Simplified Rapid Protocol for Assessing the Thoracic Aortic Dimensions and Pathology with Noncontrast MR Angiography

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Int J Angiol 2019;28:130–136.

Abstract

Keywords

- ▶ noncontrast magnetic resonance angiography
- ▶ dark blood
- ▶ bright blood
- ▶ thoracic aortic pathologies
- ▶ thoracic aortic measurements
- ▶ contrast-enhanced magnetic resonance angiography
- ▶ thoracic aortic assessments

Contrast enhanced magnetic resonance angiography (CE-MRA) is limited by long acquisition time and contrast exposure in aortic emergencies. To compare the efficacy of dark blood (DB) and bright blood (BB) noncontrast sequences with the gold standard CE-MRA using a novel protocol for performing consistent thoracic aortic measurements and thoracic aortic pathologies identifications. A total of 66 patients with suspected or known thoracic aortic pathology who underwent CE-MRA underwent DB and BB imaging prior to CE-MRA for planning purposes. Aortic dimension was measured at 10 standard reference points in the ascending, arch, and descending aorta. Detection of aortic pathologies was recorded individually for each noncontrast sequence. When comparing the CE-MRA to the DB images and CE-MRA to the BB images, a majority of the measurement differences were less than or equal to 2 mm or resulted in no change of diagnostic class (95% for CE-MRA vs. DB and 96% for CE-MRA vs. BB). Of the patients who had major changes in diagnostic class (e.g., changes in two or three classes), the absolute measurements were not clinically significant in any given patient to warrant a change in management. Individually, the DB and BB sequences allowed for accurate recognition of all 47 aortic pathologies. DB and BB sequences produced comparable and consistent measurements of the thoracic aorta when compared with CE-MRA. In a situation where CE-MRA is not readily available or contraindicated, noncontrast MRA using our protocol is a reliable alternative to CE-MRA for assessment of aortic pathologies.

To detect aortic pathology and monitor progression of disease, it is necessary to have comprehensive and precise imaging of the thoracic aorta. Magnetic resonance imaging

(MRI) is a multipurpose imaging modality with the ability to provide functional, anatomical, and pathological information about the thoracic aorta. Contrast enhanced magnetic resonance angiography (CE-MRA), which requires the injection of gadolinium, remains one of the gold standards for the

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purpose of imaging the thoracic aorta.¹ However, disadvantages to the CE-MRA include lack of immediate availability when compared with computerized tomography (CT) angiography, longer imaging times, need for additional technologist training, and a three-dimensional (3D) workstation for multiplanar reconstruction to obtain accurate measurements. In addition, using gadolinium contrast in patients with renal insufficiency has been associated with nephrogenic systemic fibrosis^{2,3} and it is of limited use in pathologies affecting the vessel wall and the surrounding structures.⁴ At least in part due to these considerations, data from International Registry of Acute Aortic Dissection (IRAD) found that MRI was the least used imaging study and was used in only 1% of patients as the initial diagnostic study.⁵

The use of MRI in emergent situations has been precluded due to limitations, such as longer acquisition times, poor image definition, artifacts, and need for breath holding, or respiratory gating. However, advances in MRI technology have made it possible to image the aorta adequately without the use of a contrast agent through half-Fourier's acquisition single-shot turbo spin-echo (HASTE) and steady state free precession (SSFP) sequences. These have transformed non-contrast imaging to be faster and have improved resolution without the need for breath holding.^{6,7}

Multiple studies have showed that in patients with thoracic aortic diseases, a respiratory gated noncontrast MRA sequence, that is, 3D SSFP provides equivalent measurements of aortic dimension with similar sensitivity, specificity, and better visualization of the aortic root when compared with CE-MRA.^{6,8–11} However, 3D SSFP requires longer imaging times, making it less useful in emergent situations. In another study, turbo spin-echo (TSE), that is, dark blood (DB) and SSFP, that is, bright blood (BB) images provided results comparable to CE-MRA when measuring aortic dimensions and detecting aortic pathologies. Acquisition times in the same study were 8 to 10 minutes for TSE and 4 to 6 minutes for balanced SSFP.⁴ Studies also have shown that two-dimensional (2D) imaging is superior to visualize pathologies affecting the vessel wall and surrounding structures compared with CE-MRA.^{4,12}

In our study, we compared the utility of DB and BB images, which were obtained for planning purposes, with the gold standard CE-MRA to perform accurate aortic measurements. We utilize a simple rapid protocol of imaging planes and reference points to obtain consistent and reliable thoracic aortic measurements. We also evaluated the ability of DB and BB images to individually detect intra and extra luminal aortic pathologies.

Method

Study Population

Retrospective analysis was done on 66 adult patients with suspected or known thoracic aortic pathology who underwent 93 CE-MRA scans between January 3, 2011 and February 5, 2016 at the University of Missouri, Columbia. Of these 66 patients, 41 were males and 25 were females with a mean age

of 51 years (range, 18–85 years). Each scan also included DB and BB images which were used to plan the CE-MRA. In patients with more than one MRI scan, only the scan with the best CE-MRA image quality was included in the study. Four patients were excluded due to inadequate image quality of the CE-MRA, metal artifacts making measurements unreliable ($n = 2$), or incomplete scans, that is, DB and BB not acquired in all three anatomic planes. The study was approved by our institutional review board. All patients underwent MRI safety screen as per institutional protocol prior to each study.

MRI Technique

A Siemens 1.5-T (Avanto or Aera) or 3-T (Verio) scanner was used for imaging. All patients underwent DB and BB images prior to CE-MRA. DB images were obtained with HASTE sequence and BB images were obtained with 2D SSFP sequence. CE-MRA was performed using gadolinium 0.1 mmol/kg MRI contrast agent (Omniscan, manufacturer GE). Contrast was timed using the care bolus technique and was injected using a power injector. For further details on the specifics of each sequence, refer to ►Table 1. Cardiac gating was used for acquisition of HASTE and SSFP sequences in all patients. Cardiac gating was used in most of the CE-MRA acquisitions except in rare instances where the patient was unable to hold breath long enough; in this case, nongated acquisition was performed to shorten breath holding times.

Imaging Times

DB and BB images together took an average of 3 minutes compared with CE-MRA which typically took in excess of 15 minutes, including the planning time.

Image Analysis

Evaluation of the MRI scans was performed using a Siemens multimodality workstation with 3D capability.

Protocol for Aortic Measurements

Our simplified rapid protocol for performing aortic measurements using DB and BB images is shown in ►Fig. 1. The aortic measurements of the angiogram, DB, and BB scans were performed independently of each other for the purposes of this study. CE-MRA measurements were performed in 3D using multiplanar reconstruction (MPR) at 10 standard reference points in the ascending, arch, and descending aorta (►Fig. 2). DB and BB aortic measurements were also performed at 10 standard reference points in the ascending, arch, and descending aorta using 2D images (►Fig. 3). Images were scrolled back and forth to avoid foreshortening; the smallest dimension was measured to prevent measurements from being made incorrectly in an oblique plane. For measurements as per our protocol, the following planes were chosen as the most suitable for each location:

- Coronal plane for aortic root measurements at aortic annulus (1), Sinus of Valsalva (2), and Sinotubular junction (3).
- Sagittal plane for aortic arch measurements at the following levels, immediately prior to origin of the innominate

Table 1 Imaging parameters for noncontrast and contrast enhanced sequences

	Dark blood (HASTE)	Bright blood (SSFP)	Contrast enhanced MRA
Number of slices	30–40	30–40	40–88
Slice Thickness	7–8 mm	7–8 mm	1.3–1.8 mm
Breath hold	No	No	Yes
Cardiac gating	Yes	Yes	Mostly
Orientation	Axial, sagittal and coronary	Axial, sagittal and coronal	Mostly axial, rarely sagittal
TE (ms)	25	1.3	1.0
TR (ms)	750–1000	200–400	3.0
Flip angle (degrees)	90	50–80	25
Matrix size	(200–300) × (300–400)	(200–300) × (300–400)	(200–300) × (300–400)
Voxel size (mm)	Not applicable	Not applicable	(1.1–1.3) × (1.1–1.3) × (1.3–1.8) mm

Abbreviations: HASTE, half-Fourier’s acquisition single-shot turbo spin-echo; MRA, magnetic resonance imaging; SSFP, steady state free precession; TE, echo time; TR, repetition time.

Fig. 1 Protocol flow diagram for performing measurements in DB and BB images. BB, bright blood; DB, dark blood.

- artery (5), between innominate and left common carotid artery (6), between left common carotid and left subclavian artery (7), and isthmus (8).
- C. Axial plane for ascending aorta at pulmonary artery bifurcation (4), descending aorta at pulmonary artery bifurcation (9), and descending aorta at diaphragm (10).

CE-MRA images were reviewed in 3D using multiplanar reconstruction (MPR) and the measurements were performed by a cardiologist with level II or III training in cardiovascular MRI as part of the standard protocol. All DB and BB measurements were performed independent of the CE-MRA images by one of the authors (MV) who received specific training on our protocol. The measurements were verified by a level III MRI trained cardiologist solely for this research study purpose.

As measurements in a 3D workstation yielded a major and minor dimension, the average of these 2Ds was used for

comparison with the 2D measurements which yielded a single dimension. Measurements at all the 10 standard reference points were analyzed by calculating the difference between CE-MRA to the DB measurements and CE-MRA to the BB measurements. For the purposes of this study, the diagnostic classes for aorta size were defined as normal < 40 mm, mild dilation 40 to 44 mm, moderate dilation 45 to 49 mm, and severe dilation ≥ 50 mm (►Table 2). The differences were then classified into the following categories: no difference (values were within 2 mm of each other), more than 2 mm difference in values but no change in diagnostic class, change in one diagnostic class, change in two diagnostic classes, or change in three diagnostic classes (►Table 3).

Recognition of Thoracic Aortic Pathologies

In addition to aortic measurements, we also studied the ability of the noncontrast DB and BB sequences to individually identify aortic pathologies when compared with the

Fig. 2 This presents the 10 standard reference points of measurement: aortic annulus (1), sinus of valsalva (2), Sinotubular junction (3), ascending aorta at pulmonary artery bifurcation (4), immediately prior to origin of the innominate artery (5), between innominate and left common carotid artery (6), between left common carotid and left subclavian artery (7), isthmus (8), descending aorta at pulmonary artery bifurcation (9), and descending aorta at diaphragm (10). This patient had undergone an ascending aortic replacement with a synthetic graft for aneurysm. Incidentally noted is a persistent ductus diverticulum (arrow).

comprehensive scan with and without contrast. Our study population included patients with suspected or known intraluminal and extraluminal thoracic aortic pathology. The aortic pathologies included in this study are aortic dissection, aneurysm, coarctation, intramural hematoma, penetrating ulcer, and aortitis.

Results

Measurement of Aortic Dimensions

Compared with the gold standard of CE-MRA, 60% of the DB measurements and 65% of the BB measurements were found to have no difference (values were within 2 mm of each other). In addition, when compared with CE-MRA, 36% of DB and 30% of BB measurements did not have a change in diagnostic class despite > 2 mm difference in values. Overall, a majority of the measurement differences were less than or equal to 2 mm or resulted in no change of diagnostic class (95% for CE-MRA vs. DB and 96% for CE-MRA vs. BB). Of the remaining patients, 4% of the DB measurements and 4% of the BB measurements were found to have a change in one diagnostic class, 0.8% of the DB measurements and 0.3% of

the BB measurements were found to have a change in two diagnostic classes, and 0.2% of the DB measurements and 0.3% of the BB measurements were found to have a change in three diagnostic classes compared with CE-MRA (**Table 3**). In patients with measurements that resulted in a change of one diagnostic class, the differences were likely due to greater slice thickness of DB and BB images (7–8 mm) when compared with CE-MRA images (< 2 mm). However, when looking at the entire dataset of measurements by each sequence in any given patient, the absolute values did not warrant a change in management (e.g., referral for surgery or change in surveillance frequency). Of the seven patients with major changes in diagnostic class (e.g., changes in two or three classes), the differences did not affect clinical decision making in any given patient based on quantitative and qualitative analysis of the entire dataset for a given sequence type. The reasons for major changes were presence of aneurysm and dissection at the measurement location in two patients; misregistration of measurement location in four patients; and presence of fluid around the aorta in one patient.

Recognition of Aortic Pathologies

Furthermore, we studied the ability of the noncontrast DB and BB sequences to individually identify aortic pathologies when compared with the comprehensive MRA scan with and without contrast. In our study, 41 patients (with one or more abnormalities) presented with a total of 47 pathologies including 33 aneurysms, five aortic dissections, four coarctations, two intramural hematomas, two penetrating ulcers, and one aortitis. All of the 47 pathologies were identified with DB and BB imaging. **Fig. 4** shows typical examples of aortic pathologies detected by DB, BB, and CE-MRA sequences.

Discussion

In emergent settings where aortic pathologies are suspected, the current practice is to obtain a CT angiogram of the thoracic aorta to identify pathologies like aneurysm, dissection, etc. However, iodinated contrast administration for CT angiogram can be harmful in certain patient populations (renal insufficiency or pregnancy) who are also poor candidates for gadolinium contrast administration for MRA.¹³ Hence, there is a need for a quick and accurate imaging modality that can be used in emergent settings and is free of ionizing radiation or contrast media. Noncontrast MRA shows great promise in this regard. We compared the efficacy of the noncontrast MRA sequences namely DB (HASTE), BB (SSFP) with the gold standard CE-MRA in performing accurate aortic measurements and detect intra and extra luminal aortic pathology.

Aortic Measurements

The dimension of the aorta was measured using DB, BB, and CE-MRA sequences. Our novel protocol highlights the use of specific planes for each of the 10 standard reference points on the aorta, a technique not described in previous reports.

Fig. 3 Sample patient measurements using our protocol. (A) It shows measurements at the aortic root in the coronal plane (standard reference points 1–3). (B) It shows measurements at the ascending and descending aorta at pulmonary artery bifurcation in the axial plane (standard reference points 4 and 9). (C) It shows measurements immediately prior to origin of the innominate artery in the sagittal plane (standard reference point 5). (D) It shows measurements between innominate and left common carotid artery in the sagittal plane (standard reference points 6). (E) It shows measurements between left common carotid and left subclavian artery and at the isthmus in the sagittal plane (standard reference points 7 and 8). (F) It shows measurements of the descending aorta at the level of the diaphragm in the axial plane (standard reference points 10).

Table 2 Diagnostic classes for aorta size

< 40 mm	Normal
40–44 mm	Mild
45–49 mm	Moderate
≥ 50 mm	Severe

When comparing the CE-MRA to the DB images and CE-MRA to the BB images, an overwhelming majority of the measurements resulted in no difference (values were within 2 mm of each other) or more than 2 mm difference in values but no change in diagnostic class (95% for CE-MRA vs. DB and

96% for CE-MRA vs. BB). Of the patients who had major changes in diagnostic class (e.g., changes in two or three classes), the absolute measurements were not clinically significant in any given patient to warrant a change in management.

Our study underscores the general reliability of the various MRI sequences in thoracic aortic measurements described in earlier studies.^{9,13} These findings are similar to those reported in a study by Gebker and colleagues.⁴ Of particular importance in our findings is the reliability of the noncontrast sequences (DB and BB) in performing aortic measurements using our novel simplified rapid protocol. Our protocol offers a consistent method for measuring the entire

Table 3 Classification of thoracic aorta measurements by changes in diagnostic class

	CE-MRA vs. DB		CE-MRA vs. BB	
No difference (values were within 2 mm of each other) (%)	393/660 (60)	96%	432/660 (65)	95%
More than 2 mm difference in values but no change in diagnostic class (%)	235/660 (36)		199/660 (30)	
Change in one class (%)	26/660 (4)		25/660 (4)	
Change in two classes (%)	5/660 (0.8)		2/660 (0.3)	
Change in three classes (%)	1/660 (0.2)		2/660 (0.3)	

Abbreviations: BB, bright blood; CE-MRA, contrast-enhanced magnetic resonance angiogram; DB, dark blood.

Pathology	DB	BB	CE-MRA
Aneurysm
Dissection
Penetrating ulcer
Coarctation
Aortitis
Intramural hematoma

Fig. 4 Typical examples of aortic pathologies detected by dark blood (DB), bright blood (BB), and contrast enhanced MRA images (CE-MRA).

thoracic aorta in various locations and obviates the need for a 3D workstation and multiplanar reformation for the interpreting physician. While these noncontrast sequences were performed with echocardiography (ECG) gating in our study, the sequences can be performed even more rapidly without need for cardiac gating and produce similar outcomes. As the breath holding is not required during DB and BB sequences,

unlike CE-MRA, there is improvement of patient comfort. Lastly, the DB and BB sequences evaluated in our study are confined to true anatomic planes in the axial, sagittal, and coronal orientations which do not require additional technologist training, and can be performed in any institution without an advanced cardiac MRI software package. While it is true that 3D SSFP can also be done without the use of

gadolinium contrast agent, it requires an advanced cardiac MRI software package, ECG, and respiratory gating, additional technologist training, as well as 3D workstation and multiplanar reformation for the interpreting physician.

Aortic Pathology

Current consensus indicates that CE-MRA remains more accurate to diagnose intraluminal pathologies and noncontrast studies are better for assessing of vessel wall and surrounding structures.⁴ All of the aortic pathologies were accurately identified with DB and BB imaging in our study. In addition, both DB and BB noncontrast sequences can be rapidly performed (approximately 3 minutes in our study) without the need for cardiac or respiratory gating, making it especially useful in emergent situations where alternate methods are not feasible.

Conclusion

DB and BB images produced comparable measurements of thoracic aorta as well as accurately identified pathology when compared with the gold standard CE-MRA. Contrast MRA remains the gold standard and method of choice due to abundance of data demonstrating its accuracy. In situation, in which contraindications exist for gadolinium administration, MRI with DB and BB sequences using our simple protocol is a reliable alternative to CE-MRA for assessment of aortic pathologies.

These sequences can be of great value in emergent situations as they can be obtained rapidly without need for cardiac or respiratory gating to quickly rule out life-threatening pathology, such as aortic dissection. For the interpreting physician, our novel protocol allows for accurate measurements to be obtained without the need for a 3D workstation and multiplanar reconstruction.

Conflict of Interest

All authors have no conflicts of interest to disclose.

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