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# Correlation between transversal and orthogonal maximal diameters of abdominal aortic aneurysms and alternative rupture risk predictors

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ABSTRACT

*Purpose:* There is no standard for measuring maximal diameter (Dmax) of abdominal aortic aneurysm (AAA) from computer tomography (CT) images although differences between Dmax evaluated from transversal (axialDmax) or orthogonal (orthoDmax) planes can be large especially for angulated AAAs. Therefore we investigated their correlations with alternative rupture risk indicators as peak wall stress (PWS) and peak wall rupture risk (PWRR) to decide which Dmax is more relevant in AAA rupture risk assessment.
*Material and methods:* The Dmax values were measured by a trained radiologist from 70 collected CT scans, and the corresponding PWS and PWRR were evaluated using Finite Element Analysis (FEA). The cohort was ordered according to the difference between axialDmax and orthoDmax ($D_{a-o}$) quantifying the aneurysm angulation, and Spearman's correlation coefficients between PWS/PWRR – orthoDmax/axialDmax were calculated.
*Results:* The calculated correlations PWS/PWRR vs. orthoDmax were substantially higher for angulated AAAs (with $D_{a-o} \geq 3mm$). Under this limit, the correlations were almost the same for both Dmax values. Analysis of AAAs divided into two groups of angulated (n=38) and straight (n=32) cases revealed that both groups are similar in all parameters (orthoDmax, PWS, PWRR) with the exception of axialDmax (p=0.024).
*Conclusions:* It was confirmed that orthoDmax is better correlated with the alternative rupture risk predictors PWS and PWRR for angulated AAAs ($D_{A-O} \geq 3mm$) while there is no difference between orthoDmax and axialDmax for straight AAAs ($D_{A-O} < 3mm$). As angulated AAAs represent a significant portion of cases it can be recommended to use orthoDmax as the only Dmax parameter for AAA rupture risk assessment.

## 1. Introduction

An abdominal aortic aneurysm (AAA) can be characterized as a permanent and progressive focal dilatation of abdominal aorta by more than 50% compared to its infrarenal diameter [1]; it affects predominantly older population [2], typically males over 65 years and smokers. Gradual enlargement of AAA increases also the risk of AAA rupture which is a life-threatening event with mortality of about 50% [3].

On the other hand, not all aneurysms do rupture during the patient´s life, and also their surgical treatment is not free of risk [4]. Thus, a lot of effort has been put in estimating parameters capable to identify the risky AAAs. Maximal AAA diameter and speed of growth are generally the most accepted criteria in clinical practice. Currently, the available guidelines [5] recommend treatment when the maximal AAA diameter (Dmax) exceeds 55 mm (50 mm for females) or it grows by more than 5 mm per six months or when the AAA becomes symptomatic (low back pain or abdominal pain with no other known reason).

Although Dmax is the most widespread parameter applied for the decision on surgery, its evaluation may be imprecise with values differing by up to 8 mm for an individual AAA [6]; evidently this occurs due to the irregular shape of AAA, see Fig. 1. The maximum difference in measurement is higher than an average AAA growth in three years [7] thus it can significantly affect the treatment decision for an individual patient. Dmax may depend on the screening methods, axis of measurement and position of callipers (if internal or external Dmax is measured) but most importantly on the plane of Dmax acquisition.

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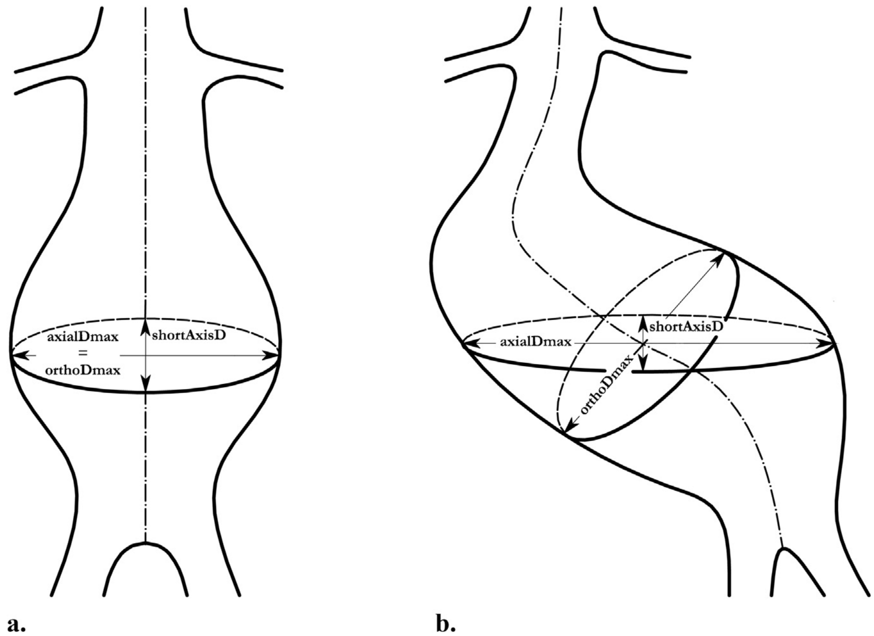


**Fig. 1.** Schematic drawing of straight (a.) and angulated or tortuous (b.) AAAs with visualized axial and orthogonal cross-sections. For a straight AAA both axial and orthogonal planes coincide and thus axialDmax=orthoDmax. On the contrary, both of these diameters differ substantially for an angulated AAA.

Although there are various methods of measurement, there is no consensus which one is the most appropriate to measure Dmax [6], especially from CT-A slices. Some investigators [8,9] measure Dmax in transversal plane, i.e. on axial slices. Others propose to measure the antero-posterior diameter [10–12] or the transverse diameter [10]. Ouriel [13] and then others [14,15] suggest to assess the AAA on the basis of the minor axis of the ellipse (ShortaxisD – [16]) fitted to the axial slice of AAA. Their reasoning is based on similarity with a tube which is cut by a plane not perpendicular to its centreline; the cut looks also elliptical in the section plane and the minor axis of this ellipse represents the true diameter of the tube. However this approach underestimates the Dmax for straight AAAs with elliptical cross section. Finally, there is also a recommendation to measure orthoDmax i.e. Dmax in a plane perpendicular to the AAA centreline [5,17,18], to eliminate the risk of overestimating the true AAA diameter. Comparative analyses of the mentioned Dmax values revealed that axialDmax is larger than orthoDmax [16,19].

From biomechanical point of view the orthoDmax seems to be more relevant. Unlike the axialDmax, orthoDmax is independent of the AAA angulation [19] and, moreover, it represents better the principal curvature which defines the membrane stress in the AAA wall via the well-known law of Laplace. The review by Khosla [20] and references therein show the peak wall stress (PWS) or peak wall rupture risk (PWRR — wall stress to local strength ratio) to have consistently better capability to discriminate between risky and safe AAAs than any Dmax value. This suggests those criteria as potential candidates for improving the reliability of AAA rupture risk assessment although their predictive capability has not yet been tested in a blinded study.

Therefore we have decided to investigate the relationship between axialDmax/orthoDmax and PWS/PWRR in order to test which of the Dmax definitions have overall better correlation with the aforementioned alternative rupture risk indicators with emphasis on the AAA angulation. Secondary, we also investigated the agreement between orthoDmax estimated by a radiologist and by A4clinics™ software (Vascops GmbH, Austria, Graz).

## 2. Material and methods

### 2.1. Selection of cases

This study was performed in accordance with the Helsinki Declaration and informed consent was waived by the Institutional Review Board. We have searched through the database of computed tomography - angiography (CT-A) scans of unruptured and asymptomatic AAAs at St. Anne´s University Hospital in Brno and General University Hospital in Prague. We included a case only if the data contained axial slices with spacing no more than 3 mm. This is necessary for a reliable geometry reconstruction as described below. No other selection criteria were applied. Overall 70 cases have been included in the study; all of them were fusiform, as typical for AAAs [21], so conclusions derived in this study cannot be applied to other shapes or etiologies of aneurysms.

All CT-A scans were obtained, according to a standardized protocol, using a GE Light speed VCT 64-slice CT scanner, after an intravenous injection of contrast IOMERON 400. The standard images acquisition was at slice thickness of 0.625 mm, collimation of 64×0.625 at 120 kV; 280 mA and an increment of 0.625 with a pitch of 0.7.

Then we used the A4clinics™ software to reconstruct the AAA geometries. Detailed information regarding the technique of reconstruction can be found elsewhere [22]. Briefly, the user defines a virtual balloon inside the 3D image set that expands by the action of an inflation pressure until boundaries between the lumen and intraluminal thrombus (ILT), as well as between aneurysmal wall and the surrounding tissue, are detected. The boundaries are defined by prescribing a proper level of Hounsfield units for each structure. This technique provides smooth surface geometry which was further used as input for the finite element analysis (FEA).

### 2.2. Finite element analysis

FEA is largely used to estimate wall stress in irregular geometries