Preoperative assessment of the aortic arch in children younger than 1 year with congenital heart disease: utility of low-dose high-pitch dual-source computed tomography. A single-centre, retrospective analysis of 62 cases

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Received 1 August 2013; received in revised form 15 October 2013; accepted 21 October 2013

Abstract

OBJECTIVES: To evaluate the feasibility, image quality and impact of 3D imaging in low-dose high-pitch dual-source computed tomography (DSCT) to assess arbitrary anatomical malformations of the aortic arch in children <1 year of age with congenital heart disease (CHD).

METHODS: Between January 2010 and May 2013, DSCT was performed to assess the aortic arch anatomy in a total of 62 consecutive patients with CHD (aged 0–348 days). DSCT was used whenever conventional echocardiography was not sufficient to display the complex anatomy entirely. Image data acquisition was realized within a single cardiac cycle using prospective ECG triggering. 3D reconstruction for surgical planning was performed. Image quality was assessed retrospectively, using a 4-point scale from '1 = no artefacts' to '4 = uninterpretable'. The accuracy and impact of the 3D reconstructions was compared with intraoperative findings using a 5-point scale (from '1 = essential' to '5 = misleading'). Administered radiation exposure was evaluated.

RESULTS: Imaging was successful in all patients, image quality was rated 1.34 on the 4-point scale and the impact of the 3D reconstructions for surgical planning was 2.05 on the 5-point scale. Mean dose-length product was 6.8 ± 2.6 mGy cm, and the effective dose was 0.45 ± 0.13 mSv (0.21–0.74).

CONCLUSIONS: DSCT is a fast and appropriate imaging modality in the preoperative assessment of the aortic arch for surgical planning in CHD.

Keywords: Newborn • Complex vascular anatomy • Computed tomography • 3D imaging • Low radiation

INTRODUCTION

Detailed anatomical information is essential for planning surgical therapy in patients with congenital heart disease (CHD). In the last years, preoperative imaging evolved from the diagnostic cardiac catheterization to less invasive modalities, namely echocardiography, computed tomography (CT) and magnetic resonance imaging (MRI). Echocardiography as the gold standard [1] is often inadequate to visualize the aortic arch sufficiently [2]. MRI imaging usually requires sedation or controlled anaesthesia in patients <6 years of age and a long scanning time of usually 45 min [3–5]. This should be avoided, especially in critically ill neonates with CHD.

The dual-source computed tomography (DSCT), a second-generation spiral CT, is characterized by markedly improved time resolution [6]. This so-called Flash-CT uses two tubes, allowing a high pitch of 3.4 (table speed of 450 mm/s). With a gantry rotation time of 280 ms and a 128 × 0.6 mm slice acquisition, the whole thorax of a patient can be scanned within considerably <1 s, making sedation or breathholding unnecessary. With prospective ECG triggering and a 80-kV tube voltage setting, the total radiation dose can be reduced following the ALARA principle (as low as reasonably achievable). These are the main reasons making this technique attractive for a fast and save image acquisition, with respect to surgical planning of patients with CHD. Furthermore, the acquired raw data permit a fast 3D reconstruction, allowing an easy comprehension of a difficult 3D anatomy. Therefore, we retrospectively evaluated 62 cases, in which the ultrafast image acquisition of DSCT was used to assess the arbitrary anatomical
malformation of the aortic arch preoperatively. Image quality and radiation dose were evaluated as well as the advantage of 3D images for surgical planning.

MATERIALS AND METHODS

Sixty-two consecutive patients <1 year of age with CHD and complex aortic arch malformation were included in this study retrospectively. CT was performed to plan surgical therapy because echocardiography left unanswered questions on detailed anatomy. Imaging was performed using a second-generation DSCT (Definition Flash, Siemens Healthcare, Forchheim, Germany) with the following scan parameters: 0.28 s gantry rotation time; 450 mm/s table speed (pitch: 3.4); 128 × 0.6 mm slice acquisition; real-time anatomy-based tube current modulation (CAREDose4D) at 80-kV tube voltage. 3D reconstruction was performed with Aquarius iNtuition (TeraRecon, Inc., San Mateo, CA, USA). In all patients, contrast agent was manually injected without delay (Iomeprol, 2 ml/kg body weight, 300 mg/ml; Imeron 300, Bracco Imaging, Konstanz, Germany). For assessment of image quality, we retrospectively analysed the datasets using a 4-point scale [7]: 1 = no artefacts, 2 = fully interpretable with mild artefacts, 3 = interpretable regarding the origin of the coronaries despite artefacts, 4 = uninterpretable. In all 62 cases, we created 3D dataset using the volume-rendering technique (VRT). All these VRT models as well as conventional 2D multiplanar reconstruction were presented to the cardiac surgeons during preoperative interdisciplinary conferences. The cardiac surgeons rated the value of the 3D image retrospectively, using a previously published 5-point Likert scale [8, 9]: If the surgery could not have been performed appropriately without the information provided by the 3D model, the case was rated ‘essential’. When it was felt to add important information to what had already been available, the case was rated ‘very useful’. Whenever the addition of 3D information for cardiac surgery was felt to be only minimally superior, the case was rated ‘useful’. If the surgery did not benefit from added 3D data, the case was rated ‘not useful’ and if the 3D information was conceived to be incorrect or misleading, the case was labelled ‘misleading’. For estimation of radiation dose, the resulting volume CT dose index (CTDIvol) and the dose length product (DLP) were recorded after each examination. The effective dose was calculated from the DLP and the related conversion factor (neonates: 0.0823, infants <1 year: 0.0525), referring to a chest scan with an 80-kV tube voltage setting, according to Deak et al. [10] (International Commission on Radiological Protection (ICRP) publication 103).

RESULTS

During the 3-year study period, in a total of 62 infants (40 neonates) with CHD, imaging was performed by DSCT to assess the malformed aortic arch preoperatively (Fig. 1). Characteristics of the study population are shown in Table 1, the underlying cardiac diagnosis in Table 2. Imaging was successful in all cases without recorded serious adverse events. The median age of the patients (36 males) was 6 (0–348) days. The median body weight was 3.45 (2.06–8.62) kg and the median height was 51 (44–76) cm. The median DLP was 6 (4–13) mGy cm and the corresponding effective dose was 0.42 (0.21–0.74) mSv (ICRP 103).

Figure 1: A 3-day old boy with interrupted aortic arch type B and bicuspid aortic valve. DSCT was performed for the accurate location of the interruption and associated defects to plan surgery. (A) View from anterior, volume-rendering technique (VRT), demonstrates the small aorta (star) with its bifurcation in the right brachiocephalic artery (BA), the left common carotid artery (LCA) and the huge pulmonary artery (circle). (B) View from posterior, the interruption of the aortic arch is shown, the descending aorta (DA) is connected with the pulmonary trunk above the arterial duct (PDA). The left subclavian artery (LSA) arises from the DA. RPA: right pulmonary artery. (C) VRT slab with axial sectional view shows the small bicuspid aortic valve, 1: left coronary artery, 2: right coronary artery. (D) VRT slab to visualize the PDA and its course to the DA, the position of the VSD (triangle) and the relationship to the aortic valve. LPA: Left pulmonary artery, LV: left ventricle, RV: right ventricle.
In most cases (95%), image quality was fully interpretable with no or mild artefacts and in 5% interpretable regarding the origin of the coronaries despite artefacts (mean score 1.34 on the 4-point scale).

The impact of the 3D VRT images on surgical planning (mean score 2.05 on the 5-point scale) was rated essential in 6 cases (10%), ‘very useful’ in 47 cases (76%) and ‘useful’ in 9 cases (14%). It was never rated not useful or even misleading. In 3 cases, the information of tracheal obstructions was essential for surgery, leading to modified surgical concepts to decompress or to reconstruct the trachea. In 3 cases, the information about an atypical course of the aorta with spatial relationship to the pulmonary arteries and the air passages was rated essential for surgery (Fig. 2).

**DISCUSSION**

Surgeons are confronted with the problem of complex anatomy in various malformations of the aortic arch in patients with CHD. The spatial relationship of the aorta, arterial duct, pulmonary arteries and venous vessels from the lungs and the body circulation as well as the air passages have to be considered in the reconstructive surgery. Therefore, the optimal preoperative planning needs adequate imaging. 3D imaging of all these structures facilitates the preparation for interventions without the need for an experienced imaginativeness of all participants [11]. In our study, we evaluated the impact of 3D imaging by DSCT in children aged ≤1 year with CHD. With our presented acquisition protocol, imaging was successful in all 62 cases with an effective dose of <0.8 mSv. The achieved image quality was rated 1.5 on a 4-point scale, and thus, it was fully interpretable in all cases.

Echocardiography as gold standard in imaging of CHD is often limited by a poor acoustic window and is often insufficient in displaying the aortic arch. Air passages and complex 3D relationships cannot be shown entirely. Neonates with critical heart disease may be seriously affected by long or invasive examinations outside the intensive care unit, such as cardiac catheterization lab or MRI imaging in general anaesthesia. Even extensive evaluations by echocardiography may hold the risk of stress or hypothermia, making a sick neonate increasingly unstable. The duration should be minimized, particularly in critically ill children [12].

A fast and comprehensive imaging modality is required in complex cases. In 2006, Lee et al. [13] first reported their experience with multidetector computed tomography (MDCT) in neonates with complex CHD to replace initial cardiac catheterization.

They confirmed the clinical and technical feasibility of MDCT. First results of use and feasibility of paediatric cardiac DSCT were presented by Kuettner et al. [14] in 2008 with good image quality, even in two neonates. In 2009, Ben Saad et al. presented a study, in which 110 babies with CHD were enrolled by DSCT. They achieved diagnostic quality in 89% of examinations. In the majority of these very young children, even visualization of the coronary arteries was possible, especially when ECG-gated cardiac DSCT was performed. The DLP was 8 ± 6 mGy cm in non-ECG-gated and 21 ± 9 in ECG-gated acquisitions [15]. In 2010, Ellis et al. reported their experience with preoperative CT scans in 33 patients, using a Siemens 64 slice MDCT scanner. They assessed the utility of CT scans and rated them important in procedures involving the aorta and underlined the impact of CT in almost all patients undergoing surgery of CHD [9]. In the study of Cheng et al. (2009), ECG-triggered DSCT was performed prospectively in 55 patients. The mean DLP was 19.86 ± 6.27 mGy cm. The diagnostic accuracy was rated over 97% and superior to that of transoesophageal echocardiography [16]. The use of ultrafast and low-dose DSCT of the paediatric chest was published by Lell et al. in 2011. They underlined their practice to perform the image acquisition without any sedation [17].

The studies mentioned above clearly demonstrate the exceptional image quality of contrast-enhanced CT scans in the investigation of children with CHD, especially when DSCT is used. As a consequence of the technical improvement of the DSCT, neonates and young children also benefit from dose reduction and shortening of the acquisition time. The improved temporal resolution enables imaging without breathhold or sedation. This underlines

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**Table 1:** Demographic and procedural data, median (with range) or number (percentage of total, median ±SD)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All</th>
<th>Neonates</th>
<th>Infants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>62 (100%)</td>
<td>40 (68%)</td>
<td>22 (32%)</td>
</tr>
<tr>
<td>Age (days)</td>
<td>6 (0–348)</td>
<td>4 (0–27)</td>
<td>96 (31–348)</td>
</tr>
<tr>
<td>Male patients</td>
<td>36 (58%)</td>
<td>24 (60%)</td>
<td>12 (55%)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>3.45 (2.06–8.62)</td>
<td>3.19 (2.06–4.54)</td>
<td>5.62 (2.35–8.62)</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>51 (44–76)</td>
<td>51 (44–56)</td>
<td>58 (48–76)</td>
</tr>
<tr>
<td>Image quality (4-point scale)</td>
<td>1.34 (±0.57)</td>
<td>1.35 (±0.62)</td>
<td>1.31 (±0.48)</td>
</tr>
<tr>
<td>Value 3D reconstruction (5-point scale)</td>
<td>2.05 (±0.49)</td>
<td>1.98 (±0.42)</td>
<td>2.18 (±0.51)</td>
</tr>
<tr>
<td>Dose-length-product total (mGy cm)</td>
<td>6 (4–13)</td>
<td>6 (4–9)</td>
<td>8 (4–13)</td>
</tr>
<tr>
<td>Effective dose (mSv)</td>
<td>0.42 (0.21–0.74)</td>
<td>0.49 (0.33–0.74)</td>
<td>0.42 (0.21–0.68)</td>
</tr>
<tr>
<td>Used conversion factor [10]</td>
<td></td>
<td></td>
<td></td>
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</table>

**Table 2:** Cardiac diagnosis of all children

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congenital corrected transposition of the great arteries</td>
<td>10</td>
</tr>
<tr>
<td>Dextro-transposition of the great arteries (5 patients</td>
<td>9</td>
</tr>
<tr>
<td>associated with ventricular septal defect and hypoplastic aortic arch, 3 patients with coronary anomalies)</td>
<td></td>
</tr>
<tr>
<td>Common arterial trunk</td>
<td>8</td>
</tr>
<tr>
<td>Aortic arch hypoplasia</td>
<td>8</td>
</tr>
<tr>
<td>Univentricular heart with complex defects</td>
<td>7</td>
</tr>
<tr>
<td>Pulmonary atresia with ventricular septal defect</td>
<td>4</td>
</tr>
<tr>
<td>Heterotaxia with aortic malformation</td>
<td>4</td>
</tr>
<tr>
<td>Interrupted aortic arch</td>
<td>4</td>
</tr>
<tr>
<td>Others</td>
<td>8</td>
</tr>
</tbody>
</table>
Figure 2: A girl with mesocardia, persistent truncus arteriosus type 1, bicarotid trunk and hypoplastic trachea caused by complete tracheal rings. Slide tracheoplasty was needed in addition to the cardiac surgery. Imaging was performed to display the arterial trunk with the uncommonly long pulmonary trunk and its relation to the air passages. (A) View from anterior, volume-rendering technique (VRT), demonstrates the mesocardia with right (RV) and left ventricle (LV), the position of the truncus arteriosus (TA), the pulmonary artery (circle) arising from the truncus and the bicarotid trunk (BCT). (B) View from the left side. The long pulmonary artery with its course over the aortic arch and the pulmonary bifurcation behind the aorta. DA: descending aorta. (C) Posterior view clearly demonstrates the right descending aorta with BCT and right subclavian artery (RSA) and the pulmonary bifurcation behind the aorta into right (RPA) and left pulmonary artery (LPA). (D) Posterior view with the course of the hypoplastic trachea (rhomb) and its relationship to aorta and pulmonary artery. The arrow indicates the nasogastric feeding tube.

Figure 3: A 5-day old girl with transposition of the great arteries (TGA), ventricular septal defect (triangle), hypoplastic aortic arch, anomalous return of the pulmonary veins (PV) via a common pulmonary vein (CPV) connected with the left atrium (LA). Complete vascular ring with right aortic arch and huge left-sided arterial duct. The DSCT was performed to assess the severely hypoplastic transverse arch and for planning of reconstructive surgery. (A) View from anterior, volume-rendering technique (VRT), demonstrates the anterior position of the aorta (star) and normal coronary anatomy with left anterior descending artery and left circumflex coronary artery from sinus 1 (1) and the right coronary artery from sinus 2 (2). RAA: right atrial appendage, LAA: left atrial appendage, PDA: arterial duct, Circle: pulmonary artery. (B) View from posterior. Right aortic arch with (1) left common carotid artery (LCA), (2) right common carotid artery (RCA) and (3) right subclavian artery (RSA). Severe hypoplastic aortic isthmus stenosis (AA) connected to the left descending aorta (DA). The left subclavian artery (LSA) arises from the DA. (C) VRT slab for planing of arterial switch and coronary transfer and to visualize the three sinus of the aortic valve, 1: left coronary sinus, 2: right coronary sinus, 3: non-facing sinus. (D) VRT slab visualizing the arterial duct and the relationship of the VSD (triangle) to the aortic valve.
the impact of this comprehensive imaging technique, particularly
in critical ill and haemodynamically instable patients.

With our acquisition protocol, our calculated effective dose was
0.45 mSv (mean value) in neonates (DLP 6 mGy cm) and 0.42 mSv
(DLP 8 mGy cm) in infants. Compared with the studies mentioned
before, our results demonstrate the potential for further reduction
of radiation dose by the use of DSCT, especially when imaging
protocols adapted to neonates and young children are implemen-
ted. The effective dose in CT is calculated from DLP using speci
cific conversion factors. In our study, we applied the new, increased
conversion factors [10] for paediatric patients, implicating the
selected tube voltage.

In our study, we were able to achieve major imaging quality
with a minimum radiation dose using the DSCT technique with
adapted dose protocols. All complex variations of aortic arch
anomalies in infants with CHD could be demonstrated in a con-
vincing image quality, including coronary arteries (Fig. 3). The
generated raw data allow a fast 3D reconstruction, making surgical
planning easier and more successful. Understanding of patho-
logical anatomy now becomes independent of an experienced
imaginativeness (Fig. 4).

Echocardiography, as the gold standard in imaging of CHD
should not be replaced. In less complex cases like coarctation of
the aorta or non-complex transposition of the great arteries,
echocardiographic analysis might be sufficient to assess aortic
malformation. However, in difficult malformations, residual doubt
in the diagnosis and unclear course and shape of the aortic arch,
DSCT is a fast, safe and exact imaging modality, with the ability to
answer all questions regarding anatomy. It allows an advanced
preoperative planning by 3D imaging. In our experience, DSCT is
especially helpful in guiding the surgical management in patients
with complex malformation, such as univentricular hearts with
complex defects, interrupted aortic arch or heterotaxia. The value
of 3D imaging for various atypical heart positions, abnormality of
systemic and pulmonary veins, great arteries and air passages in
patients with isomerism is outstanding.

STUDY LIMITATIONS

Our study is retrospective. The value of 3D imaging was subject-
ively rated by cardiac surgeons and cannot be purely objective.
We did not compare the achieved image quality of the high-pitch
spiral mode on DSCT with that of previous-generation CT.

CONCLUSION

We report preliminary data on the value and feasibility of 3D
imaging of aortic arch malformations in infants with CHD. The

Figure 4: Asplenia syndrome with mirror-image dextrocardia, pulmonary atresia, supracardiac total anomalous pulmonary venous return and atriointerventricular septal
defect in a 1-day old girl. CT imaging and 3D reconstruction to display comprehensively the atypical heart position, abnormality of systemic and pulmonary veins and
the great arteries. (A) This image in anterior view demonstrates the preoperative situs with dextrocardia. (B) After removing the rib cage, the anterior position of the
aorta is seen (star), the common pulmonary vein (CPV) with connection to the innominate vein and its course to the left superior vena cava (LSVC) and the right
atrium (RA). DA: descending aorta. (C) View from posterior displaying the aortic arch, PV: pulmonary vein, LPA: left pulmonary artery, RPA right pulmonary artery.
Right aortic arch with left subclavian artery (LSA) and left common carotid artery (LCA) followed by the arterial duct (PDA), right common carotid artery (RCA) and
right subclavian artery (RSA). (D) VRT slab from anterior demonstrating the spatial relationship between aorta and the anomalous pulmonary venous return and the
pulmonary branches.
complex vascular anatomy and the surrounding tissue can be displayed entirely by an ultrafast sub-second examination of DSCT, making breathhold or sedation unnecessary. This is most advantageous in critically ill neonates and indicated whenever conventional echocardiography is inadequate to display the complex anatomy in detail. The impact of this advanced 3D imaging on surgical planning is outstanding. Imaging can be performed with an effective dose below 0.5 mSv. The rapid development of dose-reducing scanning techniques and new methods of post-processing may support the clinical use of this modality in the future.

Conflict of interest: none declared.

REFERENCES