Routine Unenhanced 2D MRI for Maximal Segmental Diameters of Thoracic Aorta

Nomeda Valeviciene  
Vilnius University Faculty of Medicine

Darius Palionis  (✉ darius.palionis@santa.lt)  
Vilnius University Faculty of Medicine

Sigita Glaveckaite  
Vilnius University Faculty of Medicine

Lina Gumbiene  
Vilnius University Faculty of Medicine

Zaneta Petrulioniene  
Vilnius University Faculty of Medicine

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Abstract

**Background:** Increasing demand for aortic dilatation imaging and complicated use of multiplanar image reconstructions (MPR) from 3D images for less experienced users inspired research of unenhanced 2D-MRI in order to reduce need for aortic MPR.

**Purpose:** To research robustness of unenhanced 2D-MRI with no need for MPR from 3D images by comparing maximal axial measurements of thoracic aorta in unenhanced “dark blood” (DB) and “bright blood” (BB) 2D-MRI images vs. contrast enhanced 3D-T1 MR angiography (ce3D-MRA) both in patients with tricuspid (TAV) and bicuspid (BAV) aortic valves.

**Material and Methods:** Prospective study. 68 subjects underwent MRI and US examinations of aorta and were divided into 2 groups: 1) TAV patients: 26 patients, age: 53.3±8.1 years, 14 males and 12 females; 2) BAV patients: 42 patients, age: 30.8±9.8, 31 males and 11 females.

**Results:** Strongest correlation between repeated MRI studies for TAV thoracic aorta segmental measurements was in BB (AS R=0.94, AA R=0.94) as well between BB and US (AS R=0.9, AA R=0.86). Unenhanced techniques in BAV patients revealed statistically significant correlation in all segments (p<0.05) with strongest correlation in AA (R=0.96) and weakest correlation in AS (R=0.86, influenced by asymmetry of sinuses in BAV).

**Conclusion:** BB correlated better with ce3D-MRA than measurements performed in DB both in TAV and BAV cohorts, especially in the AA. Comparing aortic measurements between US and MRI unenhanced sequences - BB had the strongest correlation in TAV. Our results suggest that there is no strict need for intravenous contrast administration and MPR for routine MRI evaluation of thoracic aorta’s maximal diameters, except for AS in BAV.

Introduction

In the last decade, the method of investigation - magnetic resonance imaging (MRI) of the heart and large blood vessels - has been increasingly used in clinical practice. Because of many advantages, magnetic resonance imaging is widely used in many areas of diagnostics and one of them is the assessment of the aorta. This clinical method is very important for the detection of major vascular diseases and measuring diameters in order to confirm clinical diagnosis and as a tool for follow-up. Magnetic Resonance Angiography (MRA) with a contrast enhancement is a technique carried out using 3-dimensional (3D) fast gradient echo sequences after administration of gadolinium contrast media [1, 2]. This method allows to obtain ultra-high-quality vascular images and was generally considered an advanced method to unenhanced MRI. Because of its high diagnostic accuracy for vascular pathology, rapid acquisition of images and ability to reconstruct images in 3D, magnetic resonance angiography has become an integral part of the research methodology not only in diagnosis, but also in the planning of further surgical or interventional therapies.
Routine follow-up of aortic diameter is usually done with echocardiography, but we have considered to research robustness of unenhanced 2D MRI due to increasing demand for aortic imaging for dilatation and with no need for multiplanar image reconstructions (MPR) from 3D images, which is not as easy and robust technique for less experienced users. For moderately dilated ascending aorta (diameter 35-54 mm), current guidelines recommend continuous annual or semi-annual examinations with computed tomography or magnetic resonance imaging [3–5].

First goal of the research was to compare measurements of thoracic aorta in unenhanced “dark-blood” (DB) and “bright-blood” (BB) 2D MRI images vs. contrast enhanced 3D T1 (“gold standard”) MR angiography (MRA) in patients with tricuspid aortic valves (TAV) and in second group patients with bicuspid aortic valve (BAV).

The second goal of the research was to compare measurement of aortic root and ascending aorta in unenhanced MRI images and echocardiographic (US) images in the above-mentioned patient cohorts.

Methods

The study presented was conducted in accordance with the recommendations of the Regional Biomedical Research Ethics Committee issued on 2013 February 12 and supplemented on 2014 April 8 (Annexes 1 and 2) with permission No. 158200-13-576-178 (Supplement No. 158200-576-PP1 -14). Study Type: Clinical Prospective Study.

The study included all conscious and willing to participate (with written consent) in the study of adult patients (18-75 years of age) with cardiovascular disease, who had been referred to MRI for thoracic aorta evaluation.

During the study, MRI primary and follow-up aorta MRI examinations (in total 94) were performed in 68 subjects. All subjects were divided into 2 groups according to the selection criteria:

1. Patients with tricuspid aortic valve (TAV): 26 patients with a mean age of 53.3 ± 8.1 years, 14 males and 12 females.
2. Patients with a bicuspid aortic valve (BAV): 42 patients with an average age of 30.8 ± 9.8, 31 males and 11 females.

Exclusion criteria were: a) patient's refusal to conduct an examination; b) the patient is a minor or unable to express own will; c) vulnerable persons; d) contraindications for the MRI study.

All study patients signed written consent.

Magnetic resonance tomography imaging protocol
Prospective study was performed using a 1.5 T Siemens Avanto (Germany, Erlangen) MRI machine using prospective ECG and breath holds (~15-20 s). All patients were examined in supine position. Segmental diameters of the aorta were evaluated by "dark blood" (HASTE) and "bright blood" (TrueFISP) 2D sequences as well with 3D contrast enhanced T1 isometric sequence. Characteristics of the HASTE “dark blood” sequence: field of view (FOV) - 420 mm, FOV phase - 75%, slice thickness - 6 mm, distance between slices - 0 mm, TR 649 ms, TE 42 ms, flip angle (FA) 160 °, volume element size - 2.2 × 1.3 × 6 mm. Technical characteristics of TrueFISP “bright blood” sequence: FOV - 340 mm, FOV phase - 87.5%, thickness of layer - 6 mm, distance between slices - 0 mm, TR 270 ms, TE 1.2 ms, FA 60 °, volume element (voxel) size - 2.1 × 1.3 × 6 mm. Aortic 3D angiography was performed using a T1 isometric sequence with 0.15 mmol/kg gadolinium containing gadobenate dimeglumine or gadodiamide infusion via a brachial vein catheter using a special high-pressure automatic syringe. The scan time after contrast injection was chosen for each patient individually measuring the hemodynamic curve by injection of 1 ml of contrast media. 3D T1 angiography sequence technical characteristics: field of view (FOV) - 500 mm, FOV phase - 66%, thickness of slice - 1.4 mm, TR 3 ms, TE 1 ms, FA 25°, volume element size - 1.4 × 1.3 × 1.4 mm. Total duration of MRI study according to the protocol was 45-60 min.

Magnetic Resonance Imaging post-processing analysis

The analysis of MRI images was carried out in accordance with the recommendations of the Working Group on Image Reconstruction. An independent analysis of MRI for cardiac morphology and function was performed in each case using Siemens Argus software (version 4.01, Germany). All MRI images were evaluated by two experienced researchers (>10 years of practice with cardiovascular MRI, blinded to other available clinical data). The fact that the performance of the research and the results of the assessment are influenced by the experience of the specialist is proved by other research studies [6].

The segmental diameters of the aorta were evaluated from the 3D T1 contrast enhanced sequence from the reconstructed transverse planes using multiplanar image reconstruction (MPR), measuring the maximum diameter 2 times and choosing a larger measured result. In the same manner, the same segments were measured in “dark blood” sequences and in “bright blood” sequences measuring the largest dimension in the axial plane of the body (including aortic wall). We used aortic segmental system by T. Kaiser et al., measuring 5 main aortic segments (Fig. 1): 1) at the level of the aortic sinus, 2) ascending aorta at the right pulmonary artery (RPA) level, 3) aortic arch in the T2 segment, or between the first two branches (if there were only two branches of the aortic arch), 4) descending aorta at the left pulmonary artery (LPA) level, 5) diaphragmatic aorta. T1 contrast enhanced (C+) 3D MRA was performed with maximal aortic diameter evaluation from multiplanar reconstructions (MPR) (Fig. 2).

Ultrasound protocol

A two-dimensional (2D) cardiac ultrasound examination (US) was performed by 2 cardiologists (both with >10 years of practice with cardiovascular US) using a colour Doppler ultrasound system using a 1.0
to 5.0 MHz sensor (GE Vivid 7; General Motors Corporation, New York, USA). The aortic measurements were performed in a 3-chamber view. The maximum diameters of the aortic sinus and the proximal part of the ascending aorta were measured according to Guidelines for Performing a Comprehensive Transthoracic Echocardiographic Examination in Adults [7] (Figure 1D). Only aortic sinuses and ascending aortic segment were assessed with US. The original images were saved and the blind data was later analysed using EchoPAC software (GE Medical Systems).

**Statistical analysis**

Statistical computations were performed using STATISTICA 64 statistical package. All results are presented with 95% confidence intervals. The Pearson correlation coefficient (R) was calculated. If the correlation between the individual tests was high (R = 0.7 or higher) then measurements were considered as having a good level of testing and repeatability. P value <0.05 was considered significant.

**Results**

During the study, 94 MRI examinations were performed in 68 subjects. 52 MRI examinations performed in 26 patients with TAV were done at base with 6-9 months follow-up MRI (53.3 ± 8.1 years, 14 males and 12 females.). Analysis revealed a very high reproducibility of the measurements performed before and after 6 months, both with contrast enhanced and contrast unenhanced methods. Although the measurements of all segments strongly correlated with the statistical significance (p <0.05) using the contrast enhanced 3D-MRA method before and after 6-9 months (in the aortic sinus region R = 0.92, in the ascending aorta R = 0.92, in the aortic arch R = 0.93, in the descending aorta R = 0.83 and in the diaphragmatic aortic part R = 0.91, Table 1), but the strongest correlation was determined using the method of "bright blood" sequences (in the aortic sinus region R = 0.94, in the ascending aorta R = 0.94, in the aortic arch R = 0.94, in the descending aorta R = 0.93 and diaphragmatic aortic part R = 0.94, Table 1). Meanwhile, using the measurements of "dark blood" sequences, the weakest correlation was found in the aortic sinuses and diaphragmatic segments: in the aortic sinus region R = 0.88, in the ascending aorta R = 0.95, in the aortic arch R = 0.96, in the descending aorta R = 0.93 and in the diaphragmatic aortic part R = 0.87 (p <0.05), (Table 1). Additionally, comparisons between aortic measurements performed using contrast enhanced 3D-MRA technique and unenhanced techniques were performed in TAV patients cohort. All segment measurements between the contrast enhanced 3D-MRA technique and the “dark blood” images correlated with statistical significance (p<0.05) with the strongest correlation in the ascending aorta (R=0.93) and the weakest correlation in the diaphragmatic aorta (R=0.84). All segment measurements between the contrast enhanced 3D-MRA technique and "bright blood" images correlated with statistical significance (p<0.05) with the strongest correlation in the ascending aorta (R=0.93) and the weakest correlation in the diaphragmatic aortic part (R=0.83). Comparison of unenhanced techniques revealed statistically significant correlation in all segments (p<0.05) with the strongest correlation in the ascending aorta (R=0.95) and the weakest correlation in the diaphragmatic aortic part (R=0.89).
In order to compare aortic measurement performed using contrast enhanced 3D-MRA technique and unenhanced techniques, BAV patient cohort was also analysed. All segment measurements between the contrast enhanced 3D-MRA technique and the “dark blood” images correlated with statistical significance \((p<0.05)\) with the strongest correlation in the ascending aorta \((R=0.95)\) and the weakest correlation in the aortic sinus region \((R=0.64)\). All segment measurements between the contrast enhanced 3D-MRA technique and the “bright blood” images correlated with statistical significance \((p<0.05)\) with the strongest correlation in the ascending aorta \((R=0.97)\) and the weakest correlation in the aortic sinus and arch region \((R=0.69\) and \(R=0.62,\) respectively). Weak correlation in aortic sinus region was influenced by asymmetrical anatomy of sinuses in BAV patients and due to measurement axis (that was consistent with parasternal axis used in cardiac ultrasound examinations). Comparison of unenhanced techniques in BAV patients revealed statistically significant correlation in all segments \((p<0.05)\) with the strongest correlation in the ascending aorta \((R=0.96)\) and the weakest correlation in the aortic sinus region \((R=0.86)\).

Comparing aortic measurements in US and MRI studies, the following results were obtained: in the TAV group, US aortic sinus measurements correlated strongest with "bright blood" sequences \((R=0.9, p <0.05)\), weaker with 3D MRA with c/m \((R=0.88, p <0.05)\), and the weakest result was in “dark blood” sequence \((R=0.83, p <0.05)\), (Table 2). The US measurements of the ascending aorta strongly correlated with the "bright blood" sequences and with the 3D MRA with c/m \((R = 0.86, p <0.05)\). Minimal, but stronger correlation was observed in measurements with "dark blood" sequences \((R = 0.85, p <0.05)\). From the results obtained, it is seen that the strongest correlation in the TAV group was found between the US and "bright blood" sequences (Table 3). In BAV patients cohort all correlation were statistically significant but much weaker compared with TAV cohort. US aortic sinus measurements in BAV patients correlated most closely with "dark blood" sequences \((R = 0.86, p <0.05)\), weaker with 3D MRA with c/m \((R = 0.80, p <0.05)\), and the weakest result was in “bright blood” sequence \((R = 0.77, p <0.05)\), (Table 4). The US measurements of the ascending aorta in BAV group strongly correlated with 3D MRA with c/m \((R = 0.70, p <0.05)\), weaker with “dark blood” sequences \((R = 0.68, p <0.05)\), and the weakest result was in “bright blood” sequence \((R = 0.60, p <0.05)\). Strong correlation seen in the TAV group between the US and "bright blood" sequences was not observed in BAV group (Table 5).

**Discussion**

Thoracic aorta measurements performed in “bright blood” unenhanced sequences correlated better with contrast enhanced 3D-MRA than measurements performed in “dark blood” sequences both in TAV and BAV cohorts, especially in the ascending aorta. Comparing aortic measurements between US and MRI unenhanced sequences measurements - "bright blood" sequences had the strongest correlation in TAV group as well. Our results suggest that possibly there is no strict need for intravenous contrast administration and multiplanar reconstructions for routine MRI evaluation of maximal diameters of thoracic aorta except for evaluation of aortic sinuses in BAV.
Recent literature [8, 9] encourages the use of contrast unenhanced segmental analysis for measurement of diameters in aorta, but the data are partially controversial and there is no unified and wide accepted contrast unenhanced aortic magnetic resonance imaging protocol. Possibility for measurement of aortic diameters without contrast media due to the good tissue contrast is one of the MRI strengths compared to other imaging modalities. Studies [10–12] have shown that, without using intravenous contrast in MRI studies, qualitative and quantitative parameters of thoracic aorta diameters do not underperform comparing to contrast enhanced MRA and other imaging methods or even surpass them in evaluating aortic wall changes. We aimed to reduce need for aortic multiplanar reconstructions, especially where such competence is not readily available.

On the basis of our study results, we have found that measurements of the aortic segments in patients with TAV using "bright blood" sequences are non-inferior in terms of reproducibility to the "gold standard" – 3D magnetic resonance angiography with contrast media [12, 13]. Additionally, measurements performed in “bright blood” unenhanced sequences correlated better with contrast enhanced 3D-MRA than measurements performed in “dark blood” sequences both in TAV and BAV cohorts. Our findings correspond to Krishnam and co. performed studies with 50 patients [14], when no significant difference was observed in the measurements of aortic segments between MRA with contrast media and "bright blood" sequences. Although the Koktzoglou study [9] found that the precision of measurement in the aortic sinus region in the "bright blood" sequence was lower than in MRA with contrast, but using our 2D "bright blood" sequences, we obtained good reproducibility results in all segments. Meanwhile, using the measurements of 2D "dark blood" sequences, the weakest correlation was found in the aortic sinuses (as in the Koktzoglou study) and diaphragmatic segments: in the aortic sinus region R = 0.88 and in the diaphragmatic aortic part R = 0.87 (p <0.05).

We used routine measurements in axial slices as most robust method both to radiologists and cardiologists, because this approach is simpler to use than multiplanar reconstruction (MPR), which requires special training and software. Other anatomical planes were not used, because they are more difficult to track segments for non-experienced user. It should also be noted that measurements of the maximum segmental diameters of aorta in the normal axial body planes (as we suggest in our methodology) are simpler for less experienced image reader and suitable for a wide range of routine applications, and are statistically insignificantly different from the "golden standard" (3D-MRA with contrasting media. From the results obtained, it can be seen that although the "dark blood" and "bright blood" sequences are statistically reliably and strongly correlated with each other, but slightly better results are observed in "bright blood" sequences, therefore, when measuring aortic segmental diameters in the case of TAV, we recommend to use “bright blood” sequences.

The second important finding of this study is the fact, that in the TAV group the strongest correlation was found between US (derived aortic root and ascending aorta measurements) and "bright blood" sequences, as compared with measurements performed in "dark blood" sequences. The "dark blood" sequence is usually used as an additional assessment of the morphology of the aortic wall, but with pulsation of the wall, we have found that it is more difficult to estimate it’s true wall position than in "bright blood"
sequences - this could be one of the main reasons, why in our results, in most cases, better results were obtained with "bright blood" sequences. Since this trend has been established both between different MRI sequences (comparing sequences with and without c/m) and between different methods (US vs. MRI), therefore, in the measurement of aortic segmental diameters in TAV, we recommend using 2D “bright blood” sequences without contrast media.

Our results for the US measurements of aorta varied more than in the MRI. We believe that this is mainly due to the fact that the US measurements were performed by 2 cardiologists and is known to be more operator-dependent [15, 16], which results in a greater variation between cardiologists' US experience, methodology and the results of the measurements. Statistically significant but much weaker correlation between US derived aortic root and ascending aorta measurements and measurements in "bright blood" sequences in BAV group we think could be explained by both the physiological pulsation of the aorta root (especially if ECG synchronization is not applicable) and a significant discrepancy between US and MRI measurements due to the asymmetry of the BAV sinus. After deeper analysis, it was found that the difference is most likely due to the difference in measurement methodology. The MRI maximum diameters of aorta sinuses were determined by evaluating the image of a short-axis reconstructed by MPR, while the US plane is routed to AS from a 3-chamber image whose plane generally coincides with the smaller AS-dimension. Having detected the disadvantages of US methodology, our specialists in congenital and acquired heart disease took into account these differences in methodologies and started (in the case of BAV) measuring US diameters of the AS in a short axis image corresponding to the MRI reconstruction plane.

We see some limitation of research work presented: 1) quite small sample size, 2) aorta 3D-MRA with contrast media was performed without ECG synchronization, 3) no 3D phase contrast aorta imaging data for comparison has been acquired due to technical limitations.

In conclusion BB correlated better with ce3D-MRA than measurements performed in DB both in TAV and BAV cohorts, especially in the AA. Our results suggest that there is no strict need for intravenous contrast administration and MPR for routine MRI evaluation of thoracic aorta's maximal diameters, except for AS in BAV due to common asymmetry of the AS.

Declarations

Ethics approval and consent to participate:

all participants have signed a written informed consent. Study protocol and written informed consent was approved by Vilnius Regional Biomedical Research Ethics Committee with permission No. 158200-13-576-178 (Supplement No. 158200-576-PP1-14).

Consent for publication:
not applicable.

**Availability of data and materials:**

the datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

**Competing interests:**

not applicable.

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not applicable.

**Authors' contributions:**

all authors have equal contribution.

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authors have no conflict of interest. Only human participants were involved in this research.

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Tables

Due to technical limitations, tables are only available as a download in the Supplemental Files section.

Figures
Figure 1

(A) Aortic segmental system by T. Kaiser et al. All unenhanced MRI measurements of aorta were done in body axial slices (as presented in “dark blood” images B-E): (B) at the level of the aortic sinus, (C) ascending aorta at the right pulmonary artery (RPA) level and descending aorta at the left pulmonary artery (LPA) level, (D) aortic arch in the T2 segment, or between the first two branches (if there were only two branches of the aortic arch), (E) diaphragmatic aorta level.
Figure 2

Maximal aortic diameters were compared between 4 methods (measurements of aortic sinuses presented in A-D): A) 2D „dark blood“ sequence; B) 2D „bright blood“ sequence; C) contrast – enhanced 3D MRA with MPR reconstructed image in axial plane; D) 2D echocardiography (measurements of aortic sinus and proximal ascending aorta were performed only).

Supplementary Files

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- Tables.docx