A New Method To Quantify Aortic Biomechanics In Vivo Using Four-Dimensional (4D) Magnetic Resonance (MR) Imaging: Implications For Ascending Aortic Endografts

Rachel E. Clough, MD, PhD

Endovascular solutions are now preferable to open surgery in the management of many vascular pathologies. Stanford type A dissection of the ascending aorta has historically been treated with open surgical repair. Endovascular repair, despite its unique difficulties, has emerged as a potential alternative with successful isolated reports describing the use of devices originally designed for the descending aorta. The first devices deployed in the ascending aorta were the Gore Excluder Aortic Extender (W. L. Gore & Associates, Flagstaff, Arizona, USA) and the Medtronic endovascular stent graft (Medtronic Inc, Santa Rosa, California, USA) neither of which were designed for use in the ascending aorta. Although initially successful the durability of these procedures remains to be seen. When devices designed for the descending thoracic aorta were first placed in the distal aortic arch they were prone to failure via mechanisms such as migration, component separation leading to type III endoleak, fracture and kinking.

Endovascular treatment of the ascending aorta presents a unique challenge, including negotiation of the curvature of the aortic arch, obtaining proximal fixation close to the aortic valve and coronary ostia, distal fixation which may impinge on the innominate artery, haemodynamic forces in this arterial segment. Before placement of devices in the ascending aorta can be recommended for routine use, the anatomical suitability of candidates needs to be assessed. Moon et al provided the following criteria to define suitability for endovascular repair: presence of a proximal landing zone (diameter of the sino-tubular junction (STJ) ≤ 38mm), entry tear distal to the STJ, minimum distance between the entry tear and the STJ ≥10mm and absence of coronary artery bypass grafts originating from the ascending aorta. In their study which included all patients with acute proximal aortic dissection over a two year period, 41% (24/59) of patients had anatomy which would have been suitable for endovascular repair. These findings rely heavily on the criteria used by the authors to define suitability for endovascular repair. The proximal neck length suggested to be used for both fixation and sealing of the endovascular device was not generous.

A similar study was undertaken by Sobocinski et al; these authors used the following criteria to define suitability for endovascular repair: proximal and distal landing zone length ≥20mm; true lumen aortic diameter ≤38mm and total aortic diameter ≤46mm; absence of grade 3 or 4 aortic regurgitation; ilio-femoral vessel diameter <7mm and <90° angulation; additional debranching of the innominate and left common carotid was considered acceptable to extend the distal sealing zone. 32 of 102 (31%) patients were considered suitable based on the criteria.

Both studies indicate that a reasonably high proportion of patients may be suitable for endovascular treatment of ascending aortic pathology although the criteria to determine suitability differs between the two reports. This is because the
biomechanics of the ascending aorta and therefore the anatomical criteria required to ensure endograft stability and long-term durability are unknown.

Stent graft positional stability is governed from a mechanical standpoint, by the balance between the displacement forces or loads acting on the device and the fixation forces that keep the device attached to the wall. The fixation force of the stent graft is determined by the radial force at the proximal landing zone, which is achieved by oversizing the device relative to the normal aortic diameter. The larger the over-sizing of the device, the larger the radial force developed against the wall.

The proximity of the thoracic aorta to the heart and lungs results in a hostile environment with repetitive biomechanical forces and the intra-thoracic aorta is subject to physiological forces secondary to both cardiac and respiratory motion. These displacement forces determine the stresses acting on the layers of the aortic wall and the device, and failure occurs when the mechanical strength is exceeded.

Dynamic imaging techniques are increasingly being recognised as important in the management of patients with aortic disease. For example in the infra-renal aorta dynamic imaging has been used to demonstrate that aortic expansion is not evenly distributed, and that high preoperative abdominal aortic aneurysm neck pulsatility is associated with stent graft migration after 3 years. (1) The number of dynamic imaging studies of the thoracic aorta is limited however, perhaps related to the complexity of image acquisition. Quantification of three-dimensional (3D) aortic positional changes secondary to cardiac and respiratory motion is challenging due not only the high requirements of the image acquisition schemes but also due to difficulties quantifying the non-uniform movement of the aorta.

In this presentation new magnetic resonance (MR) imaging methodology will be described which can quantify deformation of the aorta in 3D over time using four-dimensional (4D) MR imaging techniques. The displacement of the aorta will be quantified separately for displacement due to cardiac and respiratory motion. It will be shown that the displacements are complex and time varying, and greatest in the ascending aorta, where they were accompanied by a large rotational component. It will be explained how advances in imaging technology and the development of dedicated software are mandatory to provide a better understanding of complex aortic biomechanics and to guide the design of a new generation of endografts for the ascending aorta.

References:


