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Original Article

Non contrast versus contrast enhanced MRI of the great thoracic vessels in pediatric congenital heart disease: A quantitative and qualitative analysis

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ABSTRACT

Aim: To compare 3D steady-state free-precession (SSFP) non-contrast magnetic resonance angiography (NC-MRA) with contrast-enhanced MRA (CE-MRA) for quantitative and qualitative analysis of thoracic arteries in pediatric patients with congenital heart disease.

Methodology: Forty patients with thoracic vascular anomalies (22 boys & 18 girls) ranging in age between 6 months and 14 years (mean age 4.58 ± 4.5) were included in this prospective study. Measurements of the thoracic arteries were taken by 3D SSFP NC-MRA & CE-MRA. Image quality was assessed using a four-point score. Pearson's and Spearman's Correlation Coefficients were calculated for correlation analysis while Student's t and Mann-Whitney U tests were used for comparative analysis, Bland-Altman plots were employed to demonstrate the level of agreement between the 2 techniques.

Results: Measurements from NC-CMRA images were comparable to those from CE-MRA. All measures highly correlated ($r > 0.9$), 3D SSFP NC-MRA exhibited a significantly higher image quality score than contrast- enhanced MRA, the mean difference was significantly lower than that of the 3D SSFP; (p-value < 0.0001).

Conclusion: NC-MRA produced similar and comparable measurements of the thoracic arteries with superior image quality when compared to contrast- enhanced MRA in pediatric congenital heart defects.

1. Introduction

Congenital thoracic vascular abnormalities can occur as an isolated entity or in association with other congenital heart disease [1]. The progress in modern and less invasive cross sectional imaging procedures namely CT and MRI allowed possible replacement of invasive angiographic techniques thus reducing cost and morbidity while investigating these cases [2]. Even though the past few years witnessed a prompt progress in CT angiography, it has many disadvantages; including the hazards of ionized radiation, the iodinated contrast agent induced nephrotoxicity as well as its incapability of blood flow quantification [3].

Cardiac MRI has a superior diagnostic performance to echocardiography and provides a noninvasive substitution to CT angiography avoiding radiation exposure and overcoming many of its adversities [4]. Recent advances in MR imaging technology including hardware (e.g. gradients and radiofrequency coils) and imaging techniques (e.g. parallel imaging and pulse sequences) in addition to the dramatically upgraded sequence implementation by both 1.5 T and 3 T permitted elaboration and accurate assessment of the thoracic vessels without radiation exposure or intravenous iodinated contrast agent injection [2].

Contrast-enhanced magnetic resonance angiography (CE-MRA) is the standard technique for the comprehensive assessment of thoracic vessels which normally requires gadolinium-based contrast agent administration. While traditionally considered non-hazardous, these contrast agents are not entirely flawless. First, they add to the exam expenses. Next, obtaining an intravenous line access in pediatric patients with congenital heart defect or congenital vascular anomalies is often troublesome particularly with repeated follow-up studies [5]. Finally, the contraindication in patients with renal insufficiency owing to the recent identification of nephrogenic systemic fibrosis (NFS) which urged us to be cautious when considering gadolinium contrast administration in a certain subset of patients [6,7]. In addition, the prolonged breath hold technique of CE-MRA can be inconvenient to pediatric patients or patients suffering from cardiac or respiratory

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compromise [8].

Lately, a new MRA technique evolved with no contrast administration requirement. Cardiac and navigator-gated 3D steady-state free-precession (SSFP) non-contrast MRA (NC-MRA) has been proved to yield accurate qualitative assessment of the thoracic vessels [9]. By the use of ECG triggering, this technique limited data acquisition to one or two fraction of the cardiac cycle therefore reducing cardiac motion artifact [10]. 3D SSFP is a free breathing sequence, data acquisition is gated to expiration in order to compensate for respiratory motion, and this is accomplished by the use of a navigator beam tracking the diaphragmatic motion. This application enables a substantial upgrade in spatial resolution particularly isotropic voxel size by avoiding limiting the scan duration to a single breath hold [4].

In our study, the vessel measurements obtained from CE-MRA and NC-MRA were analyzed to validate their comparability and determine the possibility of using NC-MRA as an alternative and/or an adjunct to CE-MRA in pediatric patients with congenital heart disease.

2. Patients and methods

2.1. Study population

This prospective study was approved by our hospital's ethical committee, it included forty patients suspected or known to have thoracic vascular anomalies as verified by echo examination with or without associated cardiac anomalies (22 males & 18 females) their ages ranged from 6 months to 14 years with (mean age 4.58 ± 4.5). Patients were referred from the Pediatric Cardiology Clinic after obtaining required consents starting from February 2016 until January 2017.

Nineteen of our cases were post-operative/long term follow up cases as follows: 5 cases Fallot post total repair, one case post Senning operation, 4 cases post coarctectomy, 6 cases post arch repair, one case post PDA coil insertion, and two cases post balloon dilatation for bicuspid aortic valve (BAV).

Patients with pacemakers and metallic devices were excluded for patient's safety being an absolute contraindication for MR imaging.

2.2. Methods

2.2.1. MRI technique

Magnetic resonance imaging studies were performed using 1.5 Tesla MR imaging unit (Intera; Philips Medical Systems, Netherlands) by using a phased-array cardiac coil.

The CMR protocol includes pre- and post-contrast acquisitions.

- The 3D SSFP non contrast-MRA was performed using an ECG-gated and respiratory-triggered 3D balanced steady-state free-precession sequence with T2 preparation and fat suppression. Respiratory triggering was performed using a navigator placed on the right hemi-diaphragm with a 5 mm displacement window. 3D imaging was performed in either the coronal plane or the oblique sagittal plane. We preferred the oblique sagittal plane in cases of aortic coarctation as well as the ascending aortic aneurysm in the case of Marfan syndrome, whereas the coronal plane was used in cases of PDA; however in all cases all orthogonal planes were reviewed to confirm our findings.
- Post-contrast acquisitions: Contrast-enhanced MR angiography with the 3D contrast enhanced MR-angiography technique.
  - o 0.2 mmol/kg of gadolinium contrast agent (magnetovist) at 1–2 ml/s was injected manually with saline flushing following the injection. Five back to back consecutive phases were obtained in dynamic study with different acquisition times starting after 5 s from contrast injection , the best and intensely enhancing two phases were selected out of the scanned dynamic series for post processing.
  - o The acquisition of the contrast-enhanced MRA was done in all cases in the axial plane except in Marfan, bicuspid aortic valve and aortic coarctation cases where the sagittal plane was performed.

37 patients needed light sedation using oral Chloral Hydrate (10% syrup, 100 mg/ml) at a dose of 1 mg/kg.

2.2.2. Image analysis

Measurements were made in MPR mode using Philips Advantage windows workstation (Philips View Forum 7.2.0.1) with commercially available software View form, Philips Healthcare, Netherlands. Oversaturation was avoided by adjusting the gray scale of the monitor. To obtain vessel measurements, each of the examined vessels was displayed in 3 perpendicular planes, two of which were positioned along the vessel's long axis and one was assigned to its cross section. We measured the vessel's two short-axis diameters in standard anatomical axes. To prevent recall bias measurements from both techniques were obtained at different settings.

The data collected from the studies were:

I. Quantitative analysis

Through distance measurements at predetermined anatomical locations were obtained by both 3D SSFP NC-MRA & CE-MRA, The vessels measured were: *The ascending aorta* at the levels of the aortic root, sinotubular junction, and at the level of the right pulmonary artery**,** *the main pulmonary artery* at the level of the pulmonary artery bifurcation, *the right pulmonary artery* was measured in a plane passing through the ascending aorta, *the left pulmonary artery* just proximal to the first branch in a plane cutting through the descending aorta.

II. Qualitative analysis

A. Image quality

Datasets of 3D SSFP NC-MRA and conventional CE-MRA of the thoracic arteries were evaluated for visibility and sharpness using a four-point score [11] Table 1.

B. Detection of cardiac morphology

Detailed structural analysis by 3D SSFP NC-MRA and CE-MRA (including segmental morphology and residual defects) and correlating it with the reference methods (echo, CTA, conventional MRI, cardiac catheterization or surgical details), image quality was solely evaluated according to the previously mentioned scoring system (Table 1). A summary of all patient diagnosis by NC-MRA& CE-MRA correlated by reference methods as follows:

- Tetralogy of Fallot: (n: 10); age range, (1–13 years). Hypoplasia/aplasia of the main pulmonary artery and/or its main branches, subaortic VSD (n: 5), aortic overriding (n: 5), Right-side heart dilatation [10], & right sided aortic arch (n: 4). these findings were confirmed by cardiac catheterizations in 2 patient (balloon dilatation of branch

Table 1
. The four-point scale for evaluation of the image quality.

Description	Score
• Not visualized	0
• Poorly defined with substantial blurring such that any abnormalities could not be confidently evaluated.	1
• Well defined with mild blurring such that any abnormalities could be confidently diagnosed	2
• Excellent definition without blurring with high confidence in the diagnosis of any abnormalities.	3