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Review

Measuring the Maximum Diameter of Native Abdominal Aortic Aneurysms: Review and Critical Analysis CME

A. Long [a,*], L. Rouet [b], J.S. Lindholt [c], E. Allaire [d,e]

[a] Vascular Medicine, Centre Hospitalier Universitaire de Reims, Reims, France
[b] MediSys Research Lab, Philips Healthcare, Suresnes, France
[c] Vascular Research Unit, Viborg Hospital, Viborg, Denmark
[d] Vascular Surgery Department, Centre Hospitalier Universitaire Henri Mondor, Assistance Publique – Hôpitaux de Paris, Créteil, France
[e] Vascular Surgery Department, CNRS EAC 7054, UFR de Médecine, Université Paris Est-Créteil (U-PEC) Créteil, France

WHAT THIS PAPER ADDS

- Maximum diameter is a determinant parameter for the clinical management of abdominal aortic aneurysm (AAA). Nevertheless, a review of the literature reflects a wide range of definitions and practices, with either ultrasound (US) or computed tomography (CT).
- This article identifies three steps in the decision-making process for maximum AAA diameter measurement (imaging plane, slice selection with maximum diameter and measurement itself) influencing the results.
- Since the diversity of methods impacts patient care and clinical research, harmonisation is required. Until such a consensus can be reached, publications should clearly report the method of measurement.

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ABSTRACT

Objectives: Maximum diameter is a determinant parameter for the clinical management of asymptomatic abdominal aortic aneurysm (AAA). However, its measurement is not standardised. We review the different methods used to measure AAA maximum diameter, with ultrasound (US) or computed tomography (CT).
Methods: A review of maximum diameter measurement methods with US and CT was performed, focussing on screening, surveillance before repair and decision for intervention. Diameter measurement methodology was described according to four parameters: plane of acquisition, axis of measurement, position of callipers and selected diameter. A quality score to evaluate methodology descriptions was defined (plane, axis, callipers placement and selected diameter), ranging from 0 (worst) to 4 (best).
Results: Review showed a wide range of definitions and practices. The mean value of the quality score was 2.52 in screening studies, 1.66 in guidelines for screening, 2.81 in follow-up studies and 1.63 in studies describing decision for intervention.
Conclusion: To improve the efficiency of AAA management (in screening programmes, follow-up and decision for intervention), and enable comparison between future studies, a standardised methodology for AAA maximum diameter measurement is necessary. Until such a consensus is reached, publications should at least clearly report the method of measurement.

Maximum diameter is an important parameter in the definition of abdominal aortic aneurysm (AAA) and is also used to predict the risk of rupture of AAA. Therefore, it is the most commonly used quantitative criterion for screening, surveillance and decision for intervention. Thus, one would expect its definition and the methodology for its measurement to be clearly defined. However, its evaluation depends on multiple factors. Among these, imaging

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* Corresponding author. Anne Long, Médecine Vasculaire, Centre Hospitalier Universitaire de Reims, Hôpital Robert Debré, Rue du Professeur Kochman, 51092 Reims Cedex, France. Tel.: +33 3 26 78 94 12; fax: +33 3 26 78 46 75.
E-mail addresses: along@chu-reims.fr, anne.long@wanadoo.fr (A. Long).

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modalities, selection of the aortic section and the actual definition of measurement used influence the values reported.

Ultrasound (US) is the reference imaging technique for screening[1,2] and is used for regular monitoring of small AAA. Computed tomography (CT) is the reference technique in the decision-making process for intervention.

We performed a review of diameter measurement protocols with CT and US, and evaluated the description of the methodology according to four criteria (plane of acquisition, axis of measurement, calliper placement and diameter selection). Analysis of the results was used to identify the main causes for the diversity of measurement methods and to search criteria for choice. Finally, the clinical implications for patient care and perspectives are presented.

Methods

Literature search

We focussed our literature search on three situations: AAA screening in community-based programmes, evaluation of native AAA growth rate and decision-making for intervention.

A total of 23 screening studies from 29 published articles were retained for analysis.[3–31]

The guidelines section for screening was derived from the systematic review performed by Ferket[32] and comprised nine guidelines from 10 publications.[1,2,5,33–39]

The growth rate section was derived from the review performed by Powell[40] and comprised 16 studies from 24 articles.[18,19,25,28,29,41–59]

The decision for treatment section comprised eight studies from 11 articles.[42,45,46,60–67]

Details of the search term used to identify suitable articles are available as supplementary data in the electronic version.

Literature analysis

The process of measurement in clinical practice is based on four steps: plane of acquisition, axis of measurement, calliper placement and selection of the maximum diameter. For each step described, a score of 1 point was attributed. The quality score reflects the quality of the description of the method used for measurement.

Table 1
Measurement protocols of maximum AAA diameter in screening studies (23 studies, 29 articles). The imaging modality used is ultrasound. The mean score is 2.52.

Author	Study/Country	Plane of acquisition	Axis of measurement	Position of callipers	Selected diameter	Score
Conway[5]	UK NHS AAA Screening Programme, UK	Axial	Anteroposterior Transverse	Internal	Largest of the maximum diameters	4
Svensjö[6]	Middle Sweden	Longitudinal	Anteroposterior	Leading edge to leading edge	Maximum	4
Lindholt[7,8]	Viborg Study, Denmark	Axial (=transverse)	Anteroposterior Transverse	Not specified	Maximum anteroposterior	3
Palombo[9]	Screening Abdominal aortic aneurysm Genoa, Italy	Longitudinal Transverse	Anteroposterior Transverse	Not specified	Mean value of maximum diameters measured 3 times by two examiners	3
DeRubertis[10]	United States	Longitudinal Transverse	Not specified	Not specified	Largest diameter	2
Ballard[11]	USA	Not specified	Not specified	Not specified	Not specified	0
Laws[12]	UK	Longitudinal Transverse	Anteroposterior	Not specified	Largest diameter	3
Morris-Stiff[13]	UK	Not specified	Anteroposterior Transverse	Not specified	Largest of the maximum diameters	2
Norman[14] Nicholls[15]	West Australian Aneurysm Screening Study	Not specified	Anteroposterior Transverse	Not specified	Maximum in each axis. Choice not specified	2
Puech-Leão[16]	Brazil	Not specified	Not specified	Not specified	Maximum	1
Ashton[17]	Multicentre Aneurysm Screening Study (MASS), UK	Longitudinal Transverse	Anteroposterior Transverse	Not specified	Largest of the maximum diameters	3
Wilmink[18,19]	Huntington	Not specified	Anteroposterior	External	Maximum	3
Kyriakides[20]	UK	Transverse	Anteroposterior Transverse	Not specified	Largest of the maximum diameter in either axis	3
Ishikawa[21]	Japan	Not specified	Not specified	Not specified	Not specified	0
Boll[22]	The Netherlands	Not specified	Anteroposterior Transverse	Not specified	Maximum Choice between axis not specified	2
Vazquez[23]	Belgium	Not specified	Anteroposterior Transverse	External	Maximal external Anteroposterior	3
Scott[24,25]	Chichester Study	Longitudinal Transverse	Anteroposterior Transverse	Not specified	Largest of the maximum diameter in either axis	3
Grimshaw[26]	Community Aortic Screening Trial, Birmingham, UK	Transverse perpendicular to the aorta long axis	Anteroposterior	Not specified	Maximum	3
Holdsworth[27]	UK	Not specified	Not specified	Not specified	Maximum	1
Lucarotti[28] O'Kelly[29]	Gloucestershire Aneurysm Screening Programme, UK	Longitudinal Transverse	Anteroposterior	Outer margin of the anterior wall to inner margin of the posterior wall	Maximum in the longitudinal plane	4
Krohn[30]	Norway	Not specified	Anteroposterior	Not specified	Maximum anteroposterior	2
Collin[31]	Oxford, UK	Not specified	Anteroposterior	External	Maximum external	3
Lederle[3,4]	Aneurysm Detection and Management study	Longitudinal Transverse	Any direction	External	Maximum external diameter in any direction at the widest point of any dilation	4

Abbreviation : AAA, abdominal aortic aneurysm.

Table 2
Recommendations for AAA diameter measurement available in guidelines for screening (9 guidelines, 10 articles). The imaging modality used is ultrasound. The mean score is 1.66.

Authors	Country	Plane of acquisition	Axis of measurement	Position of calliper	Selected diameter	Score
U.S. Preventive Services Task Force[33, a]	USA	No specified	No specified	Not specified	No specified	0
Hirsch[34, a]	USA	Perpendicular to the arterial axis	Anteroposterior	Not specified	Maximum diameter	3
NHS AAA Screening Programme[35, a] Conway[5]	UK	Axial	Transverse Anteroposterior	Internal	Largest of the maximum internal diameter	4
Mastracci[36, a]	Canada	Not specified	Not specified	Not specified	Not specified	0
Abramson[37, a]	Canada	Not specified	Not specified	Not specified	Not specified	0
Chaikof[38, a]	USA	Not specified	No specified	No specified	No specified	0
Kent[39, a]	USA	Not specified	Not specified	Not specified	No specified	0
Moll[1]	Europe	Perpendicular to the longitudinal axis of the aorta (angle the probe if necessary).	Anteroposterior	External	Maximum diameter	4
Becker[2]	France	Perpendicular to the longitudinal axis of the aorta, on the most circular section	Anteroposterior	External	Maximum diameter as the mean of at least three measures	4

[a] From the systematic review of guidelines on abdominal aortic aneurysm screening by Ferket.[32]

Table 3
Measurement protocols of maximum AAA diameter for growth rate evaluation during follow-up before intervention. (16 studies, 24 articles). The mean score is 2.81.

Author	Study	Imaging modality	Plane of acquisition	Axis of measurement	Position of callipers	Selected diameter	Score
Brady[41] + Ellis[42]	UK Small Aneurysm Trial	US	Not specified	Anteroposterior	External	Maximum external	3
Brown[43]	The Kingston study, Canada	US or CT	Not specified	Not specified	Not specified	Not specified	0
Karlson[44]	Sweden and Canada	US	Longitudinal Transverse	Anteroposterior	Not specified	Widest anteroposterior diameter	3
Lederle[45,46]	ADAM Study, USA	US	Longitudinal Transverse	Any direction	External	Maximum external in any direction	4
		CT[a]	Cross section Perpendicular to the direction of tortuosity if the AAA is tortuous	Any direction	External	Maximum external in any direction	
Lindholt[47]	Viborg, Denmark	US	Not specified	Anteroposterior Transverse	Not specified	Largest of the maximum diameters	2
McCarthy[48] Lucarotti[28] O'Kelly[29]	Gloucestershire Aneurysm Screening Programme, UK	US	Longitudinal Transverse	Anteroposterior	Outer margin of the anterior wall to inner margin of the posterior wall	Maximum	4
Propranolol Aneurysm Trial Investigators[49]	Canada	US	Not specified	Anteroposterior	External	Maximum	3
Santilli[50]	Aneurysm Detection Management Trial, USA	US	Longitudinal Transverse	Any direction	Not specified	Widest point of any dilation in both planes	3
Schewe[51]	Germany	US	Not specified	Anteroposterior Transverse	Not specified	Mean of both diameters	2
Schlösser[52]	SMART Study, The Netherlands	US	Not specified	Anteroposterior	Not specified	Maximum	2
Schouten[53]	The Netherlands	US	Not specified	Anteroposterior	Not specified	Maximum	2
Solberg[54] Singh[55,56]	The Tromso Study, Norway	US	Transverse with scans perpendicular to the longitudinal plane	Anteroposterior Transverse	External	Maximum external diameter in either plane in systole	4
Vardulaki[57] Wilmink[18,19]	Huntingdon	US	Not specified	Anteroposterior	External	Maximum External	3
Vardulaki[57] Scott[25]	Chichester	US	Longitudinal Transverse	Anteroposterior Transverse	Not specified	Largest of the maximum diameter in either axis	3
Vega de Ceniga[58]		US[b] CT[c]	Not specified	Transverse and Anteroposterior	External	Maximum external in each axis (choice not specified)	3
Vega de Ceniga[59]		CT[c]	Perpendicular to the aortic axis	Transverse and Anteroposterior	External	Maximum external in each axis (choice not specified)	4

Abbreviations : AAA, abdominal aortic aneurysm; US : ultrasound, CT : computed tomography.
[a] For AAA 5.3 cm or larger.
[b] For AAA between 3 and 3.9 cm.
[c] For AAA between 4 and 4.9 cm.

Table 4
Measurement protocols of maximum AAA diameter in decision-making for intervention (8 studies, 11 articles). The mean score is 1.625.

Authors	Study/Country	Imaging modality	Plane for acquisition	Axis for measurement	Position for callipers	Selected diameter	Score
Lederle[45,46]	Aneurysm Detection and management Study, USA	CT	Cross-sectional perpendicular to the direction of the AAA tortuosity when appropriate	Any direction	External	Maximum external cross-sectional diameter in any direction	4
UK Small Aneurysm Trial participants[60,61] Ellis[42]	UK Small Aneurysm Trial	US	Not specified	Anteroposterior	External	Maximum external anteroposterior diameter	3
Becquemin[62]	ACE, France	CT	Not specified	Not specified	Not specified	Not specified	0
Ouriel[63]	PIVOTAL, USA	CT	No specified	No specified	No specified	No specified	0
Lederle[64]	OVER	Not specified	Not specified	Not specified	External	Maximum external diameter	2
Cao[65]	CEASAR, Italy	CT	cross-sectional perpendicular to the vessel axis	Any direction	External	Maximum external cross-sectional diameter	4
Brown[66]	EVAR, UK	CT	Not specified	Not specified	Not specified	Not specified	0
Prinssen[67]	DREAM, The Netherlands	Not specified	Not specified	Not specified	Not specified	Not specified	0

Abbreviations as in Table 2.

This quality in any given study could range from 0 (no description) to 4 (all steps correctly described).

Results

Tables 1–4 report the different methods used for the measurement of maximum AAA diameter for screening, including guidelines for screening, in monitoring growth rates before intervention and in the decision-making process for intervention.

The mean quality score was 2.52 in screening studies, 1.66 in guidelines for screening, 2.81 in follow-up studies and 1.63 in studies describing decision for intervention.

Among the 56 studies, 32 (57%) provided an almost complete (score 3) or a complete (score 4) description of the method.

Discussion

This review highlights the diversity of methods used to measure maximum AAA diameter by CT and US in clinical situations such as screening, follow-up and decision for intervention. Even in available guidelines, there is no consensus. The second important finding is that only 32/56 studies (57%) provide a complete or almost complete description of the method used.

Explanation for diversity of measurement methods used

Diameter measurement results from successive decisions: the choice of the imaging plane, the visual selection of the aortic section presenting the maximum diameter and the actual procedure for diameter measurement, including the choice of the axis and the positioning of the callipers. The diversity observed between studies arises from numerous variations in the manner of combining the above decisions.

AAA imaging plane

Two spatial references may be used to visualise AAA:

– the 'anatomical' (*absolute*) reference defined by three planes (sagittal, axial or transverse, coronal or frontal) and three axes (sagittal or anteroposterior, transverse or left-right, longitudinal or cranio-caudal) and
– the 'aortic' (*relative*) reference defined by the longitudinal axis of the abdominal aorta, also named centreline (Fig. 1).

US imaging may be aligned with the 'anatomical' reference: AAA scanning may be performed according to the axial and sagittal planes. However, some guidelines favour the 'aortic reference',[1] specifying that measurements should be made perpendicular to the centreline. This requires the operator to angle the probe from the strict anatomical plane.

CT equipment is aligned with the 'anatomical reference'. AAA sections obtained from native planes (axial plane) and orthogonal multiplanar reconstructions (MPRs) (coronal and sagittal planes) refer to the 'anatomical reference'. Curved MPRs, aligned to the AAA centreline, generate planes based on the 'aortic reference'.

For both modalities, in tortuous AAAs, the anatomical and aortic references may differ.

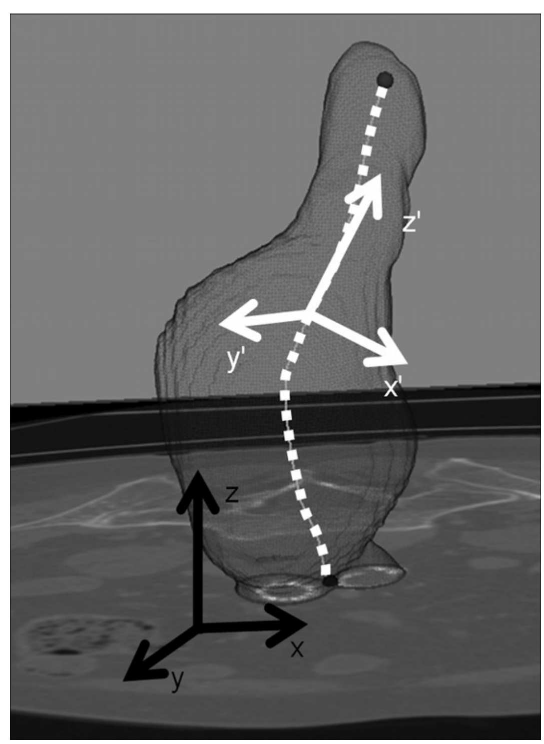

Figure 1. Aortic and anatomical references. Black: anatomical reference. White: aortic reference. White dashed line: AAA centreline.

Visual selection of aorta section with CT and US

After selection of the imaging plane, the section of AAA presenting the maximum diameter is visually estimated. US acquisitions provide sections visually selected by the operator at the time of scanning. CT acquisitions provide a volume in which the clinician can navigate in either native or MPR planes, allowing for delayed selection.

With US, the image of the aortic section of interest may be frozen during systole or diastole.[68]

Diameter measurement

Diameter measurement is performed along a pre-defined axis on the selected aortic section by positioning two callipers.

With US imaging, the choice of the axis differs according to the spatial reference and the planes. Using the anatomical reference (Fig. 2):

– in the axial plane, anteroposterior and transverse diameters are respectively measured according to the sagittal and transverse axes (Fig. 2a); maximum diameter in any direction may also be measured (Fig. 2b).
– in the sagittal plane, only the anteroposterior diameter is measured according to the sagittal axis (Fig. 2e); maximum anteroposterior perpendicular to the centreline may also be measured (Fig. 2f).

In the aortic reference (Fig. 2), the probe is angled perpendicular to the centreline to obtain the most circular section of the AAA or is aligned to the longitudinal aortic axis. The so-called anteroposterior and transverse diameters and maximum diameter in any direction are measured (Fig. 2c and d). When the AAA is tortuous or asymmetric, the so-called anteroposterior and transverse diameters are in fact measured according to other axes than in the anatomical reference.

With CT imaging, the choice of the axis differs according to planes (Fig. 3):

– On the native axial slices, possible measurements include anteroposterior and transverse diameters, maximum diameter in any direction and its perpendicular diameter.
– After orthogonal MPR reconstruction, the coronal view provides the maximum transverse diameter and the sagittal view provides the maximum anteroposterior diameter. In both cases, the axis of measurement may be strictly transverse or anteroposterior or perpendicular to the centreline.
– Curved MPR provides the maximum diameter perpendicular to the estimated centreline and the definition of the anteroposterior and transverse directions becomes relative.

Calliper position is mainly discussed for US, and the position chosen depends on the imaging resolution of AAA walls. In the

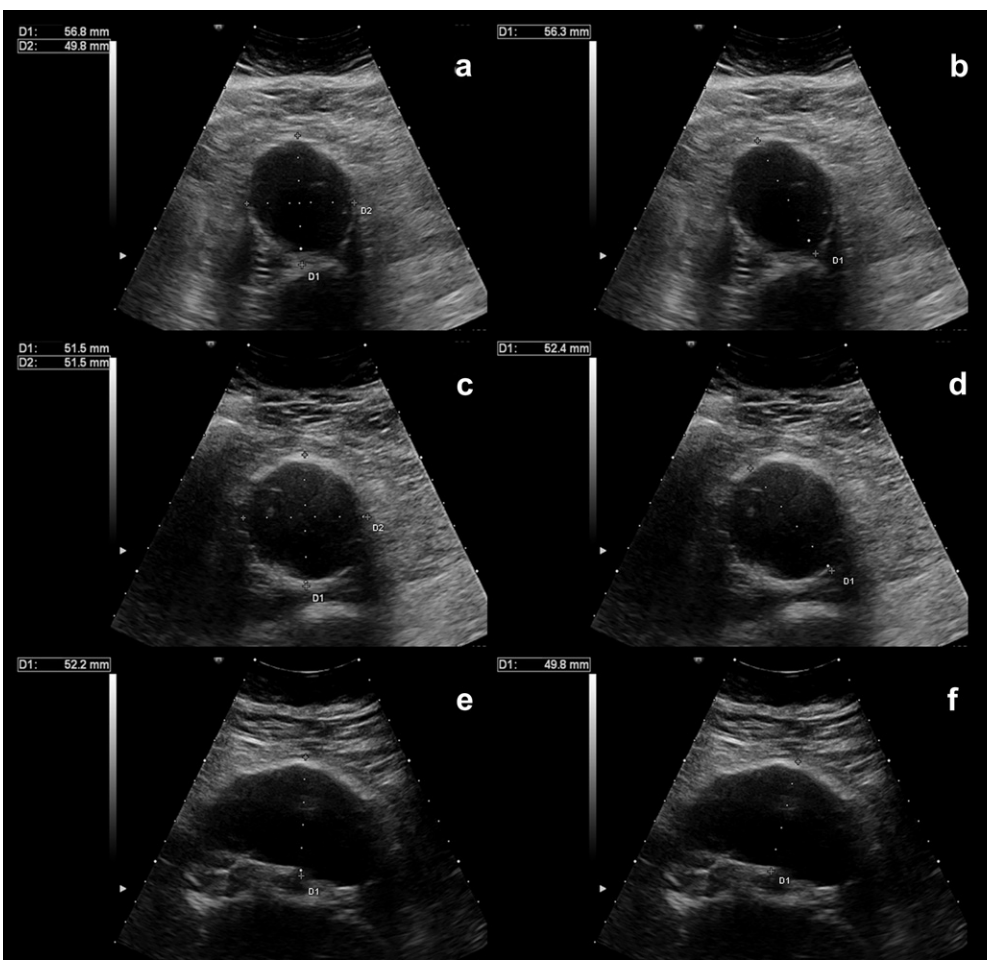

Figure 2. External diameter measurements on US views for the same patient. a) Axial plane; D1: anteroposterior diameter; D2 : transverse diameter. b) Axial plane; D1: maximum diameter in any direction. c) Axial plane perpendicular to the blood flow; D1: anteroposterior diameter; D2: transverse diameter. d) Axial plane perpendicular to the blood flow; D1: maximum diameter in any direction. e) Sagittal plane; D1: anteroposterior diameter. f) Sagittal plane; D1: maximum diameter perpendicular to the centreline.

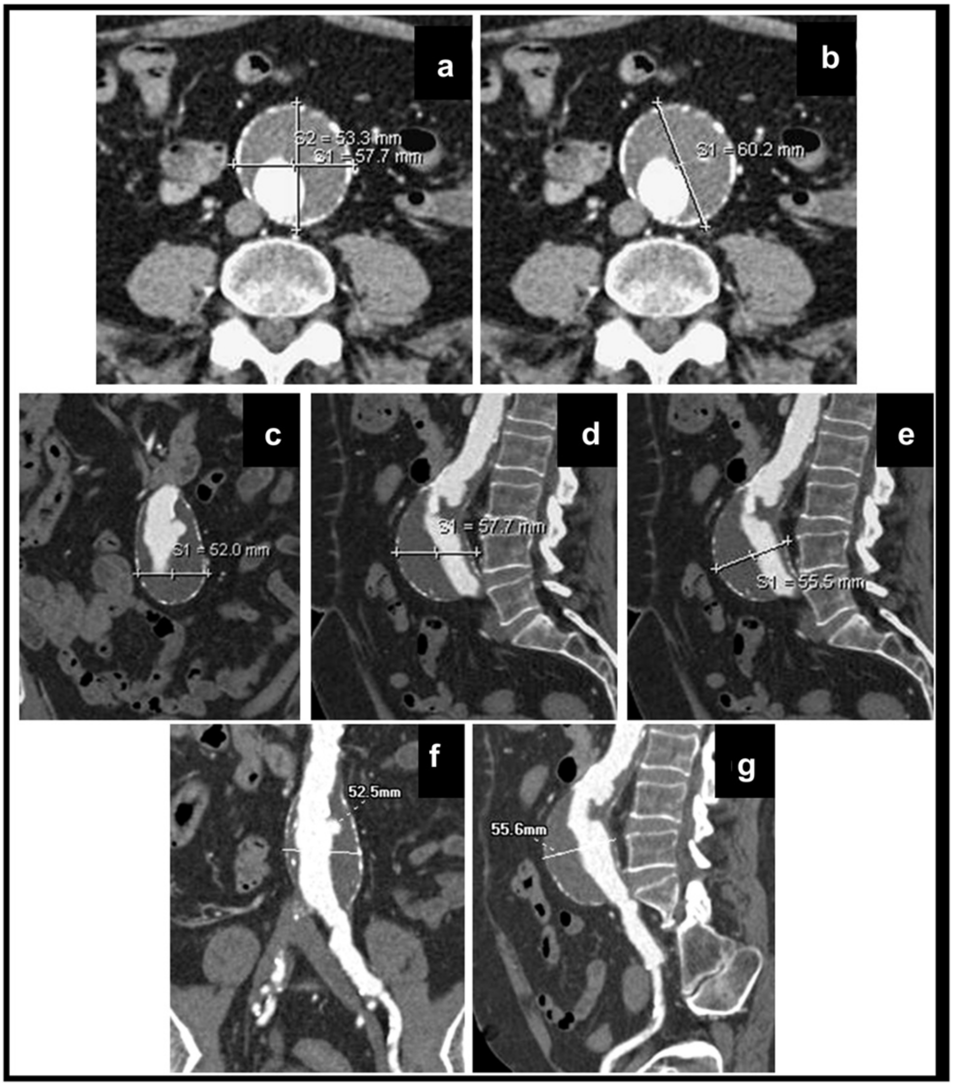

Figure 3. Diameter measurements on CT views for the same patient as in Fig. 2. a) Axial plane; S1 : anteroposterior diameter; S2 : transverse diameter. b) Axial plane; S1 : maximum diameter in any direction. c) Coronal plane; S1 : transverse diameter. d) Sagittal plane; S1: anteroposterior diameter. e) Sagittal plane; S1: maximum diameter perpendicular to the centreline. f) Curved MPR; maximum diameter perpendicular to the centreline. g) Curved MPR; maximum diameter perpendicular to the centreline.

anteroposterior axis, the possibilities are external–external, internal–internal, external–internal and middle-wall. In the transverse axis, the lateral resolution is poor. Internal diameters are reportedly smaller than external diameters by 2–7 mm,[1,69,70] and the choice between internal and external diameters remains debated.[1]

Fig. 4 shows the possible combinations of plane, axis and calliper position for the measurement of maximum AAA diameter. Table 5 provides maximum diameter values obtained in the same patient, using US and CT, according to measurement protocols used in the literature. The mean (standard deviation) diameter is 54.05 (3.1) mm.

Maximum diameter selection

The final step in the measurement process is to define which value will be selected to quantify the maximum diameter. In most studies, more than one diameter was measured, and the diameter chosen to be retained as the maximum could be either the highest value obtained, an average of several measures or the diameter obtained in a pre-defined axis, most often the anteroposterior axis.

Criteria for choice

It is difficult to decide which method is the most appropriate. One criterion could be the measure with the best reproducibility within each technique, and the best agreement between US and CT.

US/US reproducibility

In the review by Beales,[71] the intraobserver coefficients of repeatability for the anteroposterior and transverse diameters ranged from 1.6 to 7.5 mm and from 2.8 to 15.4 mm, respectively. The interobserver reproducibility was evaluated by the limits of agreement (LOA) which ranged from −1.9 to + 1.9 mm and from −10.5 to +10.4 mm for the anteroposterior diameter. The largest LOA for the transverse diameter was −5.6 to +5.2 mm. The authors did not conclude on the superiority of one diameter. Other authors[42,72,73] advocated the superiority of the anteroposterior diameter measured on the true longitudinal plane perpendicular to the centreline, rather than in the axial plane.[73]

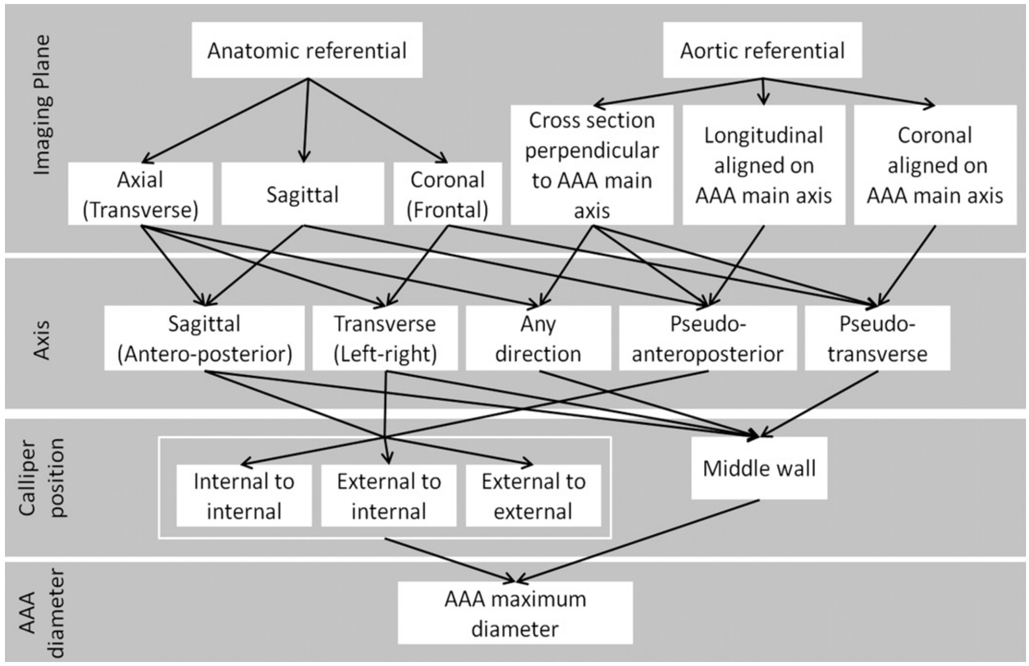

Figure 4. Combination between imaging plane, axis, calliper positions leading to the AAA maximum diameter measurement possibilities.

The calliper positions may impact reproducibility. However, it is unclear whether the external diameter displays less[70] or more variability.[69]

When guidelines specified an axis of measurement (Table 2), three out of four recommended measuring the anteroposterior diameter, due to the superior axial resolution of the probe and the difficulty of identifying the lateral AAA walls in the axial plane. However, selecting the anteroposterior diameter may be inaccurate when AAAs have an elliptic cross section with a larger transverse diameter.[74]

CT/CT reproducibility

Reproducibility evaluates agreement between multiple analyses of a single acquisition. Interobserver variability of maximum external AAA diameter in any direction was 2 mm or less in 65% of pairs, but 17% differed by at least 5 mm for Lederle.[75] Interobserver variability of maximum anteroposterior and transverse diameters measured on native axial slices was less than 5 mm in 91% and 85% of pairs, respectively, for Jaakkola.[76]

Guidelines recommended measuring the maximum diameter in the transverse axis, but the planes of measurement were not specified.[34]

Table 5
Maximum diameters measured in the same patient according to methods used in the literature.

Imaging modality	Figure	Plane	External diameter definition	Value (mm)
Ultrasound	3a	Axial	Anteroposterior	56.8
			Transverse	49.8
	3b	Axial	Maximum	56.3
	3c	Axial	Anteroposterior	51.5
		Perpendicular to the blood flow	Transverse	51.5
	3d	Axial Perpendicular to the blood flow	Maximum	52.4
	3e	Sagittal	Anteroposterior	52.2
	3f	Sagittal	Perpendicular to the centreline	49.8
CT	4a	Axial	Anteroposterior	57.7
			Transverse	53.3
	4b	Axial	Maximum	60.2
	4c	Coronal	Transverse	52
	4d	Sagittal	Anteroposterior	57.7
	4e	Sagittal	Perpendicular to the centreline	55.5
	4f	Curved MPR	Perpendicular to the centreline	52.5
	4g	Curved MPR	Perpendicular to the centreline	55.6

US/CT comparison

Since patients may undergo successive explorations with both US and CT, the correspondence between diameter measurements should be documented and validated for clinical practice. In some reports, measurements with CT provided higher values than US in native AAA.[75–78] Foo[78] showed a statistically significant underestimation of US AAA size by 2.1 ± 3.9 mm. Other studies reported larger maximum diameter with US than with CT.[42,79]

US and CT diameters identified to provide the best agreement might differ from one study to another.[42,77,80] When the best agreement between measures was evaluated according to the clinically acceptable difference,[76] defined as the proportion of differences less than 5 mm, agreement was higher for the anteroposterior diameter than for the transverse diameter (74% vs. 56%, 76 vs. 77% and 86 vs. 77%).[76,79,81]

These results do not make it possible to reach a consensus on the best method of measurement. The anteroposterior diameter seems to be the preferred choice. Reproducibility may be better when the anteroposterior diameter is measured on the true longitudinal plane, perpendicular to the centreline, rather than in the axial plane.[73]

Consequences of the diversity in AAA measurement methods on patient care

The diversity in AAA measurement methods may interfere with patient care.

Screening

In screening studies, the diagnosis of AAA is mainly based on a maximum AAA diameter ≥30 mm. The lack of harmonised measurement may lead to some patients being misclassified.

For instance, since the internal diameter can be 2–5 mm smaller than the external diameter, its use would exclude a diagnosis of AAA in patients who might otherwise have had regular US surveillance. In the recent European guidelines, Moll[1] underlined the importance of resolving such issues.

Follow-up and growth rate

AAA growth rate is derived from reproducibility studies[42,73,82,83] in which US or CT measurements were performed in the best possible conditions. However, if patients are followed up in different centres using different equipment, and different methods for measurement, as is the case in real-life clinical practice, then the threshold between reproducibility and true growth rate is unknown.

Furthermore, in the review by Powell,[40] the mean growth rate was 2.32 mm year^{-1}, ranging from 1.81 for AAA between 30 and 34 mm to 4.96 for AAA between 45 and 49 mm. These values are within the range of measurement reproducibility. Such results may preclude answering the main question, namely is this patient's AAA really growing or are the results due to intraobserver, interobserver or intertechnique variability?[81]

In another review by Powell[84] focussing on rupture rates of small AAA, one reason put forward to explain the heterogeneity of results was the method used for AAA sizing.

Indication for intervention

Intervention is proposed when AAA diameter reaches 55 mm in men and 45–50 mm in women, or when AAA growth rate is too fast (more than 10 mm year^{-1}). However, intervention may also be indicated at smaller sizes (45–55 mm).[1,85] As underlined by Moll,[1] the MASS (Multicentre Aneurysm Screening Study) trial, which used the internal diameter for measurement, reported an increased rate of ruptures in screened patients after 8 years of follow-up, thus raising the question of the safety of the 30-mm and 55-mm thresholds.

Clinical illustration

In the case presented in Table 5, if the threshold for intervention was 55 mm, then:

- maximum AAA diameter with US in the sagittal plane perpendicular to the centreline is 49.8 mm, for which follow-up would be recommended (Fig. 2f).
- maximum AAA diameter with CT in the axial plane, anteroposterior axis, is 57.7 mm, for which intervention would be recommended (Fig. 3a).

The clinical impact has been underlined by Foo,[78] noting that 75% of patients requiring follow-up according to US would have been referred to surgery according to the CT results.

Conclusion and perspectives

AAA screening has been shown to improve AAA-related mortality[1] and national screening programmes are being implemented in several countries. When small AAAs are diagnosed, US follow-up is necessary and this requires reproducible methods for maximum diameter monitoring, growth rate evaluation and decision for intervention. To improve the efficiency of such programmes and enable future comparisons, the implementation of a common methodology for AAA measurement is necessary. Until such a consensus can be reached, publications should clearly report the method of measurement, including plane of imaging, axis of measurement, position of callipers and choice of the maximum diameter when different measurements are performed. In addition, it should be specified when during the cardiac cycle the measurement was taken.[68]

Future perspectives include the automatic selection of the maximum diameter using three-dimensional (3D) imaging[86] or even volume assessment with either CT or US. In addition to anatomical characterisations of an AAA, functional parameters for growth or rupture risk are emerging, such as peak wall stress measurements or the degree of inflammation of the aortic wall.[87–89]

Conflict of Interest

The authors have no conflict of interest to disclose.

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Appendix. Supplementary data

Supplementary data related to this article can be found online at doi:10.1016/j.ejvs.2012.01.018.

References

1 Moll FL, Powell JT, Fraedrich G, Verzini F, Haulon S, Waltham M, et al, Management of Abdominal Aortic Aneurysms. Clinical practice guidelines of the European Society for Vascular Surgery. *Eur J Vasc Endovasc Surg* 2011;**41**:S1–58.
2 Becker F, Baud JM, Groupe de Travail Ad Hoc. Dépistage des anévrysmes de l'aorte abdominale et surveillance des petits anévrysmes de l'aorte abdominale: argumentaire et recommandations de la Société Française de Médecine Vasculaire: rapport final. *J Mal Vasc* 2006;**31**:260–76.
3 Lederle FA, Johnson GR, Wilson SE, Chute EP, Hye RJ, Makaroun MS, et al. The aneurysm detection and management study screening program: validation cohort and final results. Aneurysm Detection and Management Veterans Affairs Cooperative Study Investigators. *Arch Intern Med* 2000;**160**:1425–30.
4 Lederle FA, Johnson GR, Wilson SE, Chute EP, Littooy FN, Bandyk D, et al. Prevalence and associations of abdominal aortic aneurysm detected through screening. Aneurysm Detection and Management (ADAM) Veterans Affairs Cooperative Study Group. *Ann Intern Med* 1997;**126**:441–9.
5 Conway AM, Malkawi AH, Hinchliffe RJ, Holt PJ, Murray S, Thompson MM, et al. First-year results of a national abdominal aortic aneurysm screening programme in a single centre. *Br J Surg* 2012;**99**:73–7.
6 Svensjö S, Björck M, Gürtelschmid M, Djavani Gidlund K, Hellberg A, Wanhainen A. Low prevalence of abdominal aortic aneurysm among 65-year-old Swedish men indicates a change in the epidemiology of the disease. *Circulation* 2011;**124**:1118–23.
7 Lindholt JS, Sørensen J, Søgaard R, Henneberg EW. Long-term benefit and cost-effectiveness analysis of screening for abdominal aortic aneurysms from a randomized controlled trial. *Br J Surg* 2010;**97**:826–34.
8 Lindholt JS, Vammen S, Juul S, Henneberg EW, Fasting H. The validity of ultrasonographic scanning as screening method for abdominal aortic aneurysm. *Eur J Vasc Endovasc Surg* 1999;**17**:472–5.
9 Palombo D, Lucertini G, Pane B, Mazzei R, Spinella G, Brasesco PC. District-based abdominal aortic aneurysm screening in population aged 65 years and older. *J Cardiovasc Surg (Torino)* 2010;**51**:777–82.
10 DeRubertis BG, Trocciola SM, Ryer EJ, Pieracci FM, McKinsey JF, Faries PL, et al. Abdominal aortic aneurysm in women: prevalence, risk factors, and implications for screening. *J Vasc Surg* 2007;**46**:630–5.
11 Ballard JL, Mazeroll R, Weitzman R, Harward TR, Flanigan DP. Medical benefits of a peripheral vascular screening program. *Ann Vasc Surg* 2007;**21**:159–62.
12 Laws C, Eastman J. Screening for abdominal aortic aneurysm by general practitioners and practice-based ultrasonographers. *J Med Screen* 2006;**13**:160–1.
13 Morris-Stiff G, Haynes M, Ogunbiyi S, Townsend E, Shetty S, Winter RK, et al. Is assessment of popliteal artery diameter in patients undergoing screening for abdominal aortic aneurysms a worthwhile procedure. *Eur J Vasc Endovasc Surg* 2005;**30**:71–4.
14 Norman PE, Jamrozik K, Lawrence-Brown MM, Le MT, Spencer CA, Tuohy RJ, et al. Population based randomised controlled trial on impact of screening on mortality from abdominal aortic aneurysm. *Br Med J* 2004;**329**:1259–64.

15 Nicholls EA, Norman PE, Lawrence-Brown MMD, Goodman MA, Pedersen B. Screening for abdominal aortic aneurysms in Western Australia. *Aust N Z J Surg* 1992;**62**:858–61.
16 Puech-Leão P, Molnar LJ, Oliveira IR, Cerri GG. Prevalence of abdominal aortic aneurysms – a screening program in São Paulo, Brazil. *Sao Paulo Med J* 2004;**122**:158–60.
17 Ashton HA, Buxton MJ, Day NE, Kim LG, Marteau TM, Scott RA, et al, Multicentre Aneurysm Screening Study Group. The Multicentre Aneurysm Screening (MASS) into the effect of abdominal aortic aneurysm screening on mortality in men: a randomised controlled trial. *Lancet* 2002;**360**:1531–9.
18 Wilmink AB, Hubbard CS, Day NE, Quick CR. The incidence of small abdominal aortic aneurysms and the change in normal infrarenal aortic diameter: implications for screening. *Eur J Vasc Endovasc Surg* 2001;**21**:165–70.
19 Wilmink AB, Hubbard CS, Quick CR. Quality of the measurement of the infrarenal aortic diameter by ultrasound. *J Med Screen* 1997;**4**:49–53.
20 Kyriakides C, Byrne J, Green S, Hulton NR. Screening of abdominal aortic aneurysm: a pragmatic approach. *Ann R Coll Surg Engl* 2000;**82**:59–63.
21 Ishikawa S, Takahashi T, Sakata K, Suzuki M, Kano M, Kawashima O, et al. Abdominal aortic dilatation in Japanese residents. *Int J Angiol* 1999;**8**:27–8.
22 Boll AP, Verbeek AL, van de Lisdonk EH, van der Vliet JA. High prevalence of abdominal aortic aneurysm in a primary care screening programme. *Br J Surg* 1998;**85**:1090–4.
23 Vazquez C, Sakalihasan N, D'Harcour JB, Limet R. Routine ultrasound screening for abdominal aortic aneurysm among 65- and 75-year-old men in a city of 200,000 inhabitants. *Ann Vasc Surg* 1998;**12**:544–9.
24 Scott RAP, Tisi PV, Ashton HA, Allen DR. Abdominal aortic aneurysm rupture rates: a 7-year follow-up of the entire abdominal aortic aneurysm population detected by screening. *J Vasc Surg* 1998;**28**:124–8.
25 Scott RAP, Ashton HA, Kay DN. Abdominal aortic aneurysm in 4237 screened patients: prevalence, development and management over 6 years. *Br J Surg* 1991;**78**:1122–5.
26 Grimshaw GM, Thompson JM. Changes in diameter of the abdominal aorta with age: an epidemiological study. *J Clin Ultrasound* 1997;**25**:7–13.
27 Holdsworth JD. Screening for abdominal aortic aneurysm in Northumberland. *Br J Surg* 1994;**81**:710–2.
28 Lucarotti M, Shaw E, Poskitt K, Heather B. The Gloucestershire Aneurysm Screening Programme: the first 2 years' experience. *Eur J Vasc Surg* 1993;**7**:397–401.
29 O'Kelly TJ, Heather BP. General practice-based population screening for abdominal aortic aneurysms: a pilot study. *Br J Surg* 1989;**76**:479–80.
30 Krohn CD, Kullmann G, Kvernebo K, Rosén L, Kroese A. Ultrasonographic screening for abdominal aortic aneurysm. *Eur J Surg* 1992;**158**:527–30.
31 Collin J, Araujo L, Walton J, Lindsell D. Oxford screening programme for abdominal aortic aneurysm in men aged 65 to 74 years. *Lancet* 1988;**2**:613–5.
32 Ferket BS, Grootenboer N, Colkesen EB, Visser JJ, van Sambeek MR, Spronk S, et al. Systematic review of guidelines on abdominal aortic aneurysm screening. *J Vasc Surg* 2011 Feb 14 [Epub ahead of print].
33 U.S. Preventive Services Task Force. Screening for abdominal aortic aneurysm: recommendation statement. *Ann Intern Med* 2005;**142**:198–202.
34 Hirsch AT, Haskal ZJ, Hertzer NR, Bakal CW, Creager MA, Halperin JL, et al. ACC/AHA 2005 practice guidelines for the management of patients with peripheral arterial disease (lower extremity, renal, mesenteric, and abdominal aortic). *Circulation* 2006;**113**:e463–654.
35 *Abdominal aortic aneurysm screening, in UK National Screening Committee Website* [accessed 26 10 11], http://www.screening.nhs.uk/; 2007, http://aaa.screening.nhs.uk/; 2007.
36 Mastracci TM, Cina CS, Canadian Society for Vascular Surgery. Screening for abdominal aortic aneurysm in Canada: review and position statement of the Canadian Society for Vascular Surgery. *J Vasc Surg* 2007;**45**:1268–76.
37 Abramson BL, Huckell V, Anand S, Forbes T, Gupta A, Harris K, et al. Canadian Cardiovascular Society Consensus Conference: peripheral arterial disease – executive summary. *Can J Cardiol* 2005;**21**:997–1006.
38 Chaikof EL, Brewster DC, Dalman RL, Makaroun MS, Illig KA, Sicard GA, et al. The care of patients with an abdominal aortic aneurysm: the Society for Vascular Surgery practice guidelines. *J Vasc Surg* 2009;**50**:S2–49.
39 Kent KC, Zwolak RM, Jaff MR, Hollenbeck ST, Thompson RW, Schermerhorn ML, et al. Screening for abdominal aortic aneurysm: a consensus statement. *J Vasc Surg* 2004;**39**:267–9.
40 Powell JT, Sweeting MJ, Brown LC, Gotensparre SM, Fowkes FG, Thompson SG. Systematic review and meta-analysis of growth rates of small abdominal aortic aneurysms. *Br J Surg* 2011;**98**:609–18.
41 Brady AR, Thompson SG, Fowkes FG, Greenhalgh RM, Powell JT, UK Small Aneurysm Trial Participants. Abdominal aortic aneurysm expansion: risk factors and time intervals for surveillance. *Circulation* 2004;**110**:16–21.
42 Ellis M, Powell JT, Greenhalgh RM. Limitations of ultrasonography in surveillance of small abdominal aortic aneurysms. *Br J Surg* 1991;**78**:614–6.
43 Brown PM, Sobolev B, Zelt DT. Selective management of abdominal aortic aneurysms smaller than 5.0 cm in a prospective sizing program with gender-specific analysis. *J Vasc Surg* 2003;**38**:762–5.
44 Karlsson L, Gnarpe J, Bergqvist D, Lindback J, Parsson H. The effect of azithromycin and *Chlamydophilia pneumonia* infection on expansion of small abdominal aortic aneurysms – a prospective randomized double-blind trial. *J Vasc Surg* 2009;**50**:23–9.
45 Lederle FA, Wilson SE, Johnson GR, Reinke DB, Littooy FN, Acher CW, et al, Aneurysm Detection and Management Veterans Affairs Cooperative Study Group. Immediate repair compared with surveillance of small abdominal aortic aneurysms. *N Engl JMed* 2002;**346**:1437–44.
46 Lederle FA, Wilson SE, Johnson GR, Littooy FN, Acher C, Messina LM, et al, for the ADAM VA Cooperative Study Group. Design of the abdominal aortic Aneurysm Detection and Management Study. *J Vasc Surg* 1994;**20**:296–303.
47 Lindholt JS, Vammen S, Juul S, Fasting H, Henneberg EW. Optimal interval screening and surveillance of abdominal aortic aneurysms. *Eur J Vasc Endovasc Surg* 2000;**20**:369–73.
48 McCarthy RJ, Shaw E, Whyman MR, Earnshaw JJ, Poskitt KR, Heather BP. Recommendations for screening intervals for small aortic aneurysms. *Br J Surg* 2003;**90**:821–6.
49 Propranolol Aneurysm Trial Investigators. Propranolol for small abdominal aortic aneurysms: results of a randomized trial. *J Vasc Surg* 2002;**35**:72–9.
50 Santilli SM, Littooy FN, Cambria RA, Rapp JH, Tretinyak AS, d'Audiffret AC, et al. Expansion rates and outcomes for the 3.0-cm to the 3.9-cm infrarenal abdominal aortic aneurysm. *J Vasc Surg* 2002;**35**:666–71.
51 Schewe CK, Schweikart HP, Hammel G, Spengel FA, Zollner N, Zoller WG. Influence of selective management on the prognosis and the risk of rupture of abdominal aortic aneurysms. *Clin Investig* 1994;**72**:585–91.
52 Schlösser FJ, Tangelder MJ, Verhagen HJ, van der Heijden GJ, Muhs BE, van der Graaf Y, et al, SMART study group. Growth predictors and prognosis of small abdominal aortic aneurysms. *J Vasc Surg* 2008;**47**:1127–33.
53 Schouten O, van Laanen JH, Boersma E, Vidakovic R, Feringa HH, Dunkelgrun M, et al. Statins are associated with a reduced infrarenal abdominal aortic aneurysm growth. *Eur J Vasc Endovasc Surg* 2006;**32**:21–6.
54 Solberg S, Singh K, Wilsgaard T, Jacobsen BK. Increased growth rate of abdominal aortic aneurysms in women. The Tromso study. *Eur J Vasc Endovasc Surg* 2005;**29**:145–9.
55 Singh K, Bønaa KH, Jacobsen BK, Bjørk L, Solberg S. Prevalence of and risk factors for abdominal aortic aneurysms in a population-based study: The Tromsø Study. *Am J Epidemiol* 2001;**154**:236–44.
56 Singh K, Bønaa KH, Solberg S, Sørlie DG, Bjørk L. Intra- and interobserver variability in ultrasound measurements of abdominal aortic diameter. The Tromsø Study. *Eur J Vasc Endovasc Surg* 1998;**15**:497–504.
57 Vardulaki KA, Prevost TC, Walker NM, Day NE, Wilmink AB, Quick CR, et al. Growth rates and risk of rupture of abdominal aortic aneurysms. *Br J Surg* 1998;**85**:1674–80.
58 Vega de Ceniga M, Gomez R, Estallo L, Rodrıguez L, Baquer M, Barba A. Growth rate and associated factors in small abdominal aortic aneurysms. *Eur J Vasc Endovasc Surg* 2006;**31**:231–6.
59 Vega de Ceniga M, Gomez R, Estallo L, de la Fuente N, Viviens B, Barba A. Analysis of expansion patterns in 4–4.9 cm abdominal aortic aneurysms. *Ann Vasc Surg* 2008;**22**:37–44.
60 The UK Small Aneurysm Trial Participants. Long-term outcomes of immediate repair compared with surveillance of small abdominal aortic aneurysms. *N Engl J Med* 2002;**346**:1445–52.
61 The UK Small Aneurysm Trial Participants. The UK small aneurysm trial: design, methods and progress. *Eur J Vasc Endovasc Surg* 1995;**9**:42–8.
62 Becquemin JP, Pillet JC, Lescalie F, Sapoval M, Goueffic Y, Lermusiaux P, et al, ACE trialists. A randomized controlled trial of endovascular aneurysm repair versus open surgery for abdominal aortic aneurysms in low- to moderate-risk patients. *J Vasc Surg* 2011;**53**:1167–73.
63 Ouriel K, Clair DG, Kent KC, Zarins CK, Positive Impact Of Endovascular Options For Treating Aneurysms Early (PIVOTAL) Investigators. Endovascular repair compared with surveillance for patients with small abdominal aortic aneurysms. *J Vasc Surg* 2010;**51**:1081–7.
64 Lederle FA, Freischlag JA, Kyriakides TC, Padberg Jr FT, Matsumura JS, Kohler TR, et al, Open Versus Endovascular Repair (OVER) Veterans Affairs Cooperative Study Group. Outcomes following endovascular vs open repair of abdominal aortic aneurysm: a randomized trial. *J Am Med Assoc* 2009;**302**:1535–42.
65 Cao P, CAESAR Trial Collaborators. Comparison of surveillance vs Aortic Endografting for Small Aneurysm Repair (CAESAR) trial: study design and progress. *Eur J Vasc Endovasc Surg* 2005;**30**:245–51.
66 Brown LC, Epstein D, Manca A, Beard JD, Powell JT, Greenhalgh RM. The UK endovascular aneurysm repair (EVAR) trials: design, methodology and progress. *Eur J Vasc Endovasc Surg* 2004;**27**:372–81.
67 Prinssen M, Buskens E, Blankensteijn JD. The Dutch Randomised Endovascular Aneurysm Management (DREAM) trial. Background, design and methods. *J Cardiovasc Surg (Torino)* 2002;**43**:379–84.
68 Grøndal N, Bramsen MB, Thomsen MD, Rasmussen CB, Lindholt JS. The cardiac cycle is a major contributor to variability in size measurements of abdominal aortic aneurysms by ultrasound. *Eur J Vasc Endovasc Surg* 2012;**43**:30–3.
69 Hartshorne TC, McCollum CN, Earnshaw JJ, Morris J, Nasim A. Ultrasound measurement of aortic diameter in a national screening programme. *Eur J Vasc Endovasc Surg* 2011;**42**:195–9.
70 Thapar A, Cheal D, Hopkins T, Ward S, Shalhoub J, Yusuf SW. Internal or external wall diameter for abdominal aortic aneurysm screening? *Ann R Coll Surg Engl* 2010;**92**:503–5.
71 Beales L, Wolstenhulme S, Evans JA, West R, Scott DJ. Reproducibility of ultrasound measurement of the abdominal aorta. *Br J Surg* 2011;**98**:1517–25.
72 Akkersdijk GJM, Puylaert JBCM, Coerkamp EG, de Vries AC. Accuracy of ultrasonographic measurement of infrarenal abdominal aortic aneurysm. *Br J Surg* 1994;**81**:376.

73 Yucel EK, Fillmore DJ, Knox TA, Waltman AC. Sonographic measurement of abdominal aortic diameter: interobserver variability. *J Ultrasound Med* 1991;**10**:681–3.
74 Holdsworth RJ, Shearer C. Comparison of antero-posterior and transverse aortic diameters for routine aneurysm surveillance. *Eur J Vasc Endovasc Surg* 2004;**27**:100–2.
75 Lederle FA, Wilson SE, Johnson GR, Reinke DB, Littooy FN, Acher CW, et al, for the Abdominal Aortic Aneurysm Detection and Management Veterans Administration Cooperative Study Group. Variability in measurement of abdominal aortic aneurysms. *J Vasc Surg* 1995;**21**:945–52.
76 Jaakkola P, Hippeläinen M, Farin P, Rytkönen H, Kainulainen S, Partanen K. Interobserver variability in measuring the dimensions of the abdominal aorta: comparison of ultrasound and computed tomography. *Eur J Vasc Endovasc Surg* 1996;**12**:230–7.
77 Manning BJ, Kristmundsson T, Sonesson B, Resch T. Abdominal aortic aneurysm diameter: a comparison of ultrasound measurements with those from standard and three-dimensional computed tomography reconstruction. *J Vasc Surg* 2009;**50**:263–8.
78 Foo FJ, Hammond CJ, Goldstone AR, Abuhamdiah M, Rashid ST, West RM, et al. Agreement between computed tomography and ultrasound on abdominal aortic aneurysms and implications on clinical decisions. *Eur J Vasc Endovasc Surg* 2011;**42**:608–14.
79 Singh K, Jacobsen BK, Solberg S, Kumar S, Arnesen E. The difference between ultrasound and computed tomography (CT) measurements of aortic diameter increases with aortic diameter: analysis of axial images of abdominal aortic and common iliac artery diameter in normal and aneurysmal aortas. The Tromsø Study, 1994–1995. *Eur J Vasc Endovasc Surg* 2004;**28**:158–67.
80 Sprouse LR, Meier GH, Parent FN, DeMasi RJ, Glickman MH, Barber GA. Is ultrasound more accurate than axial computed tomography for determination of maximal abdominal aortic aneurysm diameter? *Eur J Vasc Endovasc Surg* 2004;**28**:28–35.
81 Wanhainen A, Bergqvist D, Björck M. Measuring the abdominal aorta with ultrasonography and computed tomography – difference and variability. *Eur J Vasc Endovasc Surg* 2002;**24**:428–34.
82 Schmidt MH, Mitchell JR, Downey DB. Sonographic surveillance of abdominal aortic aneurysms: what is the smallest change in measured diameter that reliably reflects aneurysm growth? *Can Assoc Radiol J* 1999;**50**:241–6.
83 Chaikof EL, Blankensteijn JD, Harris PL, White GH, Zarins CK, Bernhard VM, et al, for the Ad Hoc Committee for Standardized Reporting Practices in Vascular Surgery of The Society for Vascular Surgery/American Association for Vascular Surgery. Reporting standards for endovascular aortic aneurysm repair. *J Vasc Surg* 2002;**35**:1048–60.
84 Powell JT, Gotensparre SM, Sweeting MJ, Brown LC, Fowkes FGR, Thompson SG. Rupture rates of small abdominal aortic aneurysms: a systematic review of the literature. *Eur J Vasc Endovasc Surg* 2011;**41**:2–10.
85 Brewster DC, Cronenwett JL, Hallett JW Jr, Johnston KW, Krupski WC, Matsumura JS, Joint Council of the American Association for Vascular Surgery and Society for Vascular Surgery. Guidelines for the treatment of abdominal aortic aneurysms. Report of a subcommittee of the Joint Council of the American Association for Vascular Surgery and Society for Vascular Surgery. *J Vasc Surg* 2003;**37**:1106–17.
86 Rouet L, Ardon R, Rouet JM, Mory B, Long A. Semi-automatic abdominal aortic aneurysms geometry assessment based on 3D ultrasound imaging. In: *Proc IEEE ultrasound symposium*. IEEE; 2010. p. 201–4.
87 Fillinger MF, Marra SP, Raghavan ML, Kennedy FE. Prediction of rupture risk in abdominal aortic aneurysm during observation: wall stress versus diameter. *J Vasc Surg* 2003;**37**:724–32.
88 Choke E, Cockerill G, Wilson WR, Sayed S, Dawson J, Loftus I, et al. A review of biological factors implicated in abdominal aortic aneurysm rupture. *Eur J Vasc Endovasc Surg* 2005;**30**:227–44.
89 McGloughlin TM, Doyle BJ. New approaches to abdominal aortic aneurysm rupture risk assessment: engineering insights with clinical gain. *Arterioscler Thromb Vasc Biol* 2010;**30**:1687–94.