4-dimensional phase contrast MRI of blood flow patterns in chronic aortic dissections at 3T

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Purpose

Thoracic aortic dissections are life-threatening conditions with an estimated 10-year survival of 35-75%. However, regarding the overall outcome there are marked differences between patients with complicated and uncomplicated dissection. The ability to accurately predict which patients will develop complicated aortic dissection could facilitate clinical management by allowing earlier treatment prior to irreversible end organ ischemia or aortic rupture.

Our current understanding of the time-course of chronic dissection is limited. Importantly, there are no hemodynamic markers or studies that could help to predict their clinical behavior.

Recently improved Cartesian [1] and radial [2] four-dimensional (4D) flow-sensitive velocity mapping MR techniques have been used for the evaluation of flow patterns with a larger, volumetric field-of-view.

Therefore, it was the goal of this work to evaluate the feasibility of using four-dimensional (4D) phase contrast (PC) MR for the comprehensive evaluation of hemodynamics in thoracic aortic dissections.
Methods and Materials

Studies were performed according to protocols approved by each of the two centers' institutional review boards and according to HIPAA regulations.

In total, 13 MRI studies were performed in 12 patients (4 female, age 25-71 years) with thoracic aortic dissections using Cartesian (n=10) and non-Cartesian (n=2) 4D-PC-MRI with three-directional velocity encoding at 3.0T at two centers. For patient history/demographics please refer to table 1.

Institution A: Ten subjects (51±18 years; 63.4±14.0 kg; 6 male, 4 female) with a total of 11 MR examinations were included. One subject was imaged twice after a time interval of 8 months and interim surgical procedure. Studies were performed on a 3.0T scanner (TRIO, Siemens Healthcare, Erlangen, Germany) with an 8-channel phased-array body coil. 4D MR velocity mapping was performed with a referenced 4-point, Cartesian PC sequence with velocity encoding in all three spatial directions. Prospective ECG-gating and adaptive navigator gating (crossed pair navigators monitoring the position of the diaphragm) for compensation of breathing motion resulted in imaging times of 12-18 minutes.

Institution B: Two subjects were enrolled (40 and 50 years; 72.6 and 137.4 kg; 2 male) and scanned at 3.0T (MR750, GE Healthcare, Waukesha, WI) with a 32-channel phased-array body coil (NeoCoil, Pewaukee, WI). 4D MR velocity mapping was performed using phase contrast with a 5-point three-directional velocity encoding sequence with vastly undersampled isotropic projection reconstruction (PC VIPR [3]). Using retrospective ECG-gating and adaptive navigator gating for compensation of breathing motion, scan times were 9-14 minutes.

Postprocessing was performed using EnSight (CEI, Apex, NC). For quantitation, manually placed cutplanes in ascending aorta, aortic arch and descending aorta were placed and exported into a MatLab-based tool [4]. By placing cutplanes, 4 aortic segments were defined that were used for qualitative analysis (see also Figure 1, Methods and Materials section).

True and false lumen (TL, FL, respectively) net flow, retrograde flow, peak flow, and time-to-peak flow were quantified on the above four analysis planes. Flow patterns in TL and FL in four aortic segments were assessed qualitatively using time-resolved particle traces and streamlines color-coded with respect to the absolutely measured velocities.
### Table 1: Patient demographics

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age at MRI</th>
<th>Gender</th>
<th>Diagnosis</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>M</td>
<td>Type-A dissection</td>
<td>Bentall procedure</td>
</tr>
<tr>
<td>2</td>
<td>52</td>
<td>M</td>
<td>TAAA after Type-B dissection</td>
<td>TEVAR</td>
</tr>
<tr>
<td>3</td>
<td>69</td>
<td>M</td>
<td>Type-A dissection</td>
<td>Open AAo repair</td>
</tr>
<tr>
<td>4</td>
<td>71</td>
<td>M</td>
<td>Traumatic Type-A dissection</td>
<td>Open repair for newly developed TAA</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>M</td>
<td>Type-A dissection, Marfan syndrome</td>
<td>Open repair for newly developed TAAA</td>
</tr>
<tr>
<td>6</td>
<td>71</td>
<td>F</td>
<td>Traumatic Type-A dissection</td>
<td>Open valve-sparing AAo replacement</td>
</tr>
<tr>
<td>7</td>
<td>51</td>
<td>F</td>
<td>Type-A dissection, Marfan syndrome</td>
<td>Open valve-sparing AAo replacement</td>
</tr>
<tr>
<td>8</td>
<td>61</td>
<td>F</td>
<td>Type-A dissection</td>
<td>Open valve-sparing AAo replacement</td>
</tr>
<tr>
<td>9</td>
<td>59</td>
<td>M</td>
<td>Type-A dissection</td>
<td>Open valve-sparing AAo replacement, arch</td>
</tr>
<tr>
<td>10</td>
<td>50</td>
<td>F</td>
<td>Type-A dissection</td>
<td>reconstruction</td>
</tr>
<tr>
<td>11</td>
<td>26</td>
<td>M</td>
<td>Type-A dissection, Marfan</td>
<td>Bentall procedure, prior TEVAR</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>M</td>
<td>Type-B dissection</td>
<td>Open repair for recurrent symptoms while on</td>
</tr>
<tr>
<td>13</td>
<td>51</td>
<td>M</td>
<td>Type-A dissection, bicuspid aortic valve</td>
<td>medical therapy</td>
</tr>
</tbody>
</table>

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Results

Dissections were observed in 44/52 analysis planes and 34/52 segments. Retrograde flow was present on 41/52 analysis planes of the TL and 20/22 analysis planes of the FL. Interestingly, retrograde flow in the FL occurred earlier than in the TL in 14/20 analysis planes (see Figures 1 and 2). Physiological left-handed helicity in segment A (8/13) shifted towards right-handed flow in segment B and C (B: 11/13, C: 10/13) to non-discernible helicity in segment D (10/13).

In general, flow patterns were significantly altered in association with different extents of disease, vessel dilatation, and post therapeutic anatomy (see Figure 2). Complex flow patterns included 25 additional vortices and helices in 11/13 cases. Total flow per cardiac cycle and peak flow were higher in TL than FL (P < .01). Retrograde flow was less in TL than in FL (P < .01).

For quantitative results, please see Table 1. Total and peak flow were higher in TL than FL (p<0.01). Retrograde flow was less in TL than in FL (p<0.01). Time-to-peak flow in TL occurred later than in FL (p=0.05-0.08).
Table 2: Quantitative results in 4 cutplanes placed in the thoracic aorta

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Fig. 2: Figure 2. 69 year-old patient with repaired Type A aortic dissection. Color-coded streamline visualization during (A) mid systole, (B) late systole, and (C) early diastole shows the differences in flow patterns in the true lumen (TL) and false lumen (FL).

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Fig. 1: Figure 1. 62 year-old patient with repaired Type A aortic dissection. The surface-shaded display (left) demonstrates locations of cut planes - (1) in the ascending aorta, (2) proximal arch, (3) distal arch, and (4) mid descending aorta - used for emitting particle traces and streamlines. Flow patterns at each of these cut planes and within four regions - (a) between planes 1 and 2, (b) between planes 2 and 3, (c) between planes 3 and 4, and (d) distal to plane 4 - were evaluated. Particle trace visualization during early, mid and late systole revealed early backward flow (open arrow) in the false lumen. TL = true lumen, FL = false lumen.

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Conclusion

4D-PC-MRI at 3.0T provides novel qualitative and quantitative insights into hemodynamics in chronic aortic dissections. The approach may help to establish prognostic indicators for development of complications or aneurysm growth in patients with this disorder.

Multi-venc approaches may help to overcome apparent limitations such as decreased signal in regions of slower flow such as in the false lumen or dissecting aneurysms. Similarly, an approach with intravascular contrast agent (bloodpool agents) may help to improve the signal-to-noise ratio [5]. More importantly, follow-up studies are warranted to help identifying the predictive value of findings.
References


Personal Information

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