ultrasound**
Can only view in the axial plane – multiplanar reconstructions reduce accuracy	Sagittal and transverse planes can be used
Ionising radiation and intravenous contrast can cause adverse effects	Deemed safe and suitable for repeated use
Can be time consuming	Time efficient
Images are more reproducible	Results are operator dependent – affected by inter-observer error
Good contrast provides detailed visualisation of structures – suitable for pre-operative investigations	Visualisation is distorted by bowel gas and excess tissue
Overall, ultrasound is more representative of the UK National Screening Committee criteria	

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APPENDIX

UK National Screening Committee Screening Criteria[5]

Criteria for appraising the viability, effectiveness and appropriateness of a screening programme
[This information was originally developed by the UK National Screening Committee (www.screening.nhs.uk) and is used under the Open Government Licence v1.0.]

Ideally all the following criteria should be met before screening for a condition is initiated:

The condition

1. The condition should be an important health problem.
2. The epidemiology and natural history of the condition, including development from latent to declared disease, should be adequately understood and there should be a detectable risk factor, disease marker, latent period or early symptomatic stage.
3. All the cost-effective primary prevention interventions should have been implemented as far as practicable.
4. If the carriers of a mutation are identified as a result of screening the natural history of people with this status should be understood, including the psychological implications.

The test

5. There should be a simple, safe, precise and validated screening test.
6. The distribution of test values in the target population should be known and a suitable cut-off level defined and agreed.
7. The test should be acceptable to the population.
8. There should be an agreed policy on the further diagnostic investigation of individuals with a positive test result and on the choices available to those individuals.
9. If the test is for mutations the criteria used to select the subset of mutations to be covered by screening, if all possible mutations are not being tested, should be clearly set out.

The treatment

10. There should be an effective treatment or intervention for patients identified through early detection, with evidence of early treatment leading to better outcomes than late treatment.
11. There should be agreed evidence-based policies covering which individuals should be offered treatment and the appropriate treatment to be offered.
12. Clinical management of the condition and patient outcomes should be optimised in all healthcare providers prior to participation in a screening programme.

The screening programme

13. There should be evidence from high-quality Randomised Controlled Trials that the screening programme is effective in reducing mortality or morbidity. Where screening is aimed solely at providing information to allow the person being screened to make an 'informed choice' (eg Down's syndrome, cystic fibrosis carrier screening), there must be evidence from high-quality trials that the test accurately measures risk. The information that is provided about the test and its outcome must be of value and readily understood by the individual being screened.
14. There should be evidence that the complete screening programme (test, diagnostic procedures, treatment/intervention) is clinically, socially and ethically acceptable to health professionals and the public.
15. The benefit from the screening programme should outweigh the physical and psychological harm (caused by the test, diagnostic procedures and treatment).
16. The opportunity cost of the screening programme (including testing, diagnosis and treatment, administration, training and quality assurance) should be economically balanced in relation to expenditure on medical care as a whole (ie value for money). Assessment against this criteria should have regard to evidence from cost benefit and/or cost-effectiveness analyses and have regard to the effective use of available resource.
17. All other options for managing the condition should have been considered (eg improving treatment, providing other services), to ensure that no more cost-effective intervention could be introduced or current interventions increased within the resources available.
18. There should be a plan for managing and monitoring the screening programme and an agreed set of quality assurance standards.
19. Adequate staffing and facilities for testing, diagnosis, treatment and programme management should be available prior to the commencement of the screening programme.
20. Evidence-based information, explaining the consequences of testing, investigation and treatment, should be made available to potential participants to assist them in making an informed choice.
21. Public pressure for widening the eligibility criteria for reducing the screening interval, and for increasing the sensitivity of the testing process, should be anticipated. Decisions about these parameters should be scientifically justifiable to the public.
22. If screening is for a mutation the programme should be acceptable to people identified as carriers and to other family members.