Discrepancies in determination of abdominal aortic aneurysms maximum diameter and growth rate, using axial and orthogonal computed tomography measurements

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ABSTRACT

Purpose: Maximum diameter and growth rate of abdominal aortic aneurysms (AAAs) which are currently used as the only variables to set the indication for elective repair are recorded through computed tomography (CT) measurements on an axial plane or on an orthogonal plane that is perpendicular to vessel centerline, interchangeably. We will attempt to record possible discrepancies between the two methods, identify whether such differences could influence therapeutic decisions and determine in which cases this should be expected.

Materials and methods: We retrospectively reviewed sixty CT-scans performed in thirty-nine patients. Three-dimensional reconstruction of AAAs has been performed and differences in maximum diameter measured on axial and orthogonal planes were recorded. A measure for asymmetry was introduced termed ShapelIndeX defined as the value of section minor over major axis and was related with differences in maximum diameter recordings. Growth rates were also determined using both axial and orthogonal measurements.

Results: Axial measurements overestimate maximum diameter by $2 \pm 2.7$ mm ($P < 0.001$) with a range of 0–12.3 mm. Overall, 20% of the CTs had an axial maximum diameter >5.5 cm indicating the need for intervention whereas, orthogonal diameter was below that threshold. Asymmetry of the axial sections with ShapelIndeX < 0.8 was found to be related to an overestimation of maximum diameter by >5.5 mm. There were no significant differences in growth rates when determined using orthogonal or axial measurements in both examinations (median growth rate: 2.3 mm and 3.3 mm respectively $P = 0.2$). However there were significant differences when orthogonal measurements were used at initial and axial measurements used at follow-up examination or vice versa (median growth rate: 4.9 mm and 0.9 mm respectively $P = 0.001$).

Conclusions: Although the mean difference between measurements is low there is a wide range among cases, mainly observed in asymmetrical AAAs. ShapelIndeX may identify those which are more likely to be misestimated. CT measurements performed to establish AAA growth rates should consistently use either the axial or orthogonal technique to avoid inaccuracies from occurring.

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1. Introduction

Abdominal aortic aneurysms (AAAs) are a common cause of mortality in western societies especially with aging of the population [1]. Left untreated all aneurysms will eventually rupture with associated high morbidity and mortality [2]. Elective repair of AAAs aims in the prevention of this catastrophe and is currently based on the criteria of aneurysm size and expansion rate. Surgical intervention by either open or endovascular means is considered appropriate when maximum diameter ≥5.5 cm or growth rate ≥1 cm/year [3]. Current thresholds have been set by large scale randomized trials which indicated that beyond these, the risk of rupture and subsequent death exceeds the operative mortality, currently considered to be <3% [3–5].

The advents of thin-slice computed tomography (CT), digital imaging as well as technological advances that have made feasible the three-dimensional (3D) reconstruction of AAA surface allow more accurate measurements of AAA size parameters. Therefore
Maximum diameter is currently recommended to be measured on an orthogonal plane that means perpendicular to vessel centerline with 3D reconstructed CT images, since aneurysm cross sections often appear elliptic on axial images making the measurements uncertain [6]. Since AAAs 3D reconstruction is not always available and maximum diameter as well as growth rate between follow ups are estimated using axial or orthogonal measurements indiscriminately, the current study examined the presence and extend of discrepancies between the two methods. Others that attempted to address this issue indicate significant differences in the determination of maximum diameter. On the other hand they do not relate these differences to any AAA characteristics that could indicate the cases in which remarkable discrepancies should be expected and do not take into account inaccuracies with regard to growth rate that is also used as a significant variable to define therapeutic strategies [7]. In the current study differences of maximum diameter as well as growth rate as determined by axial or orthogonal measurements were assessed. Moreover we attempted to identify AAAs characteristics that foretell possible inaccuracies in measurements and should raise suspicion toward misleading results.

2. Materials and methods

2.1. Patient population

Thirty-nine patients with AAA were included in the current study. They all had undergone CT imaging for diagnosis or surveillance of AAA. Maximum diameter measured on an orthogonal plane as currently recommended [6] was <6.5 cm for all patients, varying from 32 to 65 mm. Patients with initial maximum diameter >65 mm were excluded in order to examine only cases where discrepancies in measurements could have therapeutic implications. Twenty-one patients had more than one CT scans meaning that except from the initial diagnostic imaging they had at least one follow up for detection of aneurysm expansion (mean follow up time: 11.9 months range: 3–52 months). This resulted in totally sixty CT scans, which were retrospectively reviewed to record discrepancies of maximum diameter and growth rate determined by axial and orthogonal measurements.

2.2. Image post processing, maximum diameter measurements, sectional shape determination

All CT scans were reviewed and processed using open source software ITK-SNAP [8]. From CT images, 3D AAA models were reconstructed as it has been described elsewhere [9]. Briefly, outlines of the outer surface of the AAA wall were manually obtained slice by slice and the 3D surfaces were reconstructed from the stack of contours. The reconstructed 3D wall surfaces of each case were processed using the vascular modeling tool kit (VMTK) open source software [10]. After smoothing the surface, the centerline was computed and was used to extract perpendicular cross sections at 1 mm intervals (Fig. 1A). Maximum size of each perpendicular section was computed and maximum diameter of the AAA on an orthogonal plane was recorded (D orthogonal). The AAA wall surface was also cut in axial cross sections, vertically to the z-axis of the CT scanner coordinate system (Fig. 1B). These axial cross sections were equivalent to axial sections of CT scan. Maximum size of each section was again computed and maximum diameter of the AAA using axial measurements was recorded (D axial). With regard to the axial section that presented maximum AAA diameter a measure for section asymmetry was introduced termed the shape index (ShapeIndex) using the major and minor axis on an ellipse shape. Specifically ShapeIndex is defined as the value of section minor over major axis as depicted in Fig. 2.

\[
\text{ShapeIndex} = \frac{\text{Section minor axis}}{\text{Section major axis}}
\]

(ShapeIndex approaches unity for symmetric sections while tends to be low for asymmetric sections)
Fig. 2. ShapeIndex that is a measure of asymmetry as it is computed from 3D reconstruction and its equivalent in 2D CT slices. (A) An asymmetrical AAA with ShapeIndex = 0.68. (B) A symmetrical AAA with ShapeIndex = 0.98.

Fig. 2A displays an asymmetrical AAA with low ShapeIndex, while in Fig. 2B a symmetrical AAA with ShapeIndex that approaches unity is presented.

2.3. Data analysis

The difference between axial and orthogonal measurements of maximum diameter ($D_{AXIAL} - D_{ORTHI}$), was recorded for all sixty CT scans under review.

Differences in maximum diameter between axial and orthogonal measurements were related to ShapeIndex. A threshold of ShapeIndex ≤ 0.8 was tested for identification of cases that presented differences ≥ 5 mm. AAAs with ShapeIndex > 0.8 were considered negative for having differences > 5 mm (true negative (TN) if difference < 5 mm, false negative (FN) if difference > 5 mm), whereas those with ShapeIndex ≤ 0.8 were considered positive (true positive (TP) if difference > 5 mm, false positive (FP) if difference < 5 mm). Sensitivity was calculated as:

\[ \text{Sensitivity} = \frac{TP}{TP + FN} = \text{probability of } \text{ShapeIndex} \leq 0.8 \]

given that difference is ≥ 5 mm

Negative predictive value was calculated as:

\[ \text{NPV} = \frac{TN}{TN + FN} = \text{probability of difference < 5 mm} \]

given that Shapeindex is > 0.8
2.4. Growth rate determination using different measurements

With regard to patients with at least one follow up (mean follow up time: 11.9 months with a range of 3–52 months) the growth rate of the AAA was calculated. There were twenty-one pairs of sequential CTs from which growth rates (GR) were determined using both axial and orthogonal measurements in all plausible combinations. Subsequently growth rates were calculated as:

\[ \text{GR}_{\text{AXIAL}} = D_{2,\text{AXIAL}} - D_{1,\text{AXIAL}} \]  \hspace{1cm} (1)

\[ \text{GR}_{\text{ORTH}} = D_{2,\text{ORTH}} - D_{1,\text{ORTH}} \]  \hspace{1cm} (2)

\[ \text{GR}_{\text{AXIAL-ORTH}} = D_{2,\text{AXIAL}} - D_{1,\text{ORTH}} \]  \hspace{1cm} (3)

\[ \text{GR}_{\text{ORTH-AXIAL}} = D_{2,\text{ORTH}} - D_{1,\text{AXIAL}} \]  \hspace{1cm} (4)

(GR: growth rate; D1: maximum diameter at initial CT; D2: maximum diameter at follow up). Differences between various measurements were recorded.

2.5. Statistical analysis

Differences between \( D_{\text{AXIAL}} \) and \( D_{\text{ORTH}} \) are expressed in mean ± standard deviation. A paired samples t-test was used to detect significant differences. Growth rates as determined from axial and orthogonal measurements are expressed as medians and interquartile range (IQR). \( \text{GR}_{\text{ORTH}} \) represents the recommended way to determine growth rate of AAAs and the rest of methods are compared with the latter using a Wilcoxon-rank sum test.

3. Results

Axial measurements of AAA maximum diameter were consistently higher than orthogonal measurements. A mean \( D_{\text{AXIAL}} - D_{\text{ORTH}} \) of 2 mm ± 2.7 was found and this was statistically significant (\( P < 0.001 \)). The range of this difference was 0–12.3 mm. In total there were twelve out of sixty CT scans where maximum diameter using axial measurements exceeded 5.5 cm that is the threshold for surgical repair, in the same time that orthogonal measurements were under this critical value. Therefore discrepancies between measurements due to overestimation of maximum diameter using axial cross sections, would have lead to surgical intervention in 20% (12 out of 60 CTs) of the subjects examined that would be inappropriate according to current guidelines.

\( \text{ShapeIndex} \) tended to be low (high asymmetry) for AAAs that presented large discrepancies between \( D_{\text{AXIAL}} \) and \( D_{\text{ORTH}} \). By plotting \( D_{\text{AXIAL}} - D_{\text{ORTH}} \) against \( \text{ShapeIndex} \) it was noticed that for cases without significant asymmetry, differences rarely were remarkable. On the other hand when there was increased asymmetry larger differences between the two measurements could be observed. Specifically setting a threshold of \( \text{ShapeIndex} < 0.8 \), cases with \( D_{\text{AXIAL}} - D_{\text{ORTH}} \geq 5 \text{mm} \) could be identified with a sensitivity of 83.3% whereas the negative predictive value was 98% as it is represented in Fig. 3.

Mean follow up period of patients was 11.9 months. For this time interval median[IQR] \( \text{GR}_{\text{ORTH}} \) was measured 2.3(3.5) mm. \( \text{GR}_{\text{AXIAL}} \) presented a median value of 3.3(4.5) mm. Due to consistent overestimation of maximum diameter using axial measurements, \( \text{GR}_{\text{ORTH-AXIAL}} \) provided the lower values of growth rate with a median of 0.9(3.2) mm, while \( \text{GR}_{\text{AXIAL-ORTH}} \) was higher presenting a median of 4.9(4.8) mm. The difference between \( \text{GR}_{\text{ORTH}} \) and \( \text{GR}_{\text{AXIAL}} \) was not statistically significant (\( P = 0.2 \)). On the other hand differences between \( \text{GR}_{\text{ORTH}} \) and \( \text{GR}_{\text{ORTH-AXIAL}} \) as well as \( \text{GR}_{\text{AXIAL-ORTH}} \) were statistically significant (\( P < 0.001 \)). The growth rate as it was determined for each sequential pair of CTs using axial or orthogonal measurements is displayed in Table 1.

4. Discussion

\( \text{AAA} \) probably represents the only surgical condition in which size is such a critical determinant of the need for intervention. Currently aneurysm size, as determined by its maximum diameter, as well as growth rate, are used as the only variables for the recommendation of elective repair [3]. The importance of these parameters is reflected by the large randomized trials that have been conducted to elicit the appropriate cutoff point beyond which the risk of rupture probably outweighs the morbidity and mortality associated with treatment [4,5]. These landmark studies either use ultrasound (UKSAT) to define aneurysm size or CT, but without the use of 3D reconstruction (ADAM) [11,12]. Both suggest a threshold of 5.5 cm to consider open elective repair of AAA appropriate.

The advents of endovascular aneurysm repair, thin-slice CT, digital imaging as well as technological advances that have made the 3D reconstruction of CT images of AAAs feasible, have changed the standards for reporting in aneurysm size. Currently measurements that use 3D reconstruction to record maximum AAA diameter perpendicular to vessel centerline are considered more accurate since they are not sensitive to errors due to tortuosity, extensive angulation or high regional curvature of the vessel, which can influence measurements on an axial plane. Although the current Society of Vascular Surgery recommendations require 3D reconstruction to produce a view of the aorta perpendicular to its centerline, this reconstruction is not always available and measurements in both axial and orthogonal planes are being used indiscriminately [6].

Recently there are data reported in the literature, with regard to discrepancies between recordings of maximum diameter using US and CT measurements on various planes which do not take into consideration discrepancies of the second determinant of the need for surgical intervention that is growth rate [7,13]. Our goal was to record mismatch between axial and perpendicular CT measurements with concern to maximum diameter and growth rate as calculated using recordings on different planes of the vessel. Moreover since this was performed for AAAs under or close to the thresholds for elective repair we attempted to define if there are any significant implications of such discrepancies in terms of therapeutic decisions. Furthermore we related sectional shape of AAA on an axial plane, to differences between \( D_{\text{AXIAL}} \) and \( D_{\text{PERP}} \) in an attempt to define a threshold of asymmetry beyond which large differences should be expected. Sectional shape of AAA on an axial plane as it is proposed here can be easily determined from 2D CT slices.
To the best of our knowledge, this is the first study that attempted to evaluate discrepancies in the method used to evaluate AAA diameters using computational model analysis. Our results indicated a consistent overestimation of aortic diameter when measured on an axial plane compared to perpendicular measurements. This was observed in almost all AAAs and the mean value of this difference was 2 ± 2.7 mm that was found statistically significant (P < 0.001) and which is in agreement with others that indicate an overestimation of maximum diameter using axial measurements ~3 mm [7]. Although this difference is low so that therapeutic decisions should not be influenced, there was a wide variance among cases. Frequently differences were high enough to cause deficiencies in management and in particular cases exceeding 10 mm. Therefore with regard to the same AAA, based on axial measurements someone would have proposed surgical intervention at the same time that orthogonal measurements would have lead to conservative management and surveillance. Specifically this was observed in 20% of CTs under evaluation in the current study.

Moreover AAAs asymmetry as it was depicted by ShapeIndex could differentiate between cases where axial measurements would overestimate maximum diameter and cases where such measurements did not significantly differ from those on an orthogonal plane. A ShapeIndex ≤ 0.8 predicted $D_{\text{AXIAL}} - D_{\text{ORTH}} \geq 5$ mm with a sensitivity of 83.3%, whereas it presented a negative prognostic value of 98%. Conversely a ShapeIndex > 0.8 practically excludes the possibility of differences between the two measurements that exceed 5 mm and for these AAAs axial measurements probably determine maximum diameter and thus aneurysm size accurately. On the other hand high regional asymmetry (ShapeIndex < 0.8) should raise suspicion for significant overestimation of maximum diameter. For these AAAs orthogonal measurements should be obtained because an overestimation of more than 5 mm is likely to occur which might mislead the treating physician. As it can be seen in Fig. 4, sections perpendicular to vessel centerline are usually symmetrical representing the actual size of the vessel while axial sections can be asymmetrical resulting in a significant overestimation. Therefore the use of the ShapeIndex is expected to reduce uncertainty when determining aneurysm size without the use of 3D reconstruction, and furthermore diminish the time needed by the radiologist to evaluate an AAA since it will not be necessary to perform perpendicular measurements in every case.

Furthermore growth rate of AAAs that also serves as a determinant for elective repair also varied among different measurements. When growth rates were estimated using orthogonal or axial measurements consistently, differences were not statistical significant (median $GR_{\text{ORTH}} = 2.3$ mm, median $GR_{\text{AXIAL}} = 3.3$ mm, $P = 0.2$). On the other hand, there were important discrepancies when these methods were used indiscriminately. Compared to growth rates determined using orthogonal measurements in both initial and follow up CTs as currently recommended ($GR_{\text{ORTH}}$), $GR_{\text{AXIAL}}$ significantly

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**Table 1**

Growth rates of AAAs as calculated using axial and orthogonal measurements in all possible combinations. Medians are provided. With reference to $GR_{\text{ORTH}}$, statistical significance of differences between measurements is evaluated and P values are reported. (D1: maximum diameter at initial CT; D2: maximum diameter at follow up; ORTH: Orthogonal measurements; AXIAL: axial measurements; GR: growth rate).

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overestimated (median 4.9 mm, \( P < 0.001 \)) and GRORTH-AXIAL underestimated (median 0.9 mm, \( P < 0.001 \)) the actual growth rate of AAAs, which is a possible scenario when different examiners from different diagnostic centers evaluate the initial and next CTs. Since this is commonly encountered in the clinical practice, deficiencies in terms of therapeutic strategies may arise.

5. Conclusion

There is a consistent overestimation of AAAs maximum diameter when measured on an axial plane compared to orthogonal measurements. Although the mean difference between measurements is low there is a wide range among cases that frequently can influence therapeutic decisions. This is mainly observed in AAAs with high regional asymmetry and in such cases orthogonal measurements should be pursued to determine actual aneurysm size. The proposed ShapelnIndex may offer an initial easy diagnostic tool to identify those AAAs most likely to be overestimated and are in need of a more focused evaluation. Growth rates of AAAs should be calculated using the same method of measurements in both CTs otherwise there can be significant discrepancies.

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