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The blood flow channel index as novel predictor of abdominal aortic aneurysm impending rupture based on the intraluminal thrombus angio-CT study

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ABSTRACT

Objective: In this study the hypothesis that the thickness of the thinnest part of the thrombus, combined with bleeding into the intraluminal thrombus (ILT), is associated with a possible higher risk of abdominal aortic aneurysm (AAA) rupture was investigated, independently of aneurysm diameter, by using angio-CT. This article describes blood flow channel index based on the CT imaging findings that may help identify impending rupture prior to complete rupture.
Methods: Computed tomographic images of 310 hospitalized patients with infrarenal AAA, were collected over a three-year period. They were divided into two main groups: 125 with bleeding into the ILT and control group 185 without the presence of blood in the thrombus. Patients were also analyzed in subgroups with ruptured, symptomatic and asymptomatic AAAs. A blood flow channel index was formulated as: maximal/minimal thickness ratio of thrombus from the same CT scan.
Results: In dissected ILT group blood flow channel index was over a twofold higher than in group with intact ILT (19.0 [1.2–89.3] vs. (9.7 [1.3–38.9]; $p < 0.001$), respectively. Median thickness at the thinnest part of the ILT in dissected thrombus group was lower (1.3 mm [0.3–16.0]) than in group with intact ILT (1.7 mm [0.2–23.4]; $p < 0.003$).
Conclusion: An association between a high blood flow channel index and bleeding into the ILT based on angio-CT study was demonstrated, and can suggest the aneurysm propensity for rupture.

1. Introduction

The prevalence of abdominal aortic aneurysm (AAA) among men older than 55 years of age can be up to 10%, but AAAs usually remain asymptomatic until they rupture. The frequency of occurrence of an AAA, the frequency of rupture of aneurysm causing death, and the incidence of rupture has been variously reported over the last few years [1–5]. The rupture of a large AAA has a mortality rate of up to 90%, and 2% of all deaths are related to an AAA [6]. The process of aortic rupture remains poorly understood, with a lack of adequate noninvasive imaging and biological insight. Therefore, crucial aspect of AAA diagnosis lies in the early detection of the aneurysm and its propensity for rupture.

The current dearth of effective medical treatments is attributed to insufficient understanding of the mechanisms underlying the initiation, progression and rupture of AAAs. The most commonly used predictor of rupture of an AAA is the diameter of the aneurysm [7], but this does not correlate well with the risk of rupture. Therefore, in order to make further improvements in clinical decisions regarding AAA patients, the development of additional predictive tools other than aneurysm size alone is needed.

Approximately 75% of all AAAs have varying degrees of intraluminal thrombus (ILT) [8], which is a three-dimensional fibrin network infiltrated with blood cells, platelets, and blood proteins, and appears to be a self-sustaining biologically active structure [9]. An ILT of variable size and wall-covering surface is an important structural feature of a human AAA and attention has been drawn to its potential role in aneurysmal evolution and rupture. It is thought that if an ILT is thick, that this theoretically would

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contribute to a lowering of stress values by acting as mechanical buffer. However, an eccentric intraluminal thrombus which is crescent-shaped (i.e. with thin and thick portions) is present in 97% of intact aneurysms, with a similar frequency in those ruptured [10]. This implies that there are blood flow channels (BFC) through an ILT of various lengths, and in consequence varying physical and biochemical interactions between the blood and the walls of an AAA across different portions of the ILT. The cause of high-attenuating crescents on computed tomographic (CT) scans in a ruptured aneurysm may be attributed to hemorrhage in the mural thrombus [11]. If there are cracks in the ILT that connect the lumen with the AAA wall then these can cause a two-fold increase in the physical stress in the underlying wall, and therefore if the ILT fissures reach the wall or involve large parts of the ILT, then the resulting increase in wall stress could possibly cause AAA rupture [12].

The inclusion of ILT features in the stress analysis of AAAs is of importance and would likely increase the accuracy of predicting the risk of AAA rupture. Additionally, the ambiguous role of ILT in the pathogenesis of AAAs needs to be clarified, as on the one hand they contribute to a lowering of stress values by acting as mechanical buffer but, on the other hand, they have been associated with higher AAA growth rates due to the generation of elastolytic enzymes, leading to wall degradation and thus predisposing to weakening of the AAA wall. We hypothesize that a thin portion of the thrombus-covered wall of an AAA contributes, through biomechanical and biochemical mechanisms, to an enhanced propensity for rupture.

2. Methods

2.1. Patient population

We searched computerized medical records to identify patients with bleeding into the thrombus who had been admitted to two Departments of Vascular Surgery and Angiology during over a three-year period. The inclusion criterion was that the patient had undergone multislice computed tomography (MSCT; Somatom Definition AS, Siemens, Erlangen, Germany) where the scans showed dissections of the thrombus and also, in some cases in which the AAA had ruptured, where signs of retroperitoneal bleeding were shown. Subjects with symptomatic and asymptomatic AAA with bleeding into the ILT or without the presence of blood in the thrombus who were not operated on, or who had had endovascular repair, were also included in the study. Patients with suprarenal and inflammatory aneurysms were excluded. A total of 125 patients, i.e. 100 men, 25 women, mean age 72.1 years (y), with bleeding into the thrombus were identified. A “crescent sign” or localized areas with higher attenuation in the ILT were interpreted as signs of bleeding in the thrombus. We measured the attenuation in Hounsfield units in the ILT using CT software to indicated the presence of blood in the thrombus. As controls, we analyzed CT scans of 185 patients (156 men, 29 women, mean age 71.2 y) with comparable age and AAA diameters, who had been diagnosed with intact ILT, because of absence of ILT bleeding and had been operated on or had had endovascular repair at the Departments of Vascular Surgery and Angiology over the same time period. Approval for the study was granted by a university ethics review board.

In order to establish the ILT thickness, measurements in the cross-section were performed in the middle 1/3 of the longitudinal dimension where the aneurysm diameter was greatest, because seventy-three percent of the ruptures occurred just in this location [13]. We measured thrombus thickness, before the intervention, by using medical imaging software (OsiriX MD 64-bit software version 2.6; certified for medical imaging; Pixmeo, Bernex, Switzerland), in an axial slice, at the level of the aneurysm sac where the thinnest

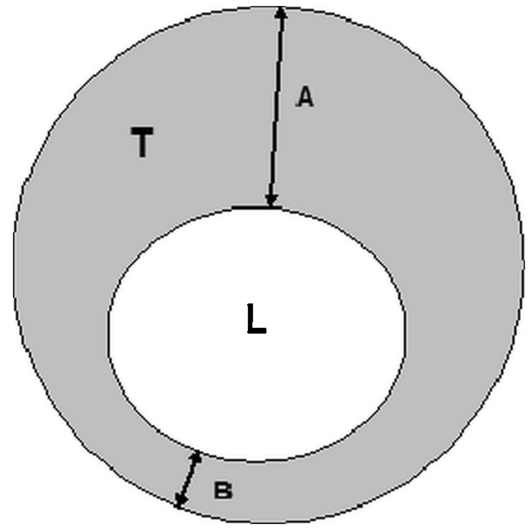

Fig. 1. BFC index as the maximal – A/minimal thickness – B of the ILT.

ILT was localized. A BFC index was then calculated as the maximal/minimal thickness of the ILT (Fig. 1), the ratio calculated from one CT scan.

2.2. Computerized tomography

CT plays a central role in the diagnosis, risk stratification and management of most aneurysms. Advantages of CT over other imaging modalities include rapid image acquisition, its multiplanar capacity with submillimetric spatial resolution and wide availability. The main limitations of CT are the radiation exposure and need for nephrotoxic contrast administration. Two radiologists with fifteen years professional experience independently reviewed all the scans. All patients had undergone MSCT examination with contrast enhancement in the arterial phase and the slice thickness was 0.6 mm. The rupture site was identified in patients with a clear leakage of contrast from the aortic lumen through the aortic wall or where discontinuation in the aortic wall with the presence of an adjacent periaortic hematoma could be seen (Fig. 2). It was possible to perform reconstructions from very thin slices in all patients.

2.3. Statistical analysis

Comparison of the groups was performed with *U* Mann–Whitney test for non-parametric data. Receiver Operating Curves (ROC) were generated for Area Under Curve (AUC) calculations. Correlation of two parametric variables (BFC index with the thickness of thinnest part of ILT) was performed by Spearman regression analysis. Relative variable autocorrelations were excluded in discriminant analysis by means of Wilk’s Lambda test. Statistical analysis was performed by Statistica.pl (Stat Soft, version 5.0) and MedCalc (MedCalc Software, trial version 12.6.0). In all tests a *p*-value less than 0.05 was considered as significant.

3. Results

Morphological parameters of aneurysms and BFC indices were compared and are presented in Table 1. Median thickness of the thinnest part of an ILT in AAA patients with bleeding into the thrombus was less (1.3 mm [0.3–16.0]) than in group with intact ILT (1.7 mm [0.2–23.4]; $p < 0.003$). The BFC index median value was twice as high in the dissected ILT group (19.0 [1.2–89.3]) than in intact ILT group (9.7 [1.3–38.9]), which was a significant difference ($p < 0.001$). Furthermore, the BFC index was significantly and