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CASE REPORT

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Computational fluid dynamics of the ascending aorta before the onset of type A aortic dissection

Pietro Giorgio Malvindi[a,*], Salvatore Pasta[b,c], Giuseppe Maria Raffa[b] and Steven Livesey[a]

[a] Wessex Cardiothoracic Centre, Southampton University Hospital NHS Trust, Southampton, UK
[b] Department for the Treatment and Study of Cardiothoracic Disease and Cardiothoracic Transplantation, Mediterranean Institute for Transplantation and Advanced Specialized Therapies (ISMETT–IRCCS), Palermo, Italy
[c] Fondazione Ri.MED, Palermo, Italy

* Corresponding author. Wessex Cardiothoracic Centre, Southampton University Hospital, Tremona Road, Southampton, SO16 6YD, UK. Tel: +44-23-80796234; fax: +44-23-80794526; e-mail: pg.malvindi@hotmail.com (P.G. Malvindi).

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Abstract

We performed a pre-dissection computational fluid analysis of an ascending aortic aneurysm associated with unicuspid aortic valve. The analysis showed an abnormal helical flow pattern inside the aneurysm and an increased wall stress on the right postero-lateral wall of the ascending aorta. These values were largely higher than the theoretical cut-off for aortic wall dissection, their topographic distribution followed the intimal tear site as subsequently diagnosed by computed tomography scan and confirmed during the operation for dissection repair.

Keywords: Aorta • Aortic dissection • Computer

Despite the growing interest in computational fluid dynamic and 4D magnetic resonance imaging (MRI) analysis, results coming from pre-dissection studies are limited [1]. Numerical methodology was applied to the pre-dissection computed tomography (CT) scan of a 26-year-old man presenting a large ascending aorta aneurysm (maximum diameter 67 mm). A concomitant transthoracic echocardiogram showed a calcified aortic valve, characterized by severe aortic regurgitation and increased transvalvular gradients (peak/mean gradient 54/27 mmHg). The patient was aware of this condition and had constantly refused an elective operation. Two months later, he developed a type A aortic dissection and underwent emergency surgical repair. Intraoperatively we found a calcified unicuspid aortic valve. Microscopic examination of the aortic wall showed severe extensive medial degenerative change, there was no evidence of inflammation, the intima showed myofibroblastic proliferation but no atheroma.

We followed a fluid–structure interaction modelling technique previously developed to study both the haemodynamic of aortic lumen and the structural loads occurring in ascending thoracic aortic aneurysms [2]. The 3D aortic arch geometry created in this study was segmented from the patient's CT scan using the vascular modelling toolkit ITK (http://www.itk.org/). The aortic anatomy was meshed into small elements to discretize the fluid domain (the aortic lumen) and the structural domain (the aneurysmal wall). To include patient-specific flow conditions and reduce the impact of theoretical assumptions, the transaortic systolic flow measurement of 3.7 m/s obtained by Doppler echocardiography was set as the inflow velocity at aortic valve. The biomechanical behaviour of the aorta was modelled using material parameters determined by testing tissue samples collected from patients who underwent surgical repair of ascending thoracic aortic aneurysm [3]. A fibre-reinforced constitutive model was applied [4]. Outlet flow conditions at supra-aortic vessels and distal descending aorta were set using a lumped-parameter model of systemic circulation. The aorta was assumed 1.7 mm thick [3], distal ascending aorta, supra-aortic vessels, and descending aorta were fixed in all directions.

The large aortic aneurysm exhibited an abnormal helical flow pattern with remarkable degree of flow skewing at the greater curvature of the ascending aorta where we found high values of systolic pressure (Fig. 1A and B). These flow instabilities are dictated by the morphology of the unicuspid aortic valve and are similar to those reported by 4D flow MRI [5] or computational analyses in stenotic or bicuspid aortic valve. Wall shear stress (WSS) is the frictional force that flowing blood exerts on the vessel wall and represents a mechanical force able to separate the aortic layers. The site of marked systolic WSS manifested in the region of the ascending aorta where the flow was moving rapidly whereas local maxima of peak systolic wall stress were found on the lateral side of the aneurysmal wall. Intramural wall stress represents an internal force within a deforming wall, it showed the highest values in the plane of the region with the maximum aortic

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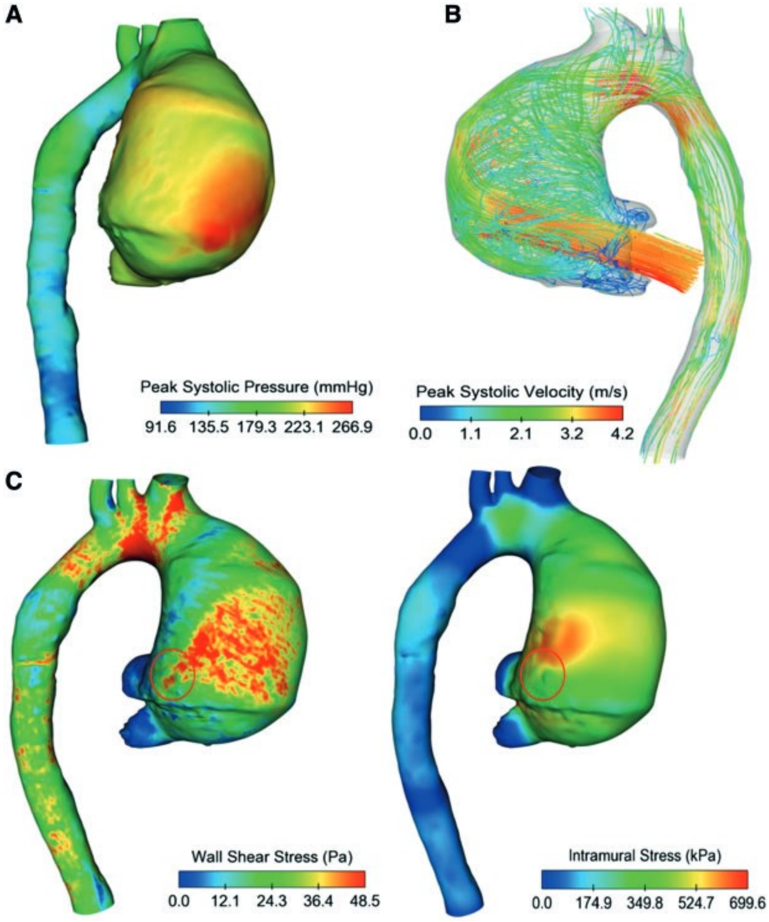

Figure 1: Peak systole pressure distribution (**A**), flow pattern (**B**), wall shear stress and intramural wall stress (**C**). The circle represents the intimal tear site as shown in Fig. 2.

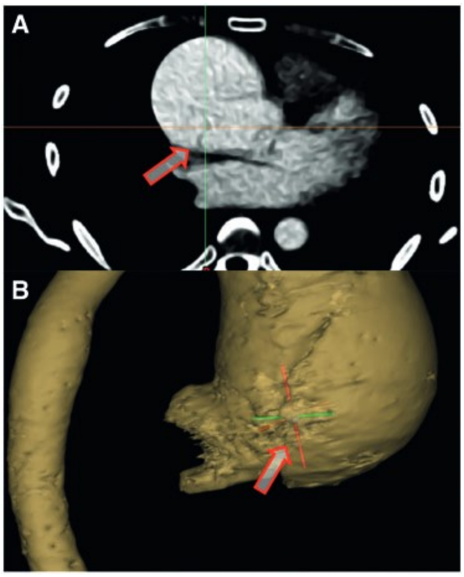

Figure 2: Computed tomography study determining the site of the intimal tear.

diameter (Fig. 1C). The combination of a severely dilated aorta and flow disturbances led to a pronounced aortic wall stress largely higher than the values previously proposed for aortic rupture/dissection. Preoperative CT scan and intraoperative finding confirmed the presence of the intimal tear in the area of higher WSS and intramural stress (Fig. 2).

Our methodology provided the simulation only at peak systole, whereas shear stress changes over the cardiac cycle can also influence the onset of aortic dissection. The need for boundary flow conditions represents a further limitation of computational fluid analysis but the combination of its high spatial and temporal resolution and the *in vivo* evaluation provided by 4D flow MRI can have a potential role for individual risk stratification and tailored surgical planning.

Conflict of interest: none declared.

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