Cine Magnetic Resonance Imaging Study of Blood Flow and Wall Motion of the Aortic Arch

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The aortic arch has 3D distortions in the transverse arch in the axial view, and we previously reported that this distortion is a risk factor in the pathogenesis of arch aneurysms. In this study, we evaluated blood flow and movement of the aortic arch.

In 10 healthy young volunteers, ECG-gated cine magnetic resonance imaging was carried out in the axial plane of the transverse arch, the coronal plane of the ascending arch, and the long axial plane along the entire arch.

1. Left anterolateral movements around the midpoint of the transverse arch in the systolic phase were observed in all of the men (6.3 ± 1.59 mm) and women (4.8 ± 0.73 mm).

2. A jet flow was detected in the systolic phase along the right side of the aortic wall. At the top of the plane, this jet flow turned to the left in a clockwise rotation in the anterior view.

3. In the long axial plane, a turbulent flow in the systolic phase was observed distal to the left subclavian arterial orifice in 6 of the 7 cases.

In conclusion, this turbulent flow and left anterolateral wall motion of the transverse arch are due to anatomical three-dimensional distortion of the transverse arch. We propose that these phenomena may be important risk factors in the pathogenesis of arch aneurysms. (*Jpn Circ J* 1996; **60**: 553–559)

WITH regard to the pathogenesis of aortic aneurysms, most previous studies have focused on background diseases such as hypertension, while few have examined structural problems of the human aortic architecture. In the case of the aortic arch, it is quite conceivable that the flow pattern could accelerate a problem once a change occurs along this aortic segment. Recent advances in clinical investigation technology have enabled us to pursue with this interesting course of study, and we previously

confirmed that a certain “resulted distortion” of the transverse aortic arch could be a major risk factor in the development of aneurysmal changes at that site.^{1,2} In the present study, we evaluated how blood flow and the aortic arch interact with each other in normal individuals in an attempt to identify a relationship with the above “resulted distortion” of this region.

MATERIALS AND METHODS

The subjects consisted of 10 young volunteers in their 20's (5 males and 5 females) who consented to take part in this study.

Key words:

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Fig 1. Cine MR images of the axial plane of the transverse arch in the systolic and diastolic phases in a typical case (Male-3). The arrow indicates the point of maximal movement of the aortic wall. Note that the direction of the movement is the same as the extended direction of the ascending arch plane.

Fig 2. Trace of aortic wall movement of the transverse arch in a cardiac cycle. Asterisks indicate the direction of wall movement in typical cases.

The subjects were each examined using a 0.5-tesla superconductive magnetic resonance (MR) system (Resona: Yokogawa Medical Co, Ltd, Japan). After the entire arch and left ventricle were imaged in the axial plane by spine echo MR, the subjects underwent ECG-gated cine MR imaging (GRASS; gradient recalled acquisition in the steady state sequence, FOV 35 cm, flip angle 30° , mean TR 856 msec, TE 16 msec, no. of slices 1, thickness 5 mm, 7 to 12 phases per cardiac cycle) in the axial plane of the transverse arch (matrix 192×128), the coronal plane of the ascending arch (matrix 160×224), and the long axial plane along

the entire arch by the double oblique technique (matrix 192×224).

The study proceeded as follows:

1. All of the phases in a cardiac cycle in the axial plane of the transverse arch were magnified to full scale, and images of the aortic wall were traced in the same plane. Aortic wall movement within a cardiac cycle was then measured. Jet and turbulent flow in the transverse arch were also observed by cine MR imaging.

2. In the coronal plane of the ascending arch, the direction and position of the flow void effect caused by either the jet stream from the left ventricle or turbulence was

Fig 3. Cine MR images of the transverse arch in men. Jet and turbulent flow in the systolic phase, indicated by arrows, are visible. The asterisks indicate typical cases.

Fig 4. Cine MR images of the transverse arch in women. The arrows indicate jet and turbulent flow.

Fig 5. Coronal cine MR images of the ascending arch in men in the systolic and diastolic phases. Arrows indicate the biased stream in the ascending arch and the rotational flow at the top of this plane.

Fig 6. Coronal cine MR images of the ascending arch in women in the systolic and diastolic phases. Arrows indicate the biased stream in the ascending arch and the rotational flow at the top of the arch.

Fig 7. Long axial cine MR images of the entire arch in the systolic and diastolic phases. Turbulent flow in the systolic phase was observed just distal to the left subclavian arterial orifice in 6 of the 7 cases, and more proximally in the other case (case Female-1), as indicated by arrows in the systolic phase.

observed by cine MR imaging.

3. Similar cine MR imaging studies were carried out in the long axial plane along the entire arch in the 7 subjects.

RESULTS

1. In the axial plane of the transverse arch, left anterolateral movement around the mid-point of the transverse arch in the systolic phase (Fig 1) was seen in all of the men (6.3 ± 1.59 mm) and women (4.8 ± 0.73 mm) (Fig 2). In the typical cases indicated by asterisks in Fig 2, the direction of movement was the same as the extended direction of the ascending arch plane by 3D analysis?

In cine MR images of these planes, the direction of the jet flow from the ascending arch in the systolic phase was towards the anterolateral aortic wall, which consequently produced wall motion. The direction of this jet flow seemed to turn to the descending arch. These phenomena were more clearly detected in men (Fig 3, 3 of the 5 cases) than in women (Fig 4, 1 of the 5 cases).

2. In the coronal plane of the ascending arch, a jet flow was detected as a flow void

effect in the systolic phase along the right side of the aortic wall. At the top of this plane, this jet flow turned to the left in a clockwise rotation. Both the biased jet flow and the clockwise rotational flow were more typical in men (Fig 5). In women, jet flow was seen near the center of the ascending aorta (Fig 6).

3. In the long axial plane of the arch (Fig 7), a turbulent flow in the systolic phase was observed distal to the left subclavian arterial orifice in 6 of the 7 cases examined, and more proximally in the remaining case (case Female-1).

DISCUSSION

Based on 3D-reconstruction studies of the aortic arch, we previously proposed that, with regard to the pathogenesis of arch aneurysms, a key risk factor is distortion of the transverse arch in the axial view! The key site of this distortion is near the orifice of the left subclavian artery, and this region may also be important in arch dissection. Many aneurysms were seen projecting from the lateral head of the transverse arch just

past this key point, and the direction of aneurysmal growth is the same as the extended direction of the ascending arch plane?

MR imaging is a non-invasive method for visualizing the 3D relationships between the left ventricle and the aortic arch. In addition, we can also detect aortic arch movement by cine MR imaging under fairly natural conditions. In cine MR imaging, blood in a normal aorta generally shows a high intensity. In contrast, high flow or jet flow is detected in aortic stenosis³ or regurgitation^{4,5} and turbulent flow is found in coarctation⁶ or dissection⁷ of the aorta as a signal void, to give the so-called flow void effect. These phenomena are theoretically difficult to understand⁸⁻¹⁰ but clinically, jet and turbulent flow are nearly identical in other Doppler echo studies^{11,12}. From this viewpoint, we planned this study with normal young volunteers to obtain standard aortic arch flow patterns and movement in a cardiac cycle by the cine MR imaging method.

Jet flow from the left ventricle was seen along the right side of the aortic wall. This phenomenon was similar to that in intra-operative invasive echo studies.¹¹ At the top of the arch, this jet flow turned to the left in a clockwise rotation. Frazin et al¹² also detected this clockwise rotational flow in the transverse arch using a trans-esophageal echo study.

Recently, Kilner et al¹³ studied flow patterns in the aortic arch by 3D magnetic resonance velocity mapping. They concluded that right-handed helical streams are consistent features of intra-aortic flow in healthy subjects. In in vitro flow models, they evaluated a "flat arch" vs a "twisted arch" under continuous and pulsatile flow, and concluded that continuous flow gives rise to a right-handed helical flow field in the upper curvature of the "anatomically" twisted arch, while during pulsatile flow, a right-handed helix becomes dominant during systole. A flat arch, on the other hand, contains bilaterally symmetric patterns.

In our study of axial cine MR imaging of the transverse arch, the left anterolateral aortic wall was moved in the left anterolateral direction by jet flow from the ascending arch. This direction is the same as that for the growth of arch aneurysms we previously

proposed? This movement is caused not only by distortion of the transverse arch, but also by the jet stream from the left ventricle through the ascending arch to the transverse arch. Wheat¹⁴ also examined the motion of the arch by aortograms in relation to the pathogenesis of aortic dissection. We speculate that jet and turbulent flow may gradually create a distortion of the arch, and both this distortion and blood flow may be important factors in the pathogenesis of arch aneurysms. In addition, turbulent flow in the systolic phase just distal to the left subclavian artery may contribute to aortic dissection.

The relationships between aging and arch distortion and between cine MR imaging and the precise hemodynamics of the arch require further clarification.

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