Follow-up of Adults With Coarctation of the Aorta*

Comparison of Helical CT and MRI, and Impact on Assessing Diameter Changes

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Objectives: To compare images of the aorta obtained with helical CT (HCT) scanning and MRI for the follow-up of adults with coarctation of the aorta (CoA).

Design: Longitudinal study.

Setting: Department of adult congenital heart disease in a tertiary university hospital.

Patients: A total of 37 adults (age range, 16 to 68 years; women, 13) with CoA (after surgery, 34 patients; native, 2 patients; after balloon-angioplasty, 1 patient)

Measurements and results: All patients underwent both HCT and MRI of the thoracic aorta within a mean (± SD) time interval of 1.86 ± 1.11 years. Aortic diameters measured at six intrathoracic levels showed a high correlation (r = 0.79 to 0.94). On average, slightly lower diameters were measured with MRI (1.2 mm). But there was a substantial variation between the two measurements with differences of up to 9 mm. All other pathomorphologic abnormalities were detected and classified similarly with both methods.

Conclusions: HCT and MRI are similarly useful for the noninvasive evaluation of the thoracic aorta in patients with CoA. But there can be a substantial variation in two subsequent measurements without an overall substantial bias toward larger diameter in one of the two methods. In repetitive studies, changes of the diameters should be interpreted with care, especially when assessing the progression of aortic diameters.

Key words: aortic coarctation; helical CT; MRI; thoracic aorta; thoracic aortic aneurysm

Abbreviations: CoA = coarctation of the aorta; HCT = helical CT

In the follow-up of patients after surgical or interventional treatment of coarctation of the aorta (CoA), imaging of the aorta is necessary to reveal or exclude residua, sequelae, or complications. Physical examination with auscultation, palpating inguinal pulses, and taking BP in all limbs can only screen for restenosis. Proper imaging is of vital importance for the depiction and quantification of ascending aortic ectasia, aortic arch hypoplasia, re-CoA, or the formation of a local aneurysm at the previous site of CoA.1

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In the patient’s follow-up after CoA repair, regular detailed measurements of the aortic diameters are necessary.1,2 While in previous years follow-up necessitated cardiac catheterization, today imaging has shifted toward the use of less invasive techniques. Particularly appropriate techniques are echocardiography,3–5 MRI,3,6–11 and CT scanning.12,13

For the assessment of CoA, a large number of studies report on the advantages and disadvantages of transthoracic and transesophageal echocardiography, axial and helical CT (HCT) scanning, MRI, as
well as angiography. However, only a few studies compare the results of different imaging modalities.

Simpson et al\textsuperscript{14} showed an excellent agreement of MRI and angiography. Rees et al,\textsuperscript{15} Stern et al,\textsuperscript{16} and Mühler et al\textsuperscript{17} compared MRI with transthoracic echocardiographic and/or angiographic data with similar results. Kappetein et al\textsuperscript{16} described significant differences between diameter ratios measured by MRI and those measured by digital subtraction angiography. They assumed that these differences had been caused by MRI images that had not been properly focused to the region where diameters are measured and therefore outlined the advantages of digital subtraction angiography.

Unfortunately, in adults with CoA both transthoracic and transesophageal echocardiography have a limited acoustic window, especially in their view of the aortic arch. Therefore, HCT scanning and MRI are the current preferred noninvasive methods for imaging the whole thoracic aorta in adults. The objective of this study was to assess the comparability of morphometric and morphologic data obtained by HCT scanning and MRI in adult patients with CoA.

**Patients and Methods**

**Patients**

Thirty-seven patients (13 women and 24 men) with CoA were assessed by both HCT scanning and MRI. Two patients had native coarctation, one patient had previous undergone balloon angioplasty, and 34 patients had previously undergone surgery. All gathered data and technical investigations were part of clinical follow-up. All patients, parents, or legal guardians gave written informed consent.

Surgical techniques consisted of patch aortoplasty in 15 patients, tube graft interposition in 8 patients, end-to-end anastomosis in 5 patients, implantation of an extraanatomic conduit in 5 patients, direct repair in 1 patient, and end-to-side anastomosis in 1 patient.

Thirty-three patients underwent HCT scanning first and MRI afterward. Four patients underwent MRI first. The mean (± SD) period between the investigations was 1.9 ± 1.1 years (range, 18 days to 3.9 years).

The mean age of the patients at the time of HCT scanning was 33.2 ± 14.6 years (age range, 16 to 68 years), and their mean age at the time of MRI was 35.2 ± 14.5 years (age range, 19 to 70 years). There was no interventional or surgical procedure performed between the two investigations.

**HCT Scanning**

HCT scans were obtained with appropriate equipment (Somaton Plus S; Siemens AG Medical Engineering; Forchheim, Germany). Contrast scans were acquired during an antecubital IV infusion of 70 to 150 mL nonionic contrast medium (Ultravist 300; Schering AG; Berlin, Germany) with an iodine concentration of 300 mg/mL. The flow rate of the contrast medium was 4 mL/s. The time delay between the start of the injection and the start of the scan was individually selected after a test injection of a small bolus of the contrast media.

The scan of the thorax was performed with 165 mA/120 kV or 145 mA/137 kV in the caudocranial direction in a single breath-hold. Rotation time was 1 s, slice collimation was 3 mm, table speed was 5 to 6 mm/s, and total scanning time was 25 to 30 s. Images were reconstructed with a field of view of 25 cm and a reconstruction interval of 2 mm using a 180° linear interpolation algorithm. This resulted in a voxel size of 0.5 × 0.5 × 3.0 mm. For aortic diameter measurements with HCT scanning, our institutional intraobserver and interobserver variabilities are 5.6% and 9.7%, respectively (unpublished data).

**MRI**

Scans were performed on appropriate equipment (Siemens Horizon Echospeed [1.5 T]; General Electric; Milwaukee, WI). First, gated spin echo sequences in the axial, frontal, and double-oblique planes through the aortic arch were sampled. The field of view was 24 cm, the scan matrix was 256 × 128 pixels, and the slice thickness was 5 to 8 mm, the spacing was 1 to 2 mm. The echo time was 11 to 40 ms, and the repetition time was triggered by the ECG signal.

Afterward, a strongly T1-weighted gadolinium-enhanced MR angiography sequence was performed. A three-dimensional volume data set was acquired following an antecubital IV injection of 30 to 40 mL the gadolinium derivative gadodiamid (Omniscan; Nycomed Imaging AS; Oslo, Norway) with a gadolinium concentration of 0.5 mmol/mL. The infusion rate was 2 mL/s. The time delay between the start of the infusion and the start of the scan was individually selected after a test injection of a small bolus of the contrast medium. Images were obtained with the patient in a sagittal oblique orientation, with a field of view of 40 cm and a matrix of 256 × 192 pixels, which was reconstructed as a matrix of 512 × 384 pixels. There were 44 slices with a thickness of 1.8 mm without spacing or slab. Therefore, resolution of the MR angiography was 0.8 × 0.8 × 1.8 mm per voxel. The echo time was 1.4 ms, and the repetition time was 6 ms. For aortic diameter measurements with magnetic resonance angiography, our institutional intraobserver and interobserver variabilities are 5.3% and 8.0%, respectively (unpublished data).

**Image Analysis**

The volume data sets of HCT and magnetic resonance angiography were reconstructed on a computer workstation (Advantage Windows; General Electric). Aortic diameters were measured at the following six intrathoracic levels: aortic valve sinus; ascending aorta at the level of the right pulmonary artery; proximal to the innominate artery; proximal transverse aortic arch; distal transverse aortic arch; and the aortic isthmus at its narrowest point (Fig 1). In patients with prosthetic bypasses, the graft and the anastomosis with the aorta were depicted. The slices for the measurements were manually adjusted separately for each aortic level to get an oblique plane that was strictly perpendicular to the course of the aorta. The internal vessel diameters were measured in three different directions by an electronic caliper. Those three estimates were made, and the arithmetic mean was used for performing further calculations. All HCT scan and MRI estimations and measurements were performed by the same person (ie, one of the authors).

To describe morphologic aortic wall irregularities and other anatomic details, additional oblique planes were reconstructed from the HCT scan data set to be compared with the axial, frontal, and double-oblique planes of the MRI spin echo sequences. Furthermore, three-dimensional reconstruction with surface rendering was performed from the volume data sets of both image modalities.
Both HCT scanning and MRI were performed in all patients without significant complications. HCT scanning and MRI clearly depicted the morphologic details of the investigated structures. All predefined levels could be adjusted perpendicular to the course of the thoracic aorta, even in patients with aortic distortion due to thoracic scar formation or kyphoscoliosis.

The aortic diameters measured with both methods correlated highly (Table 1). The mean difference of all measurements was $1.20 \pm 2.58$ mm (Fig 2). There was a slight bias toward larger diameters in HCT scans. Nevertheless, the scatter of these differences was quite high. Differences of 5 to 9 mm occurred in 15 pairs of measurements in 13 patients. They occurred at all levels. There was no correlation between these differences and the time period between the two imaging studies (Fig 3).

We did not find differences in pathomorphologic findings between HCT scanning and MRI. Both methods equivalently demonstrated restenosis or residual stenosis, hypoplastic aortic arch, distal displacement of the left subclavian artery (Fig 4), kinking of the aorta, type, localization, and course of prosthetic conduits (Fig 4), poststenotic dilatation of the descending aorta, ectasia of the ascending aorta, local aneurysm at the previous operation site, bulging patches (Fig 5), and reopening of the arterial duct in individual patients.

The differences between HCT scanning and MRI regarding image quality were negligible for clinical purposes. There was a slightly better image resolution for HCT scans in axial planes (Fig 5). In the other planes, spin echo sequences of MRI could be adjusted by the investigator to the optimal resolution (Fig 6). Due to ECG triggering of the spin-echo sequences, those MRI images provided a better image quality at the aortic bulb in some patients, while in HCT scans movement artifacts caused the

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**Table 1—Diameters of the Aorta at Six Intrathoracic Levels Measured by HCT Scanning and MRI in 37 Patients With Native, Balloon-Dilated, or Operated CoA**

<table>
<thead>
<tr>
<th>Aortic Level</th>
<th>HCT Scan</th>
<th>MRI</th>
<th>$r$ Value$^\dagger$</th>
<th>IIV, $^\ddagger$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aortic valve sinus</td>
<td>31.5 ± 6.6</td>
<td>30.1 ± 6.8</td>
<td>0.877</td>
<td>11</td>
</tr>
<tr>
<td>Ascending aorta</td>
<td>29.5 ± 6.8</td>
<td>29.1 ± 5.8</td>
<td>0.929</td>
<td>9</td>
</tr>
<tr>
<td>Proximal to innominate artery</td>
<td>25.3 ± 5.1</td>
<td>24.6 ± 4.6</td>
<td>0.889</td>
<td>9</td>
</tr>
<tr>
<td>Proximal transverse aortic arch</td>
<td>21.3 ± 4.3</td>
<td>19.9 ± 3.9</td>
<td>0.787</td>
<td>13</td>
</tr>
<tr>
<td>Distal transverse aortic arch</td>
<td>19.2 ± 3.7</td>
<td>17.6 ± 3.4</td>
<td>0.852</td>
<td>11</td>
</tr>
<tr>
<td>Aortic isthmus</td>
<td>20.7 ± 6.4</td>
<td>19.3 ± 6.7</td>
<td>0.941</td>
<td>11</td>
</tr>
</tbody>
</table>

$^\dagger$Values given as mean ± SD, unless otherwise indicated. IIV = interinvestigational variability.

$^\ddagger$p < 0.001 for all correlations.

$^\ddagger$Calculated from SD (differences)/mean (measured values) × 100%.
serration of contours on sagittal (Fig 6) and coronal reformations, and blurring in axial reformations.

**Discussion**

Our study demonstrated that both HCT scanning and MRI assess all clinically relevant anatomic features after CoA treatment with a similar high quality. Both methods are noninvasive or minimally invasive and allow the entire thoracic aorta to be viewed within a short investigation time. Conventional transverse images and also angled paraxial reformations of the thoracic arteries are possible. Three-dimensional reconstructions create excellent images of the aortic anatomy and are particularly useful for providing the spatial relation of complex vascular arrangements.

The high resolution and unrestricted choice of planes mean that all relevant vascular diameters can be measured with a high precision. Diameter measurements at our predefined levels showed that there is only minor bias to larger diameters in HCT scans, which was not relevant for diagnostic purposes.

However, there was a substantial scatter between two subsequent measurements made with different methods. Differences between the measurements reached unacceptable values of up to 9 mm. Whereas each of the methods has an acceptable intraobserver and interobserver variability, we calculated an interinvestigational variability of 11% in the present study comparing the two different imaging methods.

The time interval between the two investigations was not related to the diameter difference. Also, the natural changes could not explain the differences, as a rough estimation of the changes in the diameter of the aging aorta should be an increase of about 1 mm per decade, as was previously shown by our study group. In the present study, the first investigation was most often the HCT scan, which showed slightly higher values, and therefore a decrease with time has to be explained.

Diameter differences were at least in part due to the pulsation of the aorta. Only an exact ECG trigger allows the definition of whether diameters are obtained in systole or diastole. Both HCT and magnetic resonance angiography, as performed in our study,
lack that trigger. Therefore, HCT scanning showed a serration of contours on sagittal and coronal refor-
mations, and magnetic resonance angiography showed blurred vessel borders.

Stern et al also described this scatter when they compared ECG-triggered spin-echo MRI with an-
giography, although all measurements were performed at the end of the diastole. Differences of up to 8 mm were found in 14 patients. Kappetein et al examined the differences in aortic diameters obtained by two observers who were blinded to each other and used identical MRI data sets. Even those mean differences were 0.53 ± 1.83 mm at the distal aortic arch, 0.59 ± 1.21 mm at the isthmus, and 2.55 ± 2.39 mm in the descending aorta. Again, the scatter reached almost the same range as ours.

Consequently, it must be outlined that in repetitive studies on an individual patient changes of up to 9 mm in aortic diameters can be due to normal scatter. This fact has to be kept in mind when drawing therapeutic conclusions from an alleged “progression” of the aortic diameter. This may be relevant in patients with aortic aneurysm or some types of chronic dissection, especially in patients with Marfan syndrome, in which the increase of aortic diameters is an indication for surgical treatment. Kawamoto et al proposed that an increase of the aortic diameter of > 3 mm is significant. This

![Diagram](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/22017/)

**Figure 3.** Comparison of the thoracic aortic diameters measured by HCT scanning and MRI in 37 patients with CoA. The differences between both measurements are not correlated with the time period between the two measurements (aortic valve sinus, r = 0.073; p = 0.698; ascending aorta, r = -0.152; p = 0.413; proximal innominate artery, r = -0.145; p = 0.437; proximal transverse aortic arch, r = -0.268; p = 0.144; distal transverse aortic arch, r = 0.161; p = 0.386; isthmus, r = 0.159; p = 0.393; all levels, r = -0.033; p = 0.656). See the legend of Figure 2 for abbreviation not used in the text.
threshold, however, is based on the measurements of a single observer for a single data set (intraobserver variability) and not on the measurements of different investigators in different studies who perhaps were using different methods, which is the standard clinical setting.

**Figure 4.** Visual comparison of a three-dimensional reconstruction with surface rendering of a volume data set obtained by HCT scanning (left) and MRI (right). The pictures show the thoracic aorta of a 22-year-old patient with CoA after end-to-end anastomosis at the age of 1 month from a dorsal perspective. After restenosis, a patch aortoplasty was performed (at age 14 months). Because of severe aortic valve regurgitation and stenosis, and a dilated ascending aorta, a homograft was implanted at the age of 13 years. Six years later, the homograft degenerated and the aortic isthmus was obliterated. The aortic homograft was replaced by a valved conduit, and the atretic isthmus was bypassed with an extra-anatomic conduit (C) from the ascending aorta (AAo) to the descending aorta (DAo). Now, imaging clearly demonstrated the obliterated isthmus, the wide proximal and distal anastomoses of the conduits, a kinking of the conduit, and the distally malpositioned origin of the left subclavian artery.

**Figure 5.** Visual comparison of an axial plane through the thorax slightly under the aortic arch obtained by HCT scanning (left) and MRI (right). The pictures show the aorta of a 16-year-old patient with CoA after undergoing dacron patch aortoplasty. The patch is bulging backward (arrow). T = trachea; V = vertebral body. See the legend of Figure 4 for abbreviations not used in the text. Direct comparison reveals the higher resolution of HCT scan in the axial plane.
CONCLUSION

Both HCT scanning and MRI are very sensitive for the detailed imaging of the aorta, which facilitates diagnoses and, under certain circumstances, decisions regarding treatment. The indication of which method should be preferred depends mainly on local availability, the experience of the investigator, and sometimes on contraindications. In young patients or repetitive studies, radiograph exposure and contrast media application count against the performance of HCT scanning.

In repetitive studies, changes in the diameters should be interpreted with care. They must not be extrapolated to longer time spans as the normal scatter of the measurements can be exponentially increased and can simulate progression.

Limitations

To make HCT scanning and MRI comparable, we compared contrast-enhanced data sets only. In MRI, this is not always necessary. Operator-adjusted axial, frontal, and double-oblique spin-echo planes can be diagnostic, and contrast media need not routinely be used. Furthermore, these spin-echo images can be triggered by ECG, and, therefore, blurring at the wall of the moving ascending aorta can be avoided.

Another limitation of the study was the time period between the two imaging studies. But there was no correlation between the time period between the two imaging studies and the change in diameter.

Meanwhile, both the HCT scanning and MRI techniques have been improved further since the end of the study. Multislice CT scanning with 4 detector rows (and soon 16 detector rows) has increased resolution further and has almost completely resolved pulsation artifacts, if ECG triggering or gating is performed. Also, MRI regularly updates, and, for example, real-time MRI is already available. But these improvements will still take years to become the standard technique that is available everywhere.

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