Radiography (2010) **16**, 173—181

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Variability of vascular CT measurement techniques used in the assessment abdominal aortic aneurysms

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Received 29 October 2009; revised 16 February 2010; accepted 25 February 2010

KEYWORDS
Abdominal aortic aneurysm;
Computed tomography;
Radiological measurement;
Observer variability;
Vascular disease

Abstract *Purpose:* The aim of this project is to assess the variability of six CT measurement techniques for sizing abdominal aortic aneurysms (AAAs).
Method: 37 CT scans with known AAAs were loaded on to a departmental picture archiving and communication system (PACS). A team of three observers, with experience in aortic CT measurements and the PACS performed a series of 2D and 3D measurements on the abdominal aorta. Each observer was asked to measure 3 quantities; anterior—posterior AAA diameter, maximum oblique AAA diameter, maximum aneurysm area using both 2D and 3D techniques. In order to test intra-observer variability each observer was asked to repeat their measurements. All measurements were taken using electronic callipers, under standardised viewing conditions using previously calibrated equipment. 3D measurements were conducted using a computer generated central luminal line (CLL). All measurements for this group were taken perpendicular to the CLL.
Results: A total of 972 independent measurements were recorded by three observers. Mean intra-observer variability was lower for 2D diameter measurements (AP 1.3 ± 1.6 mm; 2D Oblique 1.2 ± 1.3 mm) and 2D areas (0.7 ± 1.3 cm^2) when compared to inter-observer variability (AP 1.7 ± 1.9 mm; Oblique 1.6 ± 1.7 mm; area 1.1 ± 1.5 cm^2). When comparing 2D with 3D measurements, differences were comparable except for 3D AP diameter and area which had lower inter-observer variability than their 2D counterparts (AP 2D 1.7 ± 1.9 mm, 3D 1.3 ± 1.3 mm; area 2D 1.1 ± 1.5 cm^2, 3D 0.7 ± 0.7 cm^2). 3D area measurement was the only technique which had equal variability for intra- and inter-observer measurements. Overall observer variability for the study was good with 94—100% of all paired measurements within 5.00 mm/cm^2 or less. Using Pitman's test it can be confirmed that area measurements in the 3D plane have the least variability ($r = 0.031$) and 3D oblique measurements have the highest variability ($r = 0.255$).
Conclusion: 3D cross-sectional area measurement techniques have the lowest variability and should be preferred for repeatable measurements of AAAs where possible. Results confirm that both inter- and intra-observer variability exists for all measurement techniques.

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doi:10.1016/j.radi.2010.02.005

Introduction

Abdominal Aortic Aneurysms (AAA) are often asymptomatic and may remain undetected; if an AAA remains unnoticed it will continue to grow with a high probability of rupture. The overall mortality rate for a rupture AAA is as high as 88%.[1] In view of this high mortality there is a need for early diagnosis and treatment to prevent rupture.[2] With the diameter of the aneurysm correlating with the risk of rupture[3,4] AAA management is guided by aneurysm size. Currently, if an aneurysm is 5.5 cm in diameter it is considered to be at high risk of rupturing and repair is recommended.[5] Surveillance of AAAs less than 5.5 cm in diameter has been reported as being safe with survival not improved by elective surgical repair. Consequently surveillance using vigilant clinical evaluation and ultrasound imaging is indicated in patients with AAAs 4.0–5.4 cm in diameter. Maximum AAA diameters are also a useful tool in monitoring patients following endovascular aortic aneurysm repair (EVAR). EVAR is a relatively new treatment option and durability problems have been reported with all commercially available aortic stent-grafts.[6] Secondary re-interventions may be required and have been reported in between 7 and 15% of EVAR patients.[7,8] The decision of whether to undertake any secondary procedures is often decided on the basis of follow-up AAA diameter measurements.

Both CT and Ultrasound can be used to diagnose and monitor AAAs but even with the same scan there is often a considerable amount of variability between measurements.[9–12] Variability can also occur internally within one observer (intra-observer variability) and between observers (inter-observer variability). In a clinical environment, minimising this variability is crucial as an inaccurate measurement could affect the decision of whether to intervene. In certain cases the risk of surgery could outweigh the risk of rupture[13] and therefore the measurements must be accurate to avoid any unnecessary risk. Furthermore, it is critical that measurements are precise when monitoring aortic aneurysms either pre- or post-treatment in order to give an accurate indication of growth or shrinkage which can again influence treatment decisions. There are a variety of measurement techniques used to size an aneurysm from CT scans including maximum diameter, area and volume.[14,15] These can be undertaken using either 2D axial images or 3D reformatted images generated from 2D datasets. As well as the established variability between and within observers there is undoubtedly variability between individual measurement techniques.

The aim of this project is to investigate variability between various CT-based measurement techniques and to identify the method with the lowest variability and highest reproducibility. 3D image analysis techniques are becoming widely available on most radiology workstations and it is important to ascertain whether this dimension influences variability.

Methods

Over a four-week period, 37 CT scans with known AAAs were selected from a clinical imaging archive. Each scan was obtained from the same CT scanner (Siemens Somatom Sensation 16, Siemens Medical Systems, Erlangen, Germany) using standard acquisition parameters (Table 1) and subsequently viewed on a departmental PACS (Kodak Carestream PACS, Carestream Health, Rochester, MY). A team of three observers all trained in the PACS software and aortic CT measurements were asked to perform specific measurements on each of the CT datasets. All anatomical CT measurements were performed on a reporting grade workstation using two EIZO (EIZO Nanao Corpora-tion, Hakusan, Ishikawa, Japan) 3-mega-pixel monochrome monitors which had been previously calibrated for DICOM image analysis. Participants passed a near vision logMAR (logarithm of the minimum angle of resolution) test prior to the clinical measurements to ensure eyesight was not a variable in the study. Any anatomical measurements from the CT scans were obtained using electronic callipers with measurements recorded to 0.01 mm (diameter) and 0.01 cm^2 (area). All images were assessed using standard CT window levels (WW 700 WL 80). Research ethics approval was obtained from the Local NHS Research Committee prior to the start of the study.

Table 1 CT image acquisition protocol.

Parameter	Description
CT Scanner	Siemens Somatom Sensation
Type	MSCT – 16 slice
Slice thickness	2 mm
Reconstruction interval	1 mm
Reconstruction algorithm	B30f
Contrast enhancement	Intravenous
Contrast type	Omnipaque 240 mg/mL
Contrast volume	100 mL
Bolus tracking	Yes, triggered at T12 (ROI abdominal aorta, 120HU threshold).

For the two-dimensional (2D) study, observers were asked to scroll through each of the patient's CT datasets and identify the slice/image where the aneurysm was at its maximum size. Using this image, observers then measured the anteroposterior (AP) diameter of the aneurysm, ensuring the line of measurement passed through the centre of the aneurysm (Fig. 1). The maximum oblique plane diameter measurement was then taken, where the aneurysm's diameter was at its greatest in any other plane than AP, again ensuring that the line passed through the centre of the aneurysm (Fig. 1). Next, using the region of interest (ROI) tool, the observers traced the outer perimeter of the aneurysm, which then indicated the aneurysm's maximum area (Fig. 2).

For the 3D study, all CTs were loaded into the 3D vessel analysis program on the PACS and a semi-automated central luminal line (CLL) was generated. 17 of the original 37 CT scans were used for this part of the study. The other 20 CT scans had to be discarded due to the interference caused by the presence of a stent graft which affected the computer generated CLL. All measurements were taken perpendicular to the CLL at the point where the aneurysm was at its maximum (Fig. 3). Using the same method as for the 2D scans, observers measured AP diameter, maximum oblique diameter and maximum area.

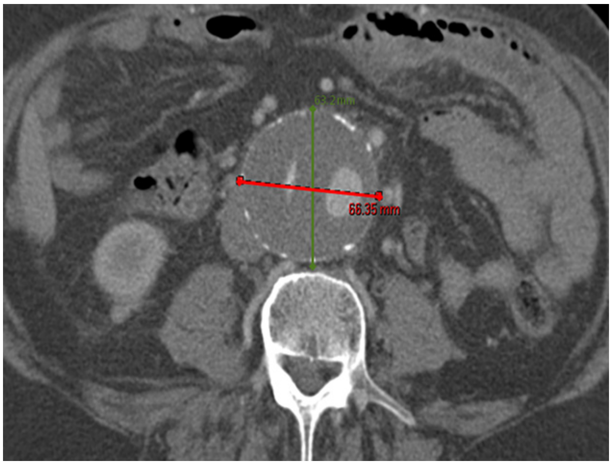

Figure 1 2D axial CT image demonstrating an anteroposterior (AP) AAA measurement (green line) and maximum oblique diameter measurement (red line).

For both the 2D and 3D phases of the project all CT scans were presented to observers in a random order. All observers completed their measurement under standard radiological reporting conditions under ambient lighting. Observers performed measurements at eye level, to avoid parallax error; all measurements were repeated to test intra-observer variability. A suitable period of time was left between repeat readings so that observers would not be aware of their previous results. Observers were also blinded to the measurements taken by fellow observers. For both 2D and 3D measurements the maximum dimensions of the aneurysm was taken to be adventitia to adventitia. Observers were instructed that if the aneurysm contours were difficult to visualise in any way they should assume that the aneurysm maintains a conventional shape and measure accordingly. Observers were also told to exclude any structures that are not the aneurysm such as the bowel or inferior vena cava. Observers were asked to zoom all images so that the aneurysm covered a large percentage of the screen prior to any measurements.

Statistical analysis

Analysis was undertaken using the statistical computer programmes SPSS 16.0 (SPSS Inc, Chicago, IL) and STATA 9.0

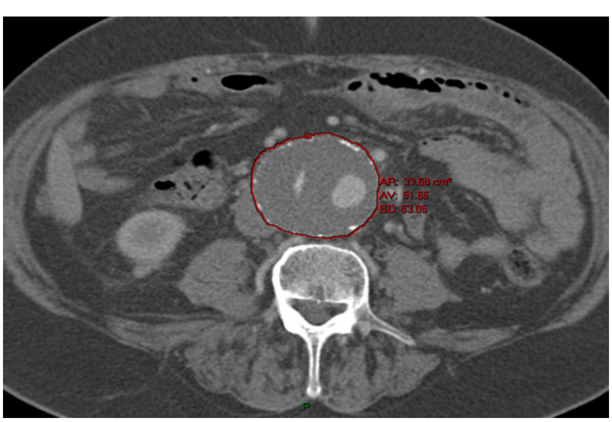

Figure 2 2D axial CT image demonstrating an area measurement (red perimeter line).

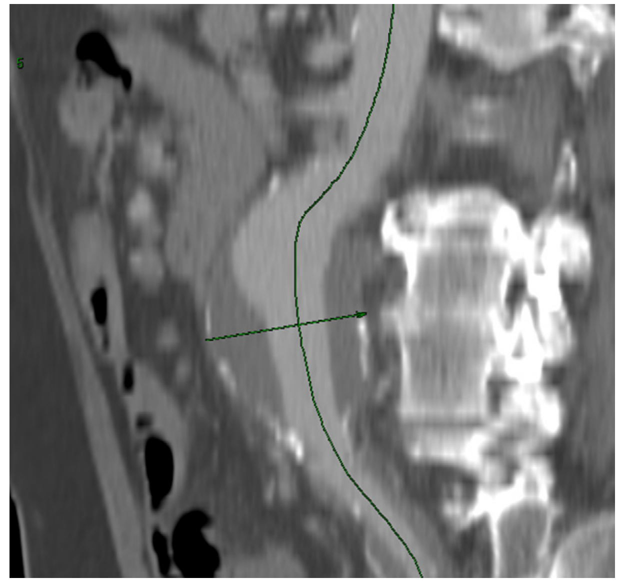

Figure 3 3D Sagittal image showing a computer generated central luminal line (CLL) (vertical green line). The aneurysm has been sized from images generated perpendicular to the CLL where the aneurysm is at its maximum.

(Statacorp, College Station, TX). Continuous data was expressed mean values plus or minus its standard deviation. Researchers also calculated the range and the percentage of paired measurements within $\leq$2 mm, $\leq$5 mm, $\leq$2 cm^2 and $\leq$5 cm^2 difference. Where inferential statistical analysis took place *P* values of less than 0.05 were statistically significant. To determine the intra-observer variability the difference between the each observer's original and repeat measurements was calculated. The mean was then calculated so that the intra-observer variability of each observer could be compared. All the intra-observer variability data for all three observers was compiled so that comparisons between the techniques could be made. To determine the inter-observer variability, comparisons were made between all observers with all possible consistencies, i.e. Obs 1 vs Obs 2, Obs 1 vs Obs 3, Obs 2 vs Obs 3. Using the intra-observer and inter-observer data Bland Altman plots were created. The Bland Altman plots[16,17] graphically portrayed the mean difference between the various measurement techniques and the size of the original measurement and enabled researchers to make a visual judgement of the variability between techniques. Pitman's test of difference in variance and intra-class correlations (ICC) were used to compare techniques with different units of measurement.[18]

Results

A total of 972 independent measurements were recorded by 3 observers. In the 2D investigation each observer made 222 measurements (including repeats) giving a total of 666 measurements, for the 3D study each observer performed 102 measurements (including repeats) giving a total of 306 measurements. The differences in paired measurements within each observer (intra-observer variability) and between observers (inter-observer variability) are summarised in Table 2.

Table 2 Demonstrating intra- and inter-observer variability for both 2D and 3D measurements.

		Intra Observer			Inter Observer		
		AP Diameter (mm)	Oblique Diameter (mm)	Area (cm^2)	AP Diameter (mm)	Oblique Diameter (mm)	Area (cm^2)
2D	Mean	1.3	1.2	0.7	1.7	1.6	1.1
	Standard Deviation	1.6	1.3	1.2	1.9	1.7	1.5
	Minimum	0	0	0	0.1	0	0
	Maximum	10.2	6.6	9.4	10.4	8.3	10
	≤2 mm/cm^2	94, (85%)	92, (83%)	106, (96%)	79, (71%)	82, (74%)	98, (88%)
	≤5 mm/cm^2	106, (96%)	109,(98%)	108, (97%)	104, (94%)	105, (95%)	108, (97%)
3D	Mean	1.1	1.2	0.7	1.3	1.6	0.7
	Standard Deviation	1.4	1.2	0.9	1.3	1.6	0.7
	Minimum	0	0	0	0	0	0
	Maximum	5.4	5.8	5.8	6.8	7.9	3
	≤2 mm/cm^2	46, (90%)	41, (80%)	49,(96%)	39, (76%)	36, (70%)	49, (96%)
	≤5 mm/cm^2	49, (96%)	49, (96%)	50, (98%)	49, (96%)	49, (96%)	51, (100%)

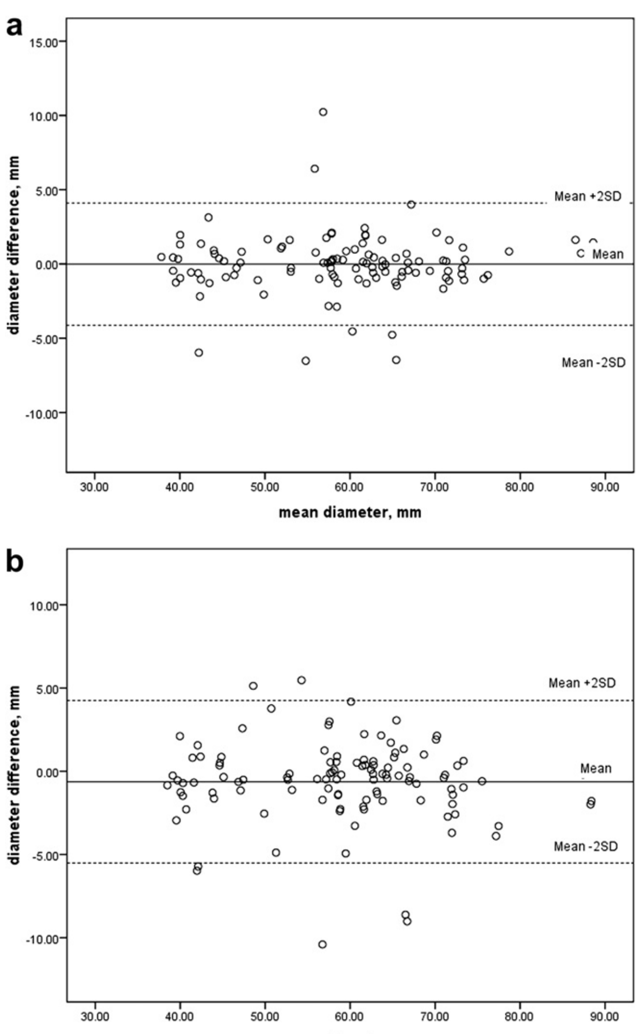

Figure 4 a) Bland Altman plot of intra-observer variability for the 2D AP technique. b) Bland Altman plot of inter-observer variability for the 2D AP technique.

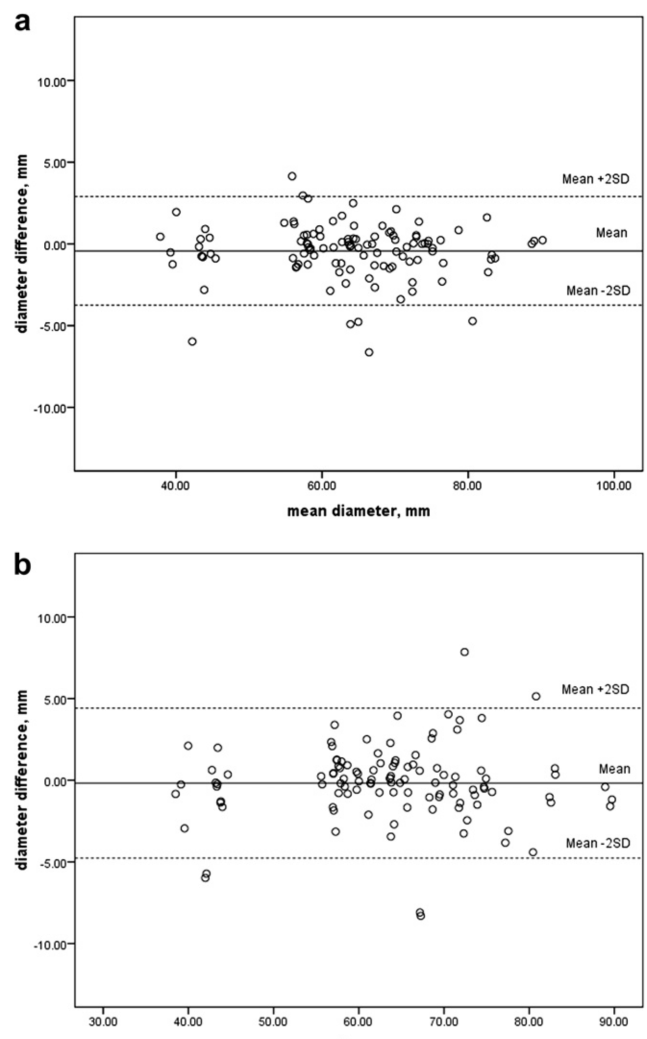

Figure 5 a) Bland Altman plot of intra-observer variability for the 2D Oblique technique. b) Bland Altman plot of inter-observer variability for the 2D Oblique technique.

Analysis of the results revealed small differences between the 2D AP and oblique diameter measurements either within a single observer or between observers. For 2D measurements there was an increase in inter-observer variability for all techniques when compared to intra-observer variability. The addition of evaluating the AAA in 3D using a CLL did not affect variability for oblique diameter measurements but did reduce variability for AP diameter measurements and the measurement of cross-sectional area. Analysis of Bland Altman graphs (Figs. 4—9) supports these findings and when combined with Pitman's analysis of variance and Intra-class correlations (ICC) confirm that measurement variability was lowest for 3D cross-sectional area measurements (Tables 3—5).

Discussion

A variety of measurement techniques are available for the CT sizing of AAAs. Currently the commonest method for sizing an AAA is its maximum cross-sectional diameter.[14,15] With advances in imaging technology AAA assessment using 3D reformatted images is increasingly more commonly. Modern workstations are able to generate parameters other than diameter and these may be useful when defining AAA size and guiding management. With variability well established between and within observers there is also the prospect of variability existing between measurement techniques. This project sought to compare variability between six CT-based measurement techniques; for 2D intra- and inter-observer measurements cross-sectional area was found to be the least variable technique with AP diameter being the most variable (Tables 2, 4, 5). For 2D techniques, findings suggest that the intra-observer variability is lower when compared to inter-observer variability. For 3D techniques, the intra-observer variability was also lower for both AP and Oblique diameter measurements. This could have been expected because all measurements are subjective; involving a decision from each observer and even in the presence of clearly defined instructions each observer will make slightly different decisions when positioning a measurement. When faced with

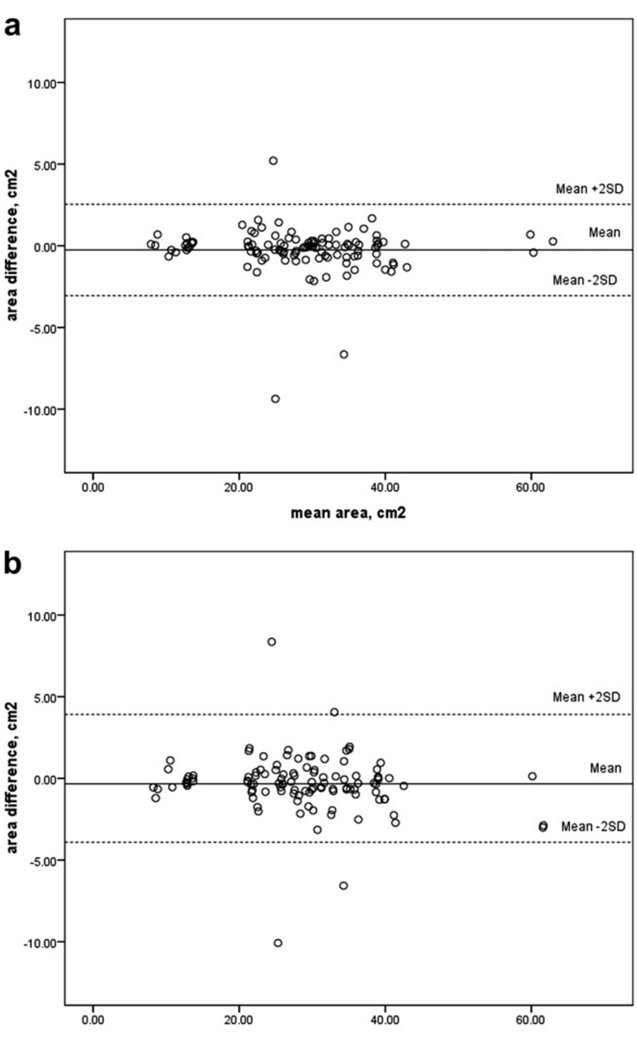

Figure 6 a) Bland Altman plot of intra-observer variability for the 2D Area technique. b) Bland Altman plot of inter-observer variability for the 2D Area technique.

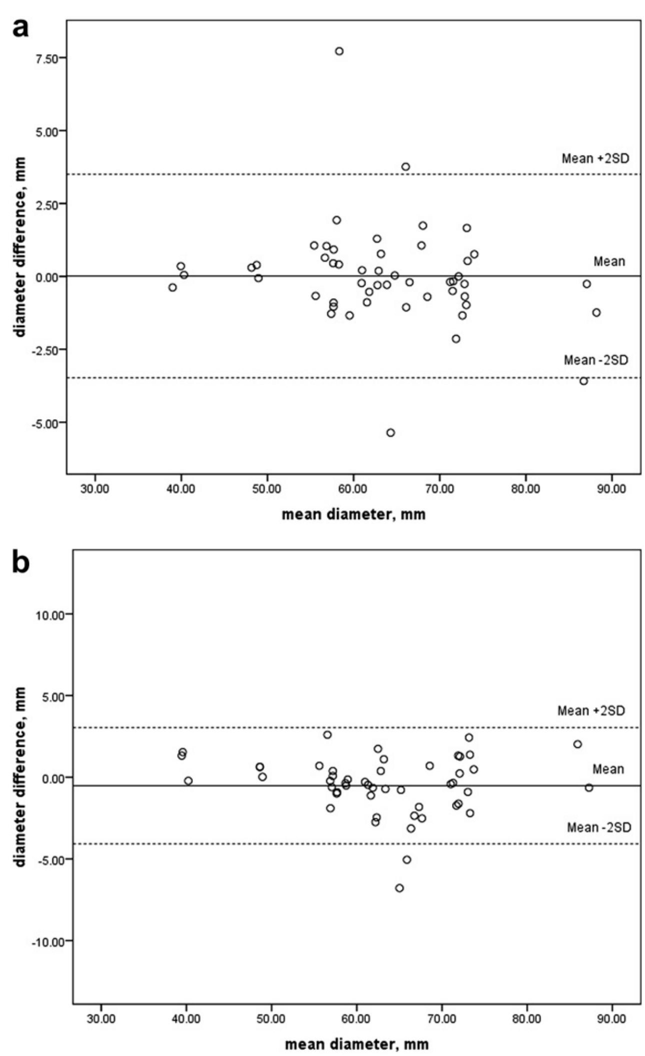

Figure 7 a) Bland Altman plot of intra-observer variability for the 3D AP technique. b) Bland Altman plot of inter-observer variability for the 3D AP technique.

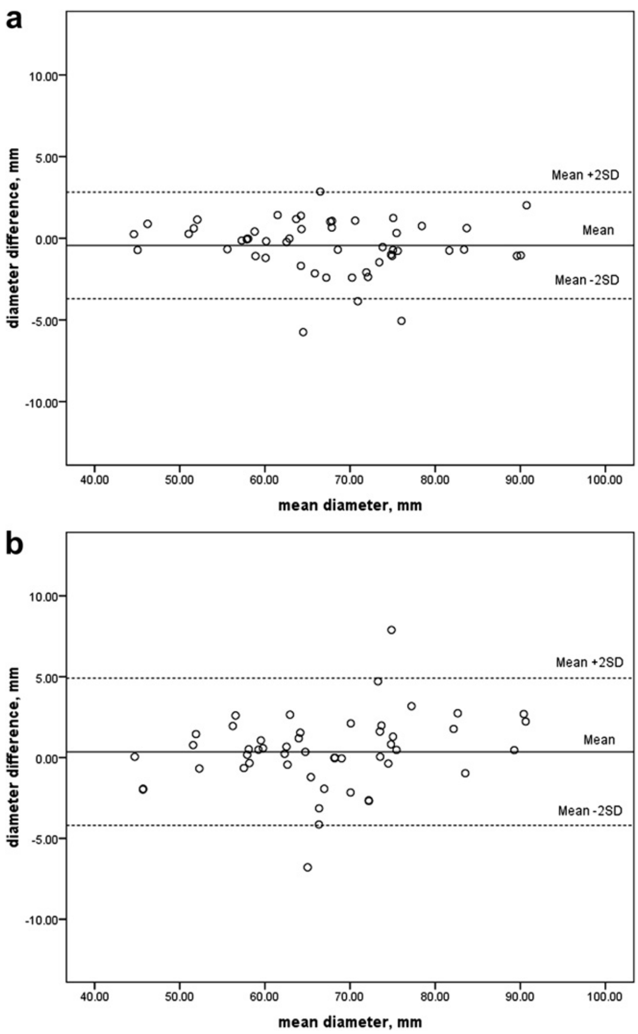

Figure 8 a) Bland Altman plot of intra-observer variability for the 3D Oblique technique. b) Bland Altman plot of inter-observer variability for the 3D Oblique technique.

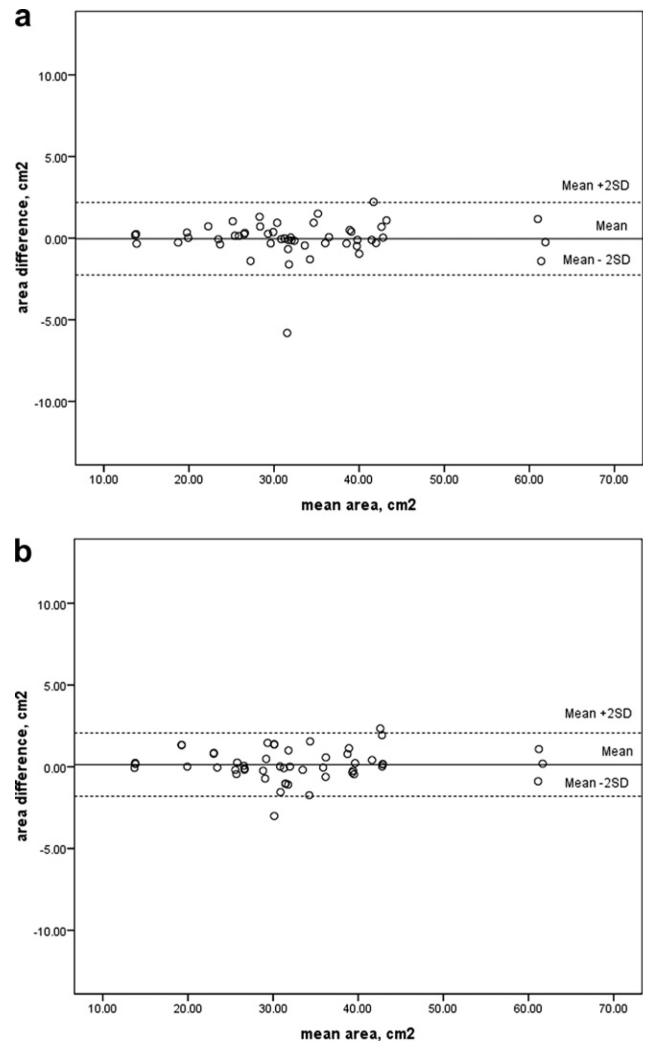

Figure 9 a) Bland Altman plot of intra-observer variability for the 3D Area technique. b) Bland Altman plot of inter-observer variability for the 3D Area technique.

the same measurement conditions it is expected that the same observer would make similar decisions and hence intra-observer variability being lower. This has been reported in a recent study by Wyss et al.[19] who compared CT measurements of aortic anatomy within and between observers. Wyss et al. concluded that agreement within observers is superior to agreement between observers.

Using Pitman's test 3D cross-sectional area has consistently the lowest variability between techniques and should be preferred for repeatable measurements of the pre-treatment aneurismal aorta. Further indicating the reliability of 3D cross-sectional area is the ICC. A 0.998 ICC for 3D cross-sectional area indicates a low variability between repeat measurements between observers. An explanation for the low variability of 3D cross-sectional area is that diameter measurements require the selection of two points on the aneurysm and then require the observer to identify the plane in which the diameter is at its maximum. This involves multiple decision processes whereas it could be argued that area calculations may be a simpler process as it requires the observer to identify the perimeter (all points surrounding the aneurysm) and then the computer calculates the area. When viewing the AAA as a 3D structure the addition of a CLL further reduces measurement variability. This can be explained by reviewing Fig. 2 where it would appear easy to identify the maximum extend of the aneurysm from the CLL image as opposed to scrolling through several hundred 2D images and selecting a single image where the aneurysm it as its maximum. From our data we can argue that 3D evaluation of the AAA in combination with outlining the perimeter to produce a cross-sectional area is a simpler task and therefore leads to lower variability.

From analysing the intra-observer results, it can be argued that there is little difference between AP and Oblique diameters and cross-sectional areas when comparing 2D versus 3D measurements. This suggests that for a single person, it does not matter which technique is used, as they all have similar variability. In clinical life there would be more than one observer undertaking CT-based measurements and therefore inter-observer variability would be just as important. In a study, by Lederle et al.,[20] who studied variability of AAA measurements, they also found that by

Table 3 Statistical analysis of Bland Altman plots (Intra-observer variability).

	2D AP	3D AP	2D Oblique	3D Oblique	2D Area	3D Area
Lim. of agreement	−4.077 to 4.110	−3.475 to −3.501	−3.758 to 2.898	−3.701 to 2.826	−3.048 to 2.545	−2.51 to 2.182
Mean diff.	0.016	0.013	−0.43	−0.437	−0.251	−0.035
95% CI	−0.369 to 0.401	−0.477 to 0.504	−0.743 to −0.117	−0.896 to 0.021	−0.514 to 0.012	−0.346 to 0.277
Pitman's Test, *r*	0.035	0.209	0.045	0.045	0.077	0.001
P Value	0.717	0.158	0.64	0.334	0.427	0.995

CI, confidence interval.

limiting the number of observers this lowers variability which is a feature in keeping with our findings.

For the 2D measurements, the lowest percentage of measurements less than 5 mm/cm^2 was 94% and the highest was 98%, demonstrating that for both inter- and intra-observer measurements, there were not many extreme outliers. For the 3D measurements, the lowest percentage of measurements less than 5 mm/cm^2 was 96% and the highest was 100%. This again may demonstrate that 3D is more reliable as there are fewer extreme outliers. When categorising the results both 2D and 3D techniques are very similar and on this basis it is difficult to justify whether one technique is clinically better than another. Large diameter differences may have clinical implications; this could ultimately influence the decision to operate or undertake secondary reintervention. Data from our study suggests that all these techniques are clinically adequate as they all demonstrate a high level of accuracy, in an age where procedural success may be determined by AAA size changes it is important to have the most precise and reproducible measurement technique.

Several comments can be made about our study. From interpretation of the Bland Altman graphs, it would appear that the variability does not increase with aneurysm size. The study dataset did use mid-ranged AAAs (39—89 mm) and therefore if the results are applied to very small or large aneurysms they should be used with caution. Both AP and Oblique diameter measurements are directly comparable because they are measured in millimetres. This is not the case with area, as it is measured in centimetres squared and therefore variability of area cannot be directly compared to AP and Oblique diameters using traditional descriptive statistics. To overcome this Pitman's and ICC tests were included to allow the comparison of measurement differences regardless of units. A further problem in 2D measurements is that the maximum extent of the aneurysm could be at a point where the aorta is bending in the abdomen. Measurements undertaken on this slice would therefore be inaccurate because an elliptical image would be produced and could lead to underestimation of the maximum diameter due to the aneurysm not lying perpendicular to the imaging plane. Use of a CLL should reduce this measurement error as all measurements are forcibly taken perpendicular to a reference line automatically plot though the centre of the aortic lumen. CLLs are not without their problems and there may be variations to the CLL generated by the computer. The 3D CLL follows the path of the contrast material in the aortic lumen; this does not always sit in the centre of the aneurysm and can therefore can occasionally lead to inaccurate cross-sectional measurements generated perpendicular to this CLL or fail to produce a line in poor or no contrast examinations. It was for this reason that 20 CT scans were excluded from the 3D analysis as they contained stent-grafts implanted into the aorta and this created an abnormal aortic lumen which could have affected the resultant CLL and cross-sectional measurement. Further discussion on this point is needed as questions may be raised about the generalisability of our findings. With no post-endovascular CT scans included in the 3D analysis lower variability of 3D techniques has only been proven for pre-operative aortic CT scans. If 3D assessment of an AAA is not possible then study findings suggest that the 2D area technique still offers lower variability (ICC 0.992 95% CI 0.988—0.995) when compared to other 2D techniques.

Further research can be recommended following this study. A comparison of area with volume may be useful as many author's report volume being a more accurate indicator of aneurysm stress/rupture risk. [21] This is debatable

Table 4 Statistical analysis of Bland Altman plots (Inter-observer variability).

	2D AP	3D AP	2D Oblique	3D Oblique	2D Area	3D Area
Lim. of agreement	−5.511 to 4.257	−4.072 to 3.036	−4.769 to 4.421	−4.193 to 4.902	−3.922 to 3.244	−1.800 to 2.072
Mean diff.	−0.627	−0.518	−0.174	0.355	−0.339	0.136
95% CI	−1.086 to −0.168	−1.017 to −0.018	−0.606 to 0.258	−0.285 to 0.994	−0.676 to −0.002	−0.136 to 0.408
Pitman's Test, *r*	−0.067	−0.161	0.047	0.255	−0.152	0.031
P Value	0.489	0.272	0.624	0.071	0.119	0.832

CI, confidence interval.

Table 5 Table to show ICC (Intra-class correlation).

		2D		3D	
		ICC	ICC, 95% CI	ICC	ICC, 95% CI
Inter	AP	0.988	0.983–0.992	0.993	0.987–0.996
	Oblique	0.990	0.985–0.993	0.989	0.981–0.994
	Area	0.992	0.988–0.995	0.998	0.996–0.999
Intra	AP	0.992	0.988–0.994	0.993	0.988–0.996
	Oblique	0.995	0.992–0.996	0.995	0.990–0.997
	Area	0.995	0.993–0.997	0.997	0.955–0.998

as many workstations do not have the ability to quantify AAA volume. In addition the calculation of volume can be time consuming and as reported by Abada et al.[22] does not necessarily provide additional clinical information and should only be reserved for cases where diameters do not allow classification. It is apparent from both this study and previous work[12] that the ability of an observer to visualise the boundaries of the aorta is undoubtedly a factor in accurate measuring. Future studies should seek to examine the effect of visual contrast sensitivity on CT measurement performance. Automated measurement techniques have been proposed as an option to further lower the variability by limiting the number of decisions made by the observer. This has been recently shown in a study by Wyss et al.[19] where measurement techniques which involved minimal observer input were subject to lower variability than techniques which required more observer decision making. Other studies have also shown that by using automated measurement techniques variability can be further reduced.[23] Fully automated measurement techniques are highly desired within the radiological community as they can significantly reduce the reporting times. Fully automated techniques will require evidence of validation against a gold standard. With no knowledge on the true dimensions of an AAA the gold standard is at present manual measurement by a radiologist. Studies will need to prove validation of these automated techniques against a gold standard prior to widespread integration of these technologies into the clinical practice.

Conclusion

Measurement of maximum AAA cross-sectional area using a central luminal line (CLL) is the least variable measurement technique for the pre-operative assessment of AAAs. Observer variability was found to be independent of AAA size and is lower for repeat measurements between the same observer (intra-observer variability). Variability exists for all techniques and clinicians' should be aware of this when defining treatment. 3D CLL assessment of maximum aortic size is limited in patients with aortic stent-grafts implanted as device interference can generate an abnormal CLL which would undoubtedly affect any corresponding measurements.

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