Quantitative Study on Abdominal Blood Flow Patterns in Patients with Aortic Dissection by 4-Dimensional Flow MRI

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Aims and objectives

Aortic dissection (AD) is a vascular disease whereby an injury in the wall of the aorta leads to the creation of a true lumen and a false lumen separated by an intimal flap which may contain multiple communicating tears between the lumina\(^{[1-2]}\). Morphological and hemodynamic changes are the most important factors that affect the stability and development of AD, and the diameter of the aorta is considered to be an important indicator for the prediction of AD progression\(^{[3-4]}\). Hemodynamic instability and vascular compromise are established risk factors for death\(^{[5]}\). In recent years, noninvasive imaging techniques such as multidetector CT (MDCT) and magnetic resonance imaging (MRI) have largely replaced conventional angiography for the diagnosis of AD\(^{[6-7]}\). Recently improved Cartesian\(^{[8]}\) and radial\(^{[9]}\) four-dimensional (4D) flow-sensitive velocity mapping techniques (4D flow MRI) have been used for the evaluation of flow patterns.

The purpose of this study is to evaluate the hemodynamic characteristics and changes in the true lumen (TL) and the false lumen (FL) in aortic dissections (AD) using four-dimensional (4D) flow magnetic resonance imaging (MRI), and to determine the relationship between blood flow index and the size, number of intimal entries and false lumen thrombosis.
Methods and materials

All 16 AD patients underwent thoracic and abdominal CT angiography (CTA) and abdominal aorta 4D flow MRI imaging within 1 week before operation. CT scanning was performed on a 320-row dynamic volume CT scanner (Aquilion One, Toshiba Medical Systems, Ottawara, Japan). Image post-processing was carried out on a Vitrea workstation#. Scan range was from the entrance of chest to the iliac artery bifurcation level. The scan was completed in one breath hold. Volumetric cine scans were automatically triggered at a preset threshold of 180 HU in the level of pulmonary artery bifurcation. 4D-flow MRI was performed on a 3 T MR system (MAGNETOM Verio) with a 32-channel body matrix coil. The prototype 4D-flow sequence covered the abdominal aorta and used prospectively ECG-gated and navigator-triggering techniques.

For all patients, CTA examinations were performed in the thoracic and abdominal great vessels, and multi-planner reconstruction (MPR), maximum-intensity projection (MIP) and volume rendering (VR) images were generated to observe various CT imaging signs associated with AD, which included mean area of the TL and FL (Fig 1 A), different AD types, origin of renal arteries, the false lumen thrombosis, and the size, number and position of entry tears. We measured the size, number and position of entry tears on MPR reconstruction images (Figs 1B and 1C). The 4D-flow data sets were transferred to a prototype 4D-flow post-processing software (V2.4, Siemens Healthcare, Erlangen, Germany) for flow analysis. Four analysis planes transecting the aortic lumen orthogonal to the anticipated main flow direction were manually placed (Fig 2A): (1) in the celiac trunk, (2) in the superior mesenteric artery, (3) in the lower renal artery opening, and (4) in the aorta-iliac bifurcation level. Outline of the TL and FL were defined manually on the axial plane in each plane. Odd numbers were assigned to the TL, and even numbers to the FL ((Fig 2A). Then, time-resolved images of the 3D velocity vector fields were generated to display the blood flow within the abdominal aorta. Next, 3D streamlines (Fig 2B) and time-density curve (TDC) (Fig 2C) of blood flow parameters were obtained from the 4D data sets. Quantitative parameters included measurement of average through-plane velocity, peak velocity magnitude, average net flow, peak flow, net forward volume and regurgitant fraction in the TL and FL of each plane.
Images for this section:

Fig. 1: Figure 1. Example of area and size measurement, number of re-entry tears. (A) Area measurement of TL and FL. TL = true lumen, FL = false lumen. (B) Size measurement of the entry tears, the primary entry tear was located in the ascending aorta. (C) MPR image displayed three re-entry tears in the abdominal aorta.

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**Fig. 2:** Figure 2. Different levels of flow, velocity and volume measurement. (A) Example of selection of analysis planes. TL: 1,3,5,7 and FL 2,4,6,8. (B) Color-coded streamline visualization revealing fast flow through the TL relative to the FL. (C) Time curves of peak velocity magnitude. It indicates the changes in blood flow parameters during the cardiac systolic and diastolic phases. The various curves represented the velocity-time curves at different locations in the true and false lumen.

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Results

The two imaging examinations were successfully performed in all 16 patients. Type A AD was found in 1 patient with the intimal tear located in the ascending aorta, while type B AD was found in 15 patients with the tear located distal to the left subclavian artery orifice or the descending aorta. Nine patients had one entry, and the remaining 7 had 2 or 3 entries. Among these 16 patients, 8 patients underwent interventional procedures, and the remaining 8 patients underwent thoracic surgery.

Comparison of the Average Lumen Area and 4D-flow Analysis of the TL and FL

The average area in the TL of the four levels of all patients was smaller than that of the FL (P < 0.05). The average through-plane velocity, peak velocity magnitude, average net flow and net forward volume were significantly higher in TL than that of the FL in the level of celiac trunk and the superior mesenteric artery#P < 0.05#. The regurgitant fraction was lower in the TL than that in the FL#P < 0.05#. However, there was no significant difference of peak flow between TL and FL#P > 0.05#. The average through-plane velocity was significantly higher in the TL than in the FL at the level of the lower renal artery opening#P < 0.05#. The regurgitant fraction was lower in the TL than in the FL#P < 0.05# There was no significant difference of peak velocity magnitude, average net flow, peak flow and net forward volume between TL and FL#P > 0.05#. The average through-plane velocity and peak velocity magnitude were significantly higher in the TL than in the FL at the aorta-iliac bifurcation level#P < 0.05#. The regurgitant fraction was lower in the TL than in the FL#P < 0.05#. But there were no significant differences of average net flow, peak flow and net forward volume between TL and FL#P > 0.05#. These 4D flow parameters at different levels are presented in Figure 3.

Correlation and regression analysis among size, number of intimal tears, false lumen thrombosis and blood flow values

The size of the entries was negatively correlated with the average through-plane velocity, peak velocity magnitude, average net flow and peak flow in the TL, and positively correlated with the average through-plane velocity, average net flow and peak flow in the FL. The number of entries was positively correlated with higher average through-plane velocity, peak velocity magnitude, average net flow and peak flow of TL, and negatively correlated with peak flow of FL. If FL had thrombosis, the average through-plane velocity and peak velocity magnitude of TL became higher.
The results showed that the size of entries had a significant influence on the blood flow values of TL and FL. The size of entries was negatively correlated with the average through-plane velocity, peak velocity magnitude, average net flow and peak flow of TL, and positively correlated with the average through-plane velocity of FL. The size of entries was negatively correlated with the peak velocity magnitude of FL.

The abdominal aorta, especially the opening level of the renal artery, often had secondary tears, which prove to be very difficult to image. 4D flow imaging combined with conventional CTA imaging can accurately display the location of secondary tears and the blood flow patterns of involved arteries#Fig 4#
Fig. 3: Figure 3. Differences of blood flow parameters in different analysis planes of abdominal aorta.

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Fig. 4: Figure 4. The location and blood flow patterns of secondary tears of AD. A-B: MPR images showing that the right renal artery originated from TL, left renal artery from FL; small secondary tear located at the opening level of left renal artery. C: Color-coded streamline visualization showing differences in flow patterns in the TL (red) and FL (blue). Due to the presence of secondary tear, the left renal artery was supplied by the true and false lumen. TL = true lumen, FL = false lumen.
Conclusion

This study shows that 4D flow imaging provides qualitative and quantitative assessments of abdominal aortic blood flow in AD patients. Blood flow values were measured to evaluate the prognosis of the AD. It is concluded that 4D flow imaging is an effective and non-invasive technique to evaluate blood flow changes in aortic dissection patients.
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