Morphologic evaluation of ruptured and symptomatic abdominal aortic aneurysm by three-dimensional modeling

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Objective: **To identify geometric indices of abdominal aortic aneurysms (AAAs) on computed tomography that are associated with higher risk of rupture.**

Methods: **This retrospective case-control, institutional review board-approved study involved 63 cases with ruptured or symptomatic AAA and 94 controls with asymptomatic AAA. Three-dimensional models were generated from computed tomography segmentation and used for the calculation of 27 geometric indices. On the basis of the results of univariate analysis and multivariable sequential logistic regression analyses with a forward stepwise model selection based on likelihood ratios, a traditional model based on gender and maximal diameter (Dmax) was compared with a model that also incorporated geometric indices while adjusting for gender and Dmax. Receiver operating characteristic (ROC) curves were calculated for these two models to evaluate their classification accuracy.**

Results: **Univariate analysis revealed that gender ($P = .024$), Dmax ($P = .001$), and 14 other geometric indices were associated with AAA rupture at $P < .05$. In the multivariable analysis, adjusting for gender and Dmax, the AAA with a higher bulge location ($P = .020$) and lower mean averaged area ($P = .005$) were associated with AAA rupture. With these two geometric indices, the area under the ROC curve showed an improvement from 0.67 (95% confidence interval, 0.58-0.77) to 0.75 (95% confidence interval, 0.67-0.83; $P < .001$). Our predictive model showed comparable sensitivity (64% vs 60%) and specificity (79% vs 77%) with current treatment criteria based on gender and diameter at the point optimizing the Youden index (sensitivity + specificity − 1) on the ROC curve.**

Conclusions: **Two geometric indices derived from AAA three-dimensional modeling were independently associated with AAA rupture. The addition of these indices in a predictive model based on current treatment criteria modestly improved the accuracy to detect aneurysm rupture. (J Vasc Surg 2014;59:894-902.)**

Abdominal aortic aneurysm (AAA) affects 2% of the elderly population,[1] and the prevalence increases by 2% to 4% per decade.[2,3] The main complication of untreated AAA is rupture, with 90% associated mortality.[4] The main predictors of rupture risk are the maximal diameter (Dmax) and the expansion rate of the aneurysm. For instance, the annual rupture risk of 6 to 7 cm aneurysm is 10% to 20%.[5] Follow-up of the AAA is necessary to determine when an intervention is warranted. Based on the rupture risk, mortality rate in elective procedure, and life expectancy of the patient, the Society for Vascular Surgery (SVS) has issued recommendations regarding AAA treatment.[6] The main indications for a procedure are Dmax ≥5.5 cm in men, ≥5.0 to 5.4 cm in women, or symptomatic AAA.

However, the maximum diameter criterion should be revisited for two reasons. First, the estimated annual rupture rate of 4.0 to 4.9 cm AAA, is small yet non-negligible, in the range of 1.0% per year.[7] Second, recent technological advances in segmentation methods and

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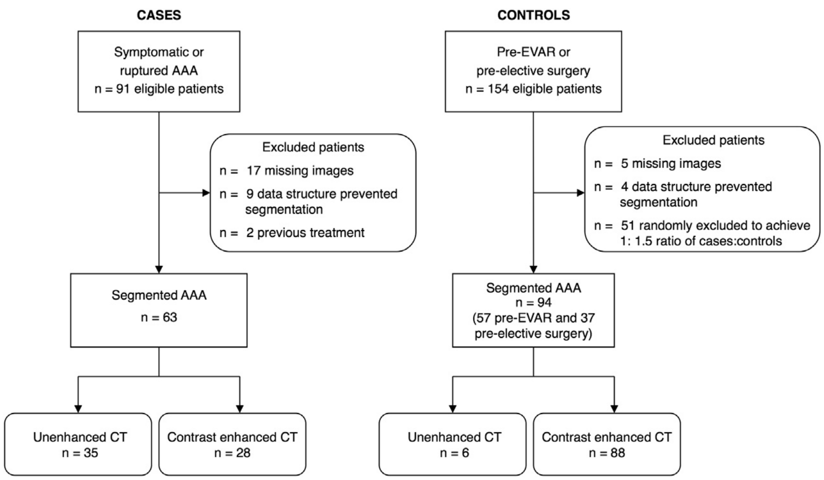

Fig 1. Study flowchart. *AAA,* Abdominal aortic aneurysm; *CT,* computed tomography; *EVAR,* endovascular aneurysm repair.

computer modeling have raised the possibility of patient-specific risk prediction based on AAA geometry.[8,9]

It was previously tedious to perform volumetric analysis of AAA because this required manually delineating the contours of AAA wall and thrombus on hundreds of images. To circumvent this limitation, semiautomated AAA segmentation and three-dimensional (3D) modelization software recently developed[10-12] provide the ability to extract AAA geometric parameters from computed tomography (CT) studies.[13-15]

We hypothesized that the knowledge of AAA geometric parameters, as defined by size and shape indices derived from AAA segmentation, would be helpful to improve the prediction of rupture risk, which presently relies on maximal diameter measurement and gender. Since it would be impossible to perform a prospective observational study on AAA rupture risk, we designed a retrospective case-control study comparing ruptured or symptomatic cases with asymptomatic controls awaiting endovascular aortic repair (EVAR) or open surgical repair.

Thus, the purpose of this study was to identify geometric indices that are associated with AAA rupture at CT.

METHODS

Study design and subjects. Our study was approved by the Institutional Review Boards of the two participating tertiary hospitals. Informed consent was waived for this retrospective case-control study.

Subjects were eligible in this study if (1) they had an AAA, defined by a Dmax threshold equal or larger than 3.5 cm, (2) they underwent a CT during their admission between January 2001 and August 2009, and (3) if the CT was available in DICOM format at one of the two participating centers. This time interval for patient selection was defined to coincide with our picture archiving and communication system records.

Subjects were excluded if (1) their CT had missing images, (2) the structure of the dataset prevented segmentation, or (3) they had previously undergone aortic open or endovascular repair or bypass surgery.

The medical archives were used to select cases whose main admission diagnosis was ruptured or symptomatic preruptured AAA. A ruptured aneurysm was defined as a painful aneurysm with the presence of a retroperitoneal hematoma adjacent to the AAA on the CT scanner (n = 44). An impending or contained AAA rupture was defined as a painful aneurysm in the presence of (1) a bulge with a focal wall discontinuity (n = 19), (2) periaortic fat infiltration (n = 4), (3) an intramural hematoma manifested by a hyper-attenuating crescent sign (n = 33), or (4) a draped aorta sign (the posterior wall of the aorta molds the contour of adjacent vertebral bodies and becomes indistinct from adjacent structures) on the CT scanner (n = 32).[16] The sum of patients with each of these inclusion criteria exceed the total number of patients with ruptured and symptomatic AAA due to the concomitant presence of more than one inclusion criterion in several patients. Patients with an inflammatory aneurysm (painful aneurysm with circumferential thickening of aortic wall without bulge) were excluded. A registry was used to select controls who underwent elective EVAR or open surgical repair during the same time period. Our dataset consisted of 63 cases with ruptured or impending or contained ruptured AAA and 94 randomly selected controls to achieve a 1:1.5 ratio (Fig 1).

Data collection. Two of the authors reviewed the laboratory data, medical records, official surgical notes, and discharge summaries of all patients. Medical records were queried to record the patient characteristics, medication list, and biochemical results most contemporaneous to CT examinations, as recorded in their charts.

CT imaging technique. Studies collected from participating institutions, or referring centers for evaluation of symptomatic AAA, were performed with 1-, 4-, 16-, or 64-section CT scanners with volumetric coverage of the entire abdomen and pelvis. Depending on scanner and local protocol of each hospital, section thickness between 0.625