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High Levels of 18F-FDG Uptake in Aortic Aneurysm Wall are Associated with High Wall Stress

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Abstract *Background:* Functional imaging using positron emission tomography (PET) showed increased metabolic activities in the aneurysm wall prior to rupture, whereas separate studies using finite element analysis techniques found the presence of high wall stresses in aneurysms that subsequently ruptured. This case series aimed to evaluate the association between wall stress and levels of metabolic activities in aneurysms of the descending thoracic and abdominal aorta.
Methods: Five patients with aneurysms in the descending thoracic aorta or abdominal aorta were examined using positron emission tomography–computed tomography (PET-CT). Patient-specific models of the aortic aneurysms were reconstructed from CT scans, and wall tensile stresses at peak blood pressure were calculated using the finite element method. Predicted wall stresses were qualitatively compared with measured levels of 18F-fluoro-2-deoxy-glucose (18F-FDG) uptakes in the aneurysm wall.
Results: The distribution of wall stress in the aneurysm wall was highly non-uniform depending on the individual geometry. Predicted high wall stress regions co-localised with areas of positive 18F-FDG uptake in all five patients examined. In the two ruptured cases, the locations of rupture corresponded well with regions of elevated metabolic activity and high wall stress.
Conclusions: These preliminary observations point to a potential link between high wall stress and accelerated metabolism in aortic aneurysm wall and warrant further large population-based studies.

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Abdominal aortic aneurysm (AAA) is an important cause of deaths in Western society, especially among elderly patients. Rupture of AAA is responsible for approximately 1.3% of all deaths in men.[1] The fact that not all AAA would eventually rupture has created a dilemma for surgeons with regard to treatment choice: Is it necessary to operate on all patients, or should we reserve prophylactic surgery only for a subgroup where factors indicative of a probable rupture could be identified? Diameter of the aneurysm is the most important factor in the decision to repair an aneurysm, but rate of enlargement is usually taken into account where watchful surveillance is employed for sub-surgical cases.[2]

On the one hand, although the size of the aneurysm still remains the most widely accepted predictor of rupture, small AAAs may also rupture. In their preliminary study, Sakalihasan et al.[3] by means of combined positron emission tomography and computed tomography (PET-CT) examination, observed positive correlation between clinically unstable AAA and positive uptake of 18F-fluoro-2-deoxy-glucose (FDG) in the aneurysm wall. Elevated FDG uptake was also related to the presence of a high density of inflammatory cells (e.g. macrophages and lymphocytes) in the aneurysmal aortic wall.[4] These observations have been confirmed by recent clinical and fundamental studies on *in vivo* demonstration of inflammatory cells using PET-CT.[5,6]

On the other hand, recent biomechanics studies using finite element analysis and patient-specific geometries of AAAs derived from CT scans have demonstrated that peak wall stress could be a better indicator of rupture than diameter.[7,8,9,10]

The role of biomechanical forces in the formation, propagation and ultimate rupture of aortic aneurysms has received some attention and is beginning to be better understood. Certain key mechanisms can be outlined. The initial change in the formation of an aneurysm is structural and results from a degenerative process in the vascular wall. As the morphology changes, related changes occur in the blood flow pattern, with consequential modification of fluid stresses and their interaction with the mechanical stresses within the arterial wall. The objective of this study was to investigate the role of increased metabolism in aneurysm rupture and whether this is linked with mechanical forces experienced by the affected aorta, by a combination of function imaging using PET and finite element stress analysis based on patient-specific data.

Materials and Methods

Patients

Since the first pilot study by Sakalihasan et al.[3] PET-CT examination has been performed routinely on almost all patients referred to the Department of Cardiovascular Surgery at the University Hospital of Liege, with known aortic aneurysms diagnosed initially by CT scans. Among 131 patients, the first three patients with thoracic aortic aneurysms (TAAs) in the descending aorta and two patients with abdominal aortic aneurysms (AAAs) with high FDG uptakes were included in this study. All patients had the first PET-CT examination within 2 weeks from the initial diagnostic contrast-enhanced CT scan. Thereafter, they were monitored by follow-up CT or PET-CT examinations or underwent surgical repair. The study protocol was approved by the University Hospital of Liege local ethics review board and a written informed consent and authorisation to use the images for research were obtained from the patients or their relatives.

PET-CT imaging

The PET-CT examination was performed by following the procedure described by Burger et al.[11] After a minimum of 6-h fasting, 3.7 mBq F18-FDG per kilogram body weight was injected through a peripheral vein catheter. The patient was placed in a quiet room and instructed not to move. One hour after injection of the tracer, static whole-body examination was performed with a PET-CT scanner (Discovery LS, GE Healthcare). The CT component of this scanner can acquire eight slices per X-ray tube rotation. After scout views, continuous CT was performed from the skull base to the femoral necks with the following parameters: 5 mm collimation, 50×50 cm field-of-view (FOV), 140 mA and 140 kVp, pitch of 1.5:1 and gantry rotation cycle of 0.8 s. The patients were asked to breath shallowly during CT data acquisition.

Emission and transmission images were recorded 60 min after the F18-FDG injection, at each couch position for 4—5 and 2—3 min, respectively. PET data were acquired as six consecutive coronal 4.25-mm-slice-thickness 2D scans in all patients, overlapping from 15—30% PET raw data, were reconstructed by means of ordered subset expectation maximisation (pixel matrix of 128×128 and FOV of 50 cm), with 5.86 mm full width at half maximum (FWHM) post filter and 3.91 mm FWHM loop filter model-based scatter correction (convolution subtraction) and normalisation correction. Additional attenuation correction was performed on PET data, using the CT raw data.[11] Attenuation-corrected PET and reformatted CT data were fused on a dedicated workstation (Advantage Windows, release 4.4.07, GE Healthcare). Both uncorrected and attenuation-corrected images were assessed to identify potential artifacts. The FDG uptake was defined as high when the maximum Standardised Uptake Value (SUV max) was greater than 2.5.

3D geometry reconstruction

The contrast-enhanced CT images were processed using our in-house MATLAB-based image processing toolkit, which has been tested extensively for accuracy and reproducibility.[12,13] The lumen boundary was segmented semi-automatically by using the region growing method (RGM),[14] which traces the perimeter of the lumen by seeking pixels of a selected range of intensities. Before applying the RGM, images were pre-processed by using a Gaussian filter to reduce the noise and improve image clarity. The segmented lumen contours were then assembled in 3D, and the lumenal surface was constructed by using cubic B splines. Similar procedures were followed for the segmentation and reconstruction of the outer wall surface. Since all patients included in this study presented intra-luminal thrombus (ILT) in their aneurysms, ILT was also reconstructed and