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Unknown unknowns: the aorta through the looking glass

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Editorial

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Innovation in cardiovascular surgery has often depended upon interdisciplinary collaboration between surgeons and engineers. It was somewhat surprising to come face to face with a fundamental difference in perspective, which may be considered an unknown unknown.[1] It is standard practice to view radiographs of the chest, abdomen, and pelvis as if the patient is standing facing the doctor. This is also the anatomical position, the basis for all anatomical descriptions. It is a convention that applies even when the image is acquired postero-anteriorly as is the case when preparing a standard chest X-ray. When computerised axial tomography first became available a matching convention was established. Of the eight possible ways of viewing a transparency the one chosen presented the back of the patient towards the bottom of the page and the right hand side of the patient to the left side of the image [1]. This convention provides for the left to right orientation to match the chest radiograph but has the inevitable consequence that the cross-sectional images are displayed as if seen from below. It is contrary to how we look at plan views in other contexts: architects, geographers, builders, engineers, even roofers, interpret plans as if they are views from above.

How clinicians choose to look at a cross-sectional image need be of no concern to other disciplines until we need to transfer data between us. An innovative operation has been devised to prevent dilation of the Marfan aortic root in its earliest stages [2]. It follows the conservative principle espoused by Robicsek and Thubrikar [3] but rather than attempting to fashion the external support from relatively stiff material during surgery, an external aortic root support, which fits the dilated root exactly, is made prior to opening the chest (Fig. 1). The means to create this support, devised by an engineer, is to use the spatial data from high-resolution digital images to construct an exact representation of the aorta in a process known as computer assisted design. On this replica of the patient's aorta is fashioned a bespoke external aortic root support. This process relies on presenting data in *X*, *Y* and *Z* co-ordinates so as to define the exact shape of the aorta in three dimensions.

The first resulting model was reviewed on the computer screen as a rotating three-dimensional image (Fig. 2) by an engineer and a surgeon specifically to check the position of the coronary arterial orifices. Having positioned the model with the right coronary arterial orifice located anteriorly, they rotated the 3D image on the screen so as to identify the left coronary aortic sinus. At first it made no sense. Each time the aorta was rotated, the aortic sinuses seemingly appeared in the wrong sequence. It then became evident that they were consistently in the opposite sequence to that expected. Given the direction of rotation of the image, it was expected to see the right coronary arterial orifice, the left coronary arterial orifice, and then the non-coronary sinus, but this sequence was reversed. The answer became clear. Cross-sectional images supplied to the engineers followed the medical imaging convention of being views from below. On the other hand, image-reconstruction was based on the assumption that they were views from above. The images of parallel sections had been concatenated in the wrong order. If the model is then viewed apparently in the anatomical position it gives a looking glass image and reverses the clockwise/anticlockwise orientation of the 3D object constructed (see Fig. 2).

The multi-disciplinary nature of this project needs to be appreciated. Not only were surgeons and engineers involved but mindful of the need to take account of other perspectives [4] opinions were sought from specialists in other disciplines. An anatomist advised to ensure that no anatomical limitations had been left unconsidered. The team referred to existing knowledge of hazard prediction gained through collaboration with mathematicians [5]. Years of design experience guided the selection of the material to be used to construct the external support. Design engineers and medical imagers collaborated on the software to be used, which was tested and modified. And yet there was an unknown unknown and only constant checking revealed it.

It transpired that anatomists were already familiar with the problem that became evident to the engineer and the surgeon. When preparing photographs of anatomical material to correlate with echocardiographic images, thin cross-sections of the heart which lack depth can be photographed

[1] http://www.slate.com/id/2081042/ 'As we know, there are known knowns. There are things we know we know. We also know there are known unknowns. That is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know.' USA Secretary of State for Defence, Ronald Rumsfeld, Feb. 12, 2002, Department of Defence news briefing.

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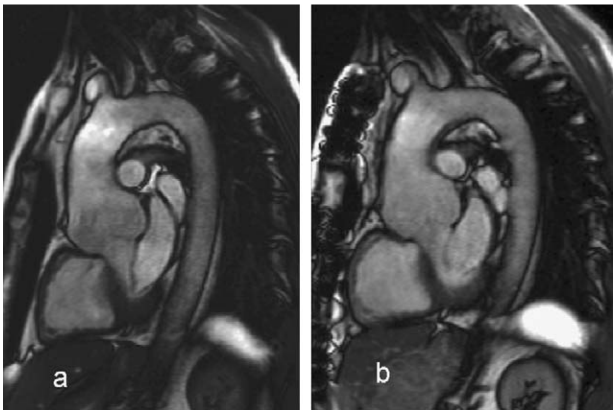

Fig. 1. Magnetic resonance image in sagittal view of the aorta in a man with Marfan syndrome. The left hand view shows the situation prior to implantation of the external support for the aortic root. On the right is the postoperative image, showing the support in place from the aorto-ventricular junction to beyond the brachiocephalic artery. The sternal wires can be seen. The support is closely applied to the aortic adventitia, with no interference to the valve or the blood/endothelial interface.

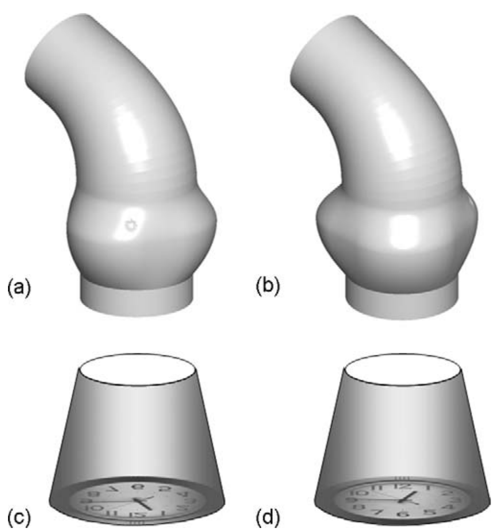

Fig. 2. The left hand 3D depiction of the model of the aortic root (a) shows a coronary arterial orifice towards the viewer in what one would expect to be the non-coronary sinus. The model has been corrected on the right (b). The orifice of the right coronary artery can be seen to the right of the image in the anteriorly placed right coronary sinus. By way of analogy, a clock face has been placed in the base of a tapering tube and on the left (c), it is mirror-imaged. It is corrected in panel (d). The left coronary orifice is approximately in the position of 12 on the clock which is on the side away from the viewer in the correctly orientated right hand version.

from above and mirror-imaged to match the clinical images or they can be photographed in an anatomically accurate fashion from below. Should a heart be dissected in its short axis so that it retains depth, it is only possible to photograph accurately the image from beneath, looking up the long axes of the ventricles from their apex, so as to make anatomically appropriate correlative images. If a specimen prepared in this fashion should be photographed from above, then a similar problem would be created as was produced by the engineers recreating the aortic root by viewing the sections as seen from above.

The surgical procedure involving provision of external support to the aortic root has now been performed successfully in 18 patients since the first operation carried out nearly five years ago [2]. This operation has the potential to circumvent the current controversies surrounding conserving or replacing the aortic valve [6]. Our story of collaboration serves as a reminder that we must spare no effort in considering the perspective of others from all angles, but even then we may be caught out by unknown unknowns.

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