ORIGINAL REPORT

Quality of 3D magnetic resonance imaging of coronary arteries in patients with D-transposition of the great arteries after the Jatene switch procedure

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Abstract
Objectives: To evaluate the quality of images obtained with 3D balanced fast-field echo whole heart (WH3D) MRI sequences for assessing the coronary anastomosis and coronary stenosis in patients with D-transposition of the great arteries who have undergone the Jatene switch procedure.
Material and methods: We retrieved 100 WH3D studies done in 83 patients who had undergone the Jatene switch procedure from our pediatric cardiac MRI database; 84 of these studies fulfilled the criteria for inclusion in the study. We evaluated coronary stenoses on WH3D MR images and their correlation with coronary CT or angiography images. We retrospectively studied the quality of the images of the proximal coronary arteries using a four-point scale and correlating the findings with age, heart rate, and heart size.
Results: Of the 84 studies, 4 (4.8%) were of a quality considered “insufficient for diagnosis”, 7 (8.3%) were considered “fair”, 23 (27.4%) “good”, and 50 (59.5%) “excellent”. The quality of the image of the coronary arteries was significantly correlated with heart rate. MRI detected stenosis in the origin of the coronary arteries in 9 (10.7%) studies.
Conclusion: Images obtained with the WH3D MRI sequence in patients who had undergone the Jatene procedure were of diagnostic quality in most cases and were better in patients with lower heart rates. In 10.7%, stenosis in the origin of the coronary arteries that required new studies was detected.

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Introduction

D-transposition of the great arteries (D-TGA) affects approximately 0.24/1000 of newly born children. It is the second most diagnosed congenital cardiopathy in the neonatal period, and the most common cause for referring newborn patients to units specialized in neonatal cardiology. Although it is thought that it originates when the arterial cone is malformed, the embryologic mechanism is not known, and genetic alterations have not been detected up to this date. It is an inverted anatomic relation of the great arteries with the ventricles in which the aorta—extending the right ventricle, is usually located to the front and to the right while the pulmonary artery—stemming from the left ventricle, is located to the left and to the rear end. When talking about D-TGA we mean the anomalous position of the great vessels with right ventricular loop (D loop) not including other types of transposition of the great arteries (L-TGA, ventricular anomalies with TGA, etc.). In newborns with closed foramen ovale, this disposition of the great vessels is only compatible with life while the ductus arteriosus remains open. In the different variants with correlated anomalies (atrial septal defect, ventricular septal defect, pulmonary stenosis), patients can survive for years with more or less cyanosis, depending on the degree of shortcircuit.

The initial treatment of D-TGA seeks to keep the newborn alive, first with prostaglandin E1, to keep the ductus arteriosus open and then referring patients without prenatal diagnosis to a neonatal unit specialized in neonatal cardiac care. If not operated urgently a balloon intratrial communication is generally performed (Rashkind’s procedure) and, at a later time, the anatomic alteration is surgically corrected in most patients through the technique described by Jatene (Jatene’s arterial switch) in 1976 that became the elected technique in the late 1980s. It consists of cutting the trunk from the pulmonary artery and the aortic root above the aortic sinus, and the origin of the coronary arteries to later reimplant the aorta and pulmonary artery in the normal place, and the coronary arteries in the new location of the aorta. The operative complications include stenoses of the supravalvular pulmonary artery and pulmonary arteries, the dilatation of the new aortic sinus with secondary valvular failure, the alteration of heart rate (way stranger than with prior atrial physiological correction) and the obstruction of coronary flow with subsequent ventricular dysfunction. The cardiac magnetic resonance (CMR) allows us to study from the morphological level the great vessels, the cavities and cardiac valves, the ventricular and valvular function and the status of the myocardium. Through high-resolution sequences such as whole heart 3D (balanced fast field echo, whole heart 3D [WH3D]) it is also possible to determine the patency of the coronary artery anastomosis. The incidence of long-term coronary events due to post-operative stenosis is present in 3–10% of patients. That is why our goal was to assess the quality of images and the presence of proximal coronary stenosis through WH3D sequences in patients undergoing the Jatene technique.

Material and methods

Patients

We went through the pediatric CMR examination data base in our hospital (1537 examinations from February 2005 to November 2013). The patients’ informed consent
or permission from the Hospital Ethics Committee was not requested because this was a retrospective study on the image quality of the examinations and it did not represent any changes in the management of patients. The studies of patients operated with the Jatene procedure who had been examined with the WH3D sequence were included. The endoprostheses in the pulmonary arteries that made it impossible to assess coronary arteries were the only criteria of exclusion. The reason for excluding the patients with pulmonary endoprostheses was the bias that they introduced when correlating age, heart rate and ventricular volume with image quality, because these endoprostheses are carried by older patients, whose heart rate and ventricular volume are greater.

Study modality

All the examinations were performed with the magnetic resonance machine Intera 1.5 T (Philips Medical Systems, Best, Holland). Based on the patient’s age and weight, a flexible multielement antenna was used (infants and young children) or a heart-specific multielement antenna (older patients). The parameters for the WH3D sequence were: FOV 250–350 mm; effective cut thickness 1–2 mm (interpolated thickness 0.5–1 mm); repetition time 4 ms; echo time 2 ms; Tilt angle 90; Factor Sense 2. The sequence was performed with free respiration in nonanesthetized patients and with controlled respiration in anesthetized patients using respiratory synchronization with navigating pulse and cardiac synchronization (in tele-diastole in patients with <100 bpm frequency and in tele-systole with frequencies ≥100 bpm) with vectocardiogram. The acquisition time ranged from 4 to 10 min based on heart and respiratory rate, the efficiency of the navigating pulse and geometric parameters.

Two pediatric radiologists with 9 (CMR) and 2 (ALZ) years of experience in congenital cardiopathies assessed independently the quality of the images in a ViewForum R 6.1 station (Philips Medical Systems, Best, Holland). In general, IV contrast (Gadoteridol; 0.2 mmol/kg) was injected in the first postoperative study as part of our follow-up protocol, but not in the following studies.

To be able to determine the presence of coronary stenosis, we went through the radiological diagnosis in all studies to select the patients with a diagnosis of coronary stenosis and we analyzed the clinical evolution, the CT, the coronaryography and the surgical proceedings.

Analysis

The image quality of the WH3D sequence was established through a qualitative scale (Fig. 1): (1) not diagnostic: When the coronary arteries were not observed with enough quality so as to issue a diagnosis; (2) discreet: Image with noise, low signal, blurriness or not well-defined borders, but enough to rule out stenosis; (3) good: well-defined borders, with good signal; (4) excellent: perfectly-defined borders, good signal, very little blurriness or noise.

We checked the normal distribution of the population data through a histogram, interquartile coefficient/standard deviation and chart of the normal probability of quantitative parameters (age, heart rate and heart volume). The relation between image quality and the categorical variables (IV contrast, anesthesia) was analyzed through the Chi-square test, and the quantitative variables through the ANOVA test and Bonferroni’s correction. We separated the studies in 2 groups depending on the quality of images: non-diagnostic (1 point) and diagnostic (2, 3 and 4 points), and we linked them with the same quantitative variables with Student’s t test. The inter-observer concordance was studied through the kappa index. We used the statistical software SPSS 15.0 (SPSS Inc., Chicago, USA). The statistical significance was established for a p < 0.05.

Results

We recovered 100 child CMR studies in patients operated through the Jatene procedure. Sixteen of them were excluded for carrying endovascular pulmonary endoprostheses and 84 studies remained (30 female, 54 males) in 77 patients. The mean age was 10.59 years (range 0.66–19.96 years).

Inter-observer concordance for image quality was good (kappa 0.647; p < 0.001). The study did not allow us to assess the coronary arteries (quality 1, non-diagnostic) in 4 patients (4.8%) and quality was discreet in 7 (8.3%), good in 23 (27.4%) and excellent in 50 (59.5%).

In 7 patients (8.3%), the WH3D sequence was performed after injecting IV gadolinium for an angiographic sequence with contrast. Thirty-six of the studies were performed under general anesthesia (42.9%), with an mean age of 5.56 years, and 54 without anesthesia (57.1%), with a mean age of 14.36 years. No statistically significant relation was observed between image quality or diagnostic quality and the use of IV contrast agent or the use of anesthesia in the study, or with age though quality tended to be better in older patients (Fig. 2).

The average cardiac volume was 198.23 cm³ (range 44–474 cm³) and the average heart rate was 76.53 bpm (range 42–122 bpm). Both the quality of images and diagnostic quality statistically correlated with heart rate (p < 0.05) above all in the non-diagnostic examinations of excellent quality (Bonferroni, p < 0.05). The heart rate was significantly greater (t-Student, p < 0.017) in patients with non-diagnostic tests (average rate 96 bpm) than in those with examinations of diagnostic quality (average rate 75 bpm) (Fig. 3). Out of the 10 patients with over 100 bpm, 2 were non-diagnostic and only 3 of excellent quality—these numbers are lower than for the rest of patients.

In 9 studies (10.7%) we diagnosed a coronary stenosis. In 3 of these patients the CT coincided (Fig. 4), it was mild or doubtful in 4 (Fig. 5) and not performed in two.

Discussion

In 86.9% of the WH3D examinations the test quality was good or excellent, and only in 4.8% it was insufficient for diagnosis. High heart rate especially when >100 bpm, significantly predicted worse image quality and more insufficient studies for diagnosis. Quality tended to be worse in younger patients and in those with smaller cardiac volume. In 10.7% of the cases a coronary stenosis was diagnosed.
Jatene’s procedure has posed a fundamental change in managing and diagnosing D-TGA patients though it can have complications such as stenosis of the coronary artery anastomosis in the new aortic sinus, which is one of the most significant ones. In the case of coronary alterations, the CMR sequences have shown unequal results. Among the 3D modalities, the gradient-echo steady-state balanced FFE sequence has been one of the most reliable ones. Even though it is not possible to assess with good diagnostic quality as many coronary segments as with the CT, especially with machines of 64 or more detectors, if the diagnostic quality of the segment studied is good enough, its diagnostic accuracy, and especially its negative predictive value is similar to that of CT. Therefore, WH3D can be suitable to follow up patients in which the Jatene procedure is used. There are few series focused on the follow-up of D-TGA patients in which the Jatene procedure is used through multidetector CT and coronary MR 3D sequences.

In the only WH3D sequence study in patients in which the Jatene procedure is used 32 coronary arteries of 16 patients were studied. In 72% of the segments the quality was diagnostic going up to 100% in those >11 years old. In our series, in more than 95% of the patients the quality was good enough to be able to diagnose stenosis. The only variable that related statistically with both the diagnostic quality and the quality scale was heart rate. Quality got worse with rate making insufficient examinations grow. Although not significantly, image quality increased with the child’s age and heart size. The relation might not have been significant because all the patients under 8 years old were anesthetized for the test. This fact includes a bias when assessing these variables, because only the anesthetized patients maintain a constant respiratory rhythm (which is important to be able to synchronize the navigating pulse) and they do not show artifacts due to voluntary moves during the sequence—a common issue in children. In addition, the size of the sample can have an effect on this result. The intravascular signal is something we might expect to increase as well when contrast shortens the T1 but given the small number of cases with contrast no significant results were obtained for this variable.

Nine patients (10.7%) were diagnosed with coronary stenosis. Due to the possible limitations in space resolution and artifacts when a possible stenosis is detected through WH3D it is recommended to perform another bloodless procedure to be able to confirm it, especially a coronary CT with a multi-detector scanner. Although we have not assessed the specificity or the positive predictive value of CMR in coronary stenoses it definitely seems reasonable to assume that a positive result should be taken into account and it would

![Figure 1](image-url) Examples of the image quality scale for coronary artery (arrow). (A) Non-diagnostic quality. The coronary artery is hardly visible, and the possible stenosis cannot be assessed in the ostium. (B) Poor quality. Although there is noise and blur, stenosis in the coronary artery origin can be ruled out. (C) Good quality. Borders visualized clearly and stenosis can be ruled out with absolute certainty though there is a certain degree of noise and blur. (D) Excellent quality. Visualization of the proximal coronary artery with sharp borders and little noise.
change the complete diagnostic course of action for these patients. Similarly patients with a negative CMR result can be reasonably followed up through 2-year controls provided that they have a normal ventricular function and that there are not myocardial lesions or other complications.

The limitations of this study are the relatively limited number of patients as well as the biases aforementioned which influence the interpretation of the different variables. Nevertheless the study allows us to conclude that WH3D sequences showed diagnostic quality in most studies—actually excellent in more than half of them. We can also say that in patients with high heart rates the odds that the examination is non-diagnostic are higher, so another test might be needed for the study of coronary arteries. Another evident limitation is the lack of a reference standard to assess the diagnostic accuracy. The CT scans were heterogeneous (different techniques and different centers), non-systematized and with diagnostic limitations in 2 cases—heart rate and movement. The 64-cut CT scanner was installed in our hospital during the study and the more technical experience and study systematization we acquire the easier it is to enhance the quality of such examinations and standardize follow-up. As a matter of fact this study did not intend to analyze the diagnostic performance of the WH3D modality just its technical quality. Nevertheless it seems reasonable to perform regular controls in these children through MRIs and save CT for dubious cases or cases of poor quality as

Figure 2  Quality curves of the coronary artery image depending on cardiac volume (A), heart rate (B) and age in months (C).

Figure 3  Bar chart showing the image quality groups (A), and diagnostic quality (B) depending on heart rate. There was a statistically significant difference in both cases.
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Figure 4  Serious stenosis in the beginning of the left coronary artery (arrows) in the WH3D sequence (A) and after confirming it through CT (B). Catheterization (C and D) confirmed the diagnosis (black arrow), and one endoprosthesis was placed in the coronary ostium (arrow head).

Figure 5  Proximal segment stenosis of right coronary artery (arrow) in a 7-year-old patient with a heart rate of 80 bpm. In the CMR (A) it is possible to observe a stenosis of the proximal segment of the right coronary artery that cannot be ruled out through coronary CT (B) due to poor image quality.

long as digital angiography is not chosen based on clinical or therapeutic reasons only.

In sum in patients who underwent D-TGA through the Jatene procedure the quality of WH3D sequences to assess the stenosis of coronary anastomosis is diagnostic in nearly all patients and excellent in more than half of them. Heart rates >100 bpm foresee that the quality of the study will be worse and that the number of non-diagnostic examinations will go up. The diagnosis of coronary stenosis was suggested in 1 of every 10 studies which led to conducting alternative diagnostic tests.

Ethical responsibilities

Protection of people and animals. Authors declare that for this investigation no experiments on human beings or animals were performed.

Data confidentiality. Authors declare that in this article there are no data from patients.

Right to privacy and informed consent. Authors declare that in this article there are no data from patients.

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Conflict of interests

Authors declare no conflict of interests.

References