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THE ROLE OF SHAPE FOR ANEURYSM RISK ASSESSMENT

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SUMMARY

Although the shape of intracranial aneurysms and the geometry of the surrounding vasculature are commonly taken into account by clinicians when assessing and treating aneurysms, it remains difficult to quantify shape and develop clinical guidelines or tools that accommodate aneurysm shape. Here, we present new evidence that aneurysm shape is a meaningful proxy for disease status, the results of a benchmark analysis comparing novel and established measurement methods for their ability to discriminate between ruptured and unruptured aneurysms, and how these findings can be translated into clinics. We conclude with a plea for multi-centric data collections and present our own contributions to it.

Key words: *Intracranial aneurysms, morphology, data-driven analysis*

1 INTRODUCTION

Intracranial aneurysms (IAs) have a complex pathobiology and are therefore difficult to assess clinically. Confronted with an increased rate of incidentally diagnosed unruptured IAs, clinicians are in need of a marker for disease instability to better balance the risks of rupture against the risks of treatment. In this context, aneurysm shape has been proposed as a candidate for such an image-derived marker. This is supported by pathophysiological evidence, which suggests that structural changes in the aneurysmal wall are linked to macroscopic deformations of the wall. [1, 2]. Furthermore, the local geometry of aneurysms governs the blood flow and the fluidic forces exerted on the vessel wall. Variations of these forces have been associated with wall damage, aneurysm initiation and growth [3, 4, 5]. Finally, angiographic imaging is a non- or low-invasive utility readily available in clinics from which aneurysm shape can be inferred by radiologists.

This wealth of evidence is contrasted by the lack of guidelines that address morphology quantitatively. To date, the assessment of aneurysm shape is based mainly on the subjective opinion of the clinician. The purpose of this contribution is to emphasis the diagnostic value of aneurysm shape (especially irregularity), to benchmark different morphometrics and to examine how shape relates to the disease status.

2 METHODOLOGY

2.1 Imaging and patient data

The data used for this study are part of the AneuX morphology database, a collection of 3D geometric models of totally 750 IAs (261 ruptured, 474 unruptured). The main portion of the data ($n = 357$ IAs) was collected prospectively and consecutively between September 2006 and July 2015 at the Geneva University Hospital (HUG). For external model validation, data from the publicly available @neurIST ($n = 151$) and Aneurisk ($n = 97$) projects [6, 7] were included.

All geometric datasets, represented as 3D surface meshes, have been extracted from 3D rotational angiography (3DRA) and processed following a very similar procedure. A collection of exemplary geometries is given in Figure 1. In addition, the data include patient age, sex, as well as the rupture status and anatomical location of the aneurysm.

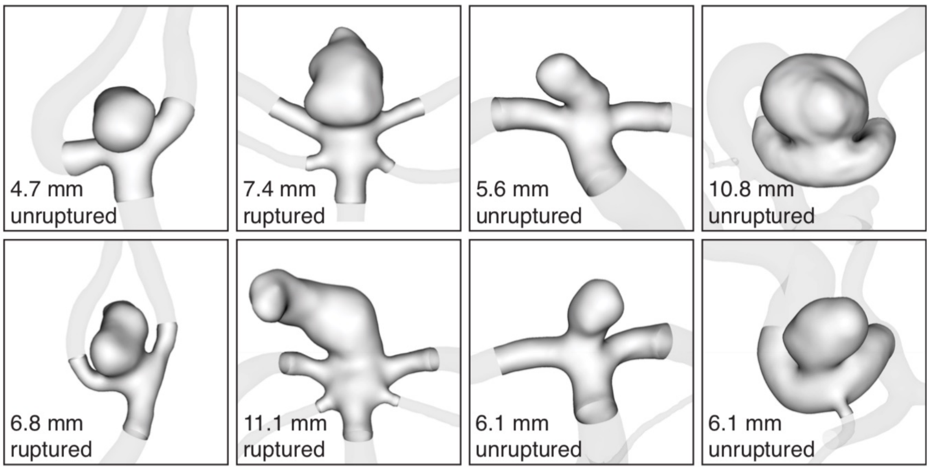

Figure 1: A selection of aneurysm geometries from the AneuX morphology database

2.2 Morphological data

A set of 150 different morphometric indices were computed, covering established and novel metrics for size and shape, curvature, writhe, as well as Zernike moment invariants [8, 9, 10, 11]. The only non-morphometric feature included in the set of possible predictors was aneurysms location.

2.3 Benchmarking

Following a method involving LASSO logistic regression with 5-fold cross validation, we analyzed the predictive ability for a collection of univariate and multivariate model. The goal was to identify morphological features that are able to identify the subtle differences between ruptured and unruptured aneurysms. We examined how the predictors generalize for external datasets. To compare the predictive performance of the models, we report here the area under the receiver operating characteristic (ROC-AUC, mean $\pm$ standard deviation of multiple model evaluations)

For better interpretation of the morphometric features, we also examined the association of morphometrics with shape characteristics qualitatively perceived by human raters such as shape irregularity, presence of blebs. [12, 13]

3 RESULTS AND CONCLUSIONS

Non-sphericity (NSI, AUC $= 0.80 \pm 0.05$), total curvature (GLN, AUC $= 0.80 \pm 0.05$), surface-normalized mean writhe ($\bar{W}^{L_1}_{mean}$, AUC $= 0.78 \pm 0.04$), and normalized ZMI energy (Z_6^{surf}, AUC $= 0.80 \pm 0.05$) were among the best univariate predictors for aneurysm rupture (data based on HUG data only). Interestingly, those metrics correlate well with perceived irregularity. [12]. Aneurysm location was a good predictor for rupture on its own (AUC $= 0.78 \pm 0.04$). Combination of shape and location significantly improved the prediction accuracy (e.g. NSI and location: AUC $= 0.87 \pm 0.04$).

Our analysis further revealed that in this monofactorial setup, the decision boundaries to discriminate ruptured and unruptured aneurysms varied for different datasets. We identified multiple discrepancies between the data sources used in this study (HUG, Aneurisk, @neurist). A multifactorial analysis and larger, multi-centric studies with compatible data collection protocols will improve the generalizabiliy and utility of data-driven methods.

This study is based on 3DRA, an angiographic method offering high contrast and resolution when compared with computed tomography angiography (CTA) and magnetic resonance angiography (MRA). Next, these findings need to be reproduced on MRA and CTA data, which are the primary diagnostic tools to diagnose IAs.

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