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MORPHOLOGY/FUNCTION

Assessment of Left Atrial Volume by Contrast Enhanced Magnetic Resonance Angiography

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ABSTRACT

Left atrial (LA) volume is associated with cardiovascular morbidity, particularly atrial fibrillation. Contrast-enhanced magnetic resonance angiography (CE-MRA) visualizes the LA, but the validity of LA volume measurements using this technique has not been evaluated. We performed CE-MRA and cine magnetic resonance (MR) in 18 consecutive patients referred for CE-MRA prior to atrial fibrillation ablation. The CE-MRA LA volumes were compared to cine MR LA volumes at the maximal LA size and at LA end-diastole using linear regression and limits of agreement analysis. The mean cine MR LA volume was 118 ± 39 mL at maximal LA size and 91 ± 38 mL at LA end-diastole. Left atrial volume determined by CE-MRA was 93 ± 38 mL. Although the CE-MRA LA volume had a strong correlation with the maximal cine MR LA volume ($R^2 = 0.86$, $p < 0.001$), the 95% limits of agreement were relatively wide (−54 to 3 mL). The cine MR LA end-diastolic and CE-MRA LA volumes were more closely correlated ($R^2 = 0.98$, $p < 0.001$) with narrow 95% limits of agreement (−8 to 11 mL). The CE-MRA LA volumes correspond most closely to LA end-diastolic cine MR LA volumes and may be a useful measure of LA size.

Key Words: Magnetic resonance; Left atrium; Volume.

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INTRODUCTION

Left atrial (LA) cavity size is related to several cardiovascular risk factors and the occurrence of adverse cardiovascular events (Benjamin et al., 1995; DiTullio et al., 1999; Vaziri et al., 1995), especially the occurrence of atrial fibrillation (AF) and adverse outcomes associated with AF (Henry et al., 1976; Sanfilippo et al., 1990; The Stroke Prevention in Atrial Fibrillation Investigators, 1992; Vaziri et al., 1994). Although the M-mode echocardiography LA dimension from the parasternal long-axis view is the most commonly used measure of LA size, LA volume may be a better determinant of adverse outcomes (Tsang et al., 2001, 2002; Pritchett et al., 2003). Left atrial volume and its phasic changes during the cardiac cycle can be assessed using echocardiography, cine computed tomography, or cine magnetic resonance (MR) imaging (Jarvinen et al., 1994, 1996; Kircher et al., 1991; Lester et al., 1999; Putanen et al., 2000; Rodevand et al., 1999; Tseng et al., 2002). Contrast enhanced magnetic resonance angiography (CE-MRA) visualizes the LA, but the validity of LA volume measurements using this technique has not been evaluated. As CE-MRA produces nongated, time-averaged images, LA volume measurements may represent mean LA size rather than maximal LA size.

We prospectively evaluated a series of patients referred for CE-MRA to evaluate the anatomy of the pulmonary veins (PV) prior to AF ablation. We determined the LA volume from CE-MRA images and compared these data with the LA volume as determined by cine MR at two points in the cardiac cycle: ventricular end-systole (reflecting maximal LA volume) and LA end-diastole (reflecting mean LA volume).

METHODS

Study Cohort

The study cohort consisted of a series of 18 consecutive patients referred for CE-MRA evaluation of PV anatomy prior to AF ablation. Patients with contraindications to MR were excluded (e.g., pacemaker, intraauricular implants, intracranial clips). Cine MR and CE-MRA were performed during a single imaging session. The study was approved by the Beth Israel Deaconess Medical Center Committee on Clinical Investigation.

Cine MR Protocol

Cine MR imaging was performed using a 1.5 T whole-body MR system (Gyroscan NT, Philips Medical Systems, Best, The Netherlands) with a five-element cardiac synergy coil for radiofrequency signal reception. Steady-state free-precession breath-hold gradient echo cine MR of the entire LA was performed with contiguous slices in the four-chamber orientation. The following parameters were used: repetition time, 3.0 ms; echo time, 1.5 ms; flip angle, 60 degrees; slice thickness, 10 mm; field of view, 480 mm; matrix, 208×256. The images were gated prospectively with 20 phases per RR interval (temporal resolution of 50 ms for a heart rate of 60 bpm).

CE-MRA Protocol

First pass breath-hold 3D CE-MRA of the entire LA and proximal PV was obtained after manual bolus administration of a 0.2 mmol/kg bolus of gadopentetate dimeglumine (Magnevist®, Berlex Laboratories, Wayne, NJ), immediately followed by a saline flush. Data acquisition began after a delay determined by a small timing bolus given prior to CE-MRA. A spoiled 3D gradient echo sequence with the following paameters was used: repetition time, 3.6 ms; echo time, 1.1 ms; flip angle, 30 degrees; 50 slices, slice thickness 4 mm interpolated to 2 mm; field of view, 480 mm; matrix, 272×512. Images were prospectively acquired in the axial plane.

Determination of LA Volumes

Cine MR and CE-MRA datasets were transferred to a dedicated work station for further analysis using commercially available software (EasyVision 5.1, Philips Medical Systems, Best, The Netherlands). For both techniques, LA volume was determined using modified Simpson's rule (disk summation) (Fig. 1) with the LA area traced in each contiguous 10-mm-thick image spanning the left atrium. For cine images, these were traced in the four-chamber orientation; for CE-MRA images, these were traced in the axial and four-chamber orientations. For cine MR only, the LA volume was calculated both at LA end-diastole (just prior to LA contraction, reflecting mean LA volume) and at ventricular end-systole (reflecting maximal LA volume). The borders of the LA were defined as the plane of the mitral valve and the visually apparent juncture of the LA with the pulmonary veins. The LA appendage was not included in the LA volume for either technique. Two observers (THH, GK) independently performed measurements on the datasets. Measurements performed on cine MR and CE-MRA datasets were separated by >2 weeks. Intraobserver error was also assessed by repeat measurements separated by >2 weeks. The time required for LA volume determination for both methods was <5 minutes.

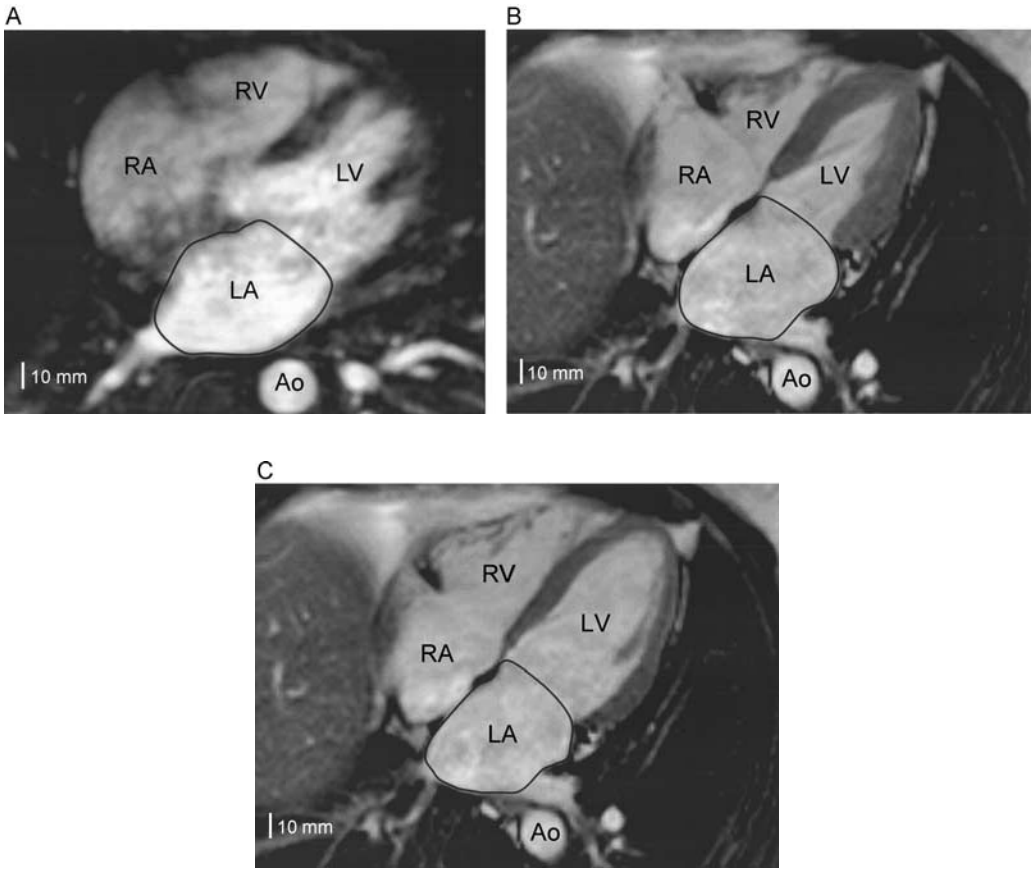

Figure 1. Contrast-enhanced magnetic resonance angiography (CE-MRA) and cine magnetic resonance (MR) images of the left atrium (LA). (A) Shows an axial CE-MRA image of the cardiac chambers. (B) and (C) are four-chamber cine MR images. (B) Shows the LA at its maximum size during the cardiac cycle, which occurs during ventricular systole. (C) Shows the LA at atrial end-diastole. Lines represent the traced area for determination of LA volume. Abbreviations used: Ao=descending aorta, LV=left ventricle, RA=right atrium, RV=right ventricle.

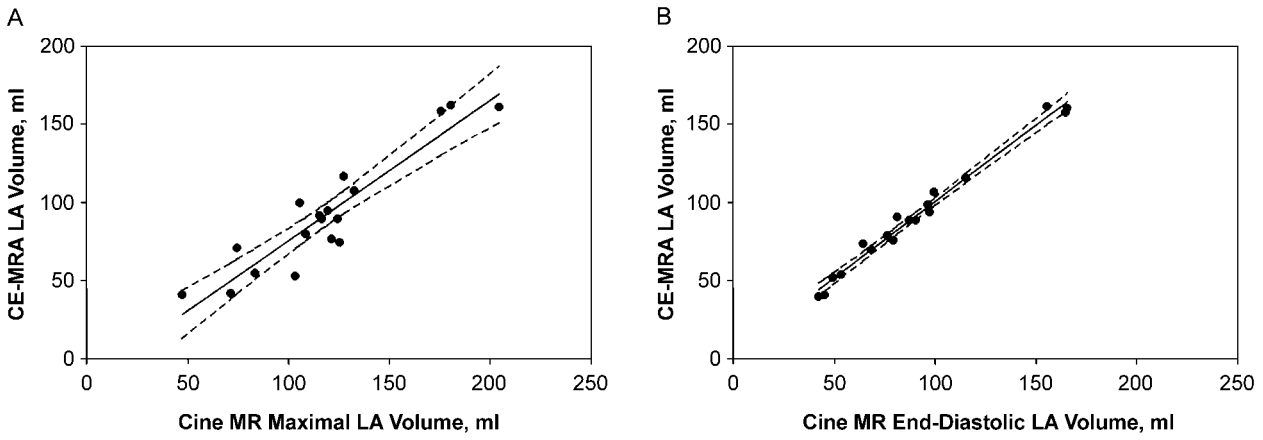

Figure 2. Linear regression comparison of the CE-MRA LA volume to the cine MR LA volume at its maximal size (A) and at atrial end-diastole (B). Solid lines represent the regression line and dashed lines represent the 95% confidence interval for the regression line.

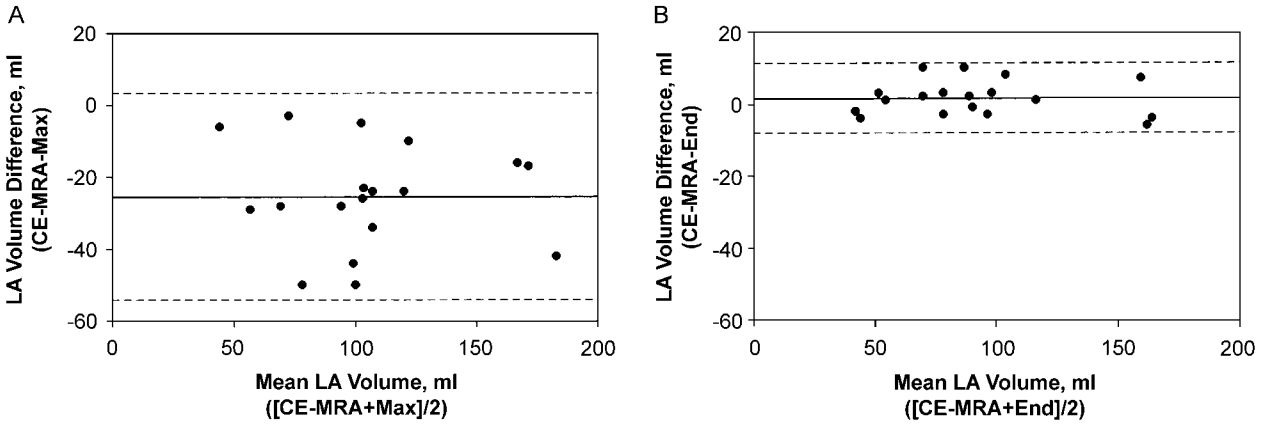

Figure 3. Limits of agreement comparison of the CE-MRA LA volume to the cine MR LA volume at its maximal size (A) and at atrial end-diastole (B). Solid lines represent the mean difference (bias) and dashed lines represent the 95% limits of agreement. Abbreviations used: End = cine MR end-diastolic LA volume, Max = cine MR maximal LA volume.

Statistical Analysis

Continuous values are reported as the mean ± standard deviation. Categorical values are reported as counts and percentages. Left atrial volumes calculated by cine MR and CE-MRA were compared using standard linear regression and limits of agreement analysis in the manner of Bland and Altman (1986). Observer variations were calculated as the root of the mean squared differences between corresponding observations, divided by the average of the observations. Observer variations were further analyzed with standard linear regression. A p value of 0.05 was used for determination of statistical significance. All statistical analysis was performed using SAS for Windows (v8.2, SAS Institute, Cary, NC).

RESULTS

Study Cohort

The study cohort included 13 (72%) men and 5 (28%) women with a mean age of 47 ± 10 years. All subjects were in sinus rhythm at the time of imaging.

Comparison of CE-MRA and Cine MR LA Volumes

The LA volume determined by cine MR was 118 ± 39 mL at maximal LA size and 91 ± 38 mL at LA atrial end-diastole. The LA volume determined by CE-MRA was 93 ± 38 mL. Linear regression revealed a strong correlation between the cine MR maximal LA volume and the CE-MRA LA volume ($y = 0.90x - 14.16$, $R^2 = 0.86$, $p < 0.001$) (Figs. 2 and 3). Limits of agreement analysis, however, demonstrated a significant bias (−26 mL) and relatively wide 95% limits of agreement (−54 to 3 mL). The correlation between the cine MR atrial end-diastolic LA volume and the CE-MRA LA volume was stronger ($y = 0.98x + 3.30$, $R^2 = 0.98$, $p < 0.001$) with a minimal bias (2 mL) and narrow 95% limits of agreement (−8 to 11 mL) (Figs. 2 and 3).

Reproducibility of CE-MRA LA Volume Measurements

The variability of repeated LA volume measurements performed on the CE-MRA datasets is shown in Table 1. Repeated measurements by the same observer and a different observer had minimal variability and were highly correlated. Similarly, measurements performed in the four-chamber orientation were highly correlated to measurements performed in the axial orientation with minimal variability.

DISCUSSION

In this study of consecutive patients, we found that the LA volume determined by CE-MRA strongly correlated with the cine MR end-diastolic LA volume with narrow limits of agreement. There was also a strong correlation of the CE-MRA LA volume with the

Table 1. Variability of repeated CE-MRA LA volume measurements by observer and image orientation.

	Intraobserver	Interobserver	4-Chamber orientation[a]
Variability (%)	5.1	4.8	4.4
Mean difference ± SD (mL)	−0.4 ± 4.8	−2.2 ± 4.1	1.1 ± 4.0
SEE (mL)	4.8	4.1	4.1
R^2	0.99	0.99	0.99

Note: SD = standard deviation, SEE = standard error of the estimate.
[a]Compared to measurements performed in the axial orientation.

maximal cine MR LA volume, but the limits of agreement were relatively wide.

Comparison of CE-MRA and Cine MR LA Volumes

While LA size is associated with hypertension (Vaziri et al., 1995), stroke (Benjamin et al., 1995; DiTullio et al., 1999; The Stroke Prevention in Atrial Fibrillation Investigators, 1992), cardiomyopathy, (Jarvinen et al., 1996; Rossi et al., 2002) and death (Benjamin et al., 1995; Rossi et al., 2002), its relationship to AF has been most thoroughly investigated. Increased LA size is associated with the development of AF, and LA size increases as the duration of AF, increases (Henry et al., 1976; Sanfilippo et al., 1990; Vaziri et al., 1994). Most of these studies used the echocardiography M-mode LA dimension as the measure of LA size. A major limitation of this technique is the assumption that there is a direct relationship between this one-dimensional measurement and LA volume (Manning, 1997). Left atrial volume can be estimated by 2D echocardiography assuming an elliptical geometry of the LA (Kircher et al., 1991; Lester et al., 1999; Rodevand et al., 1999). Left atrial volume estimates using this technique have been found to have a stronger association with the incidence of AF and the occurrence of adverse events associated with AF (Pritchett et al., 2003; Tsang et al., 2001, 2002). Cine MR utilizing modified Simpson's rule requires no assumptions about the geometry of the LA and is a generally accepted standard for the determination of LA volume (Jarvinen et al., 1994, 1996; Putanen et al., 2000; Rodevand et al., 1999; Tseng et al., 2002).

Radiofrequency ablation for the treatment of AF has become increasingly common (Oral et al., 2002; Pappone et al., 2000). Patients routinely undergo CE-MRA to evaluate pulmonary vein anatomy prior to the procedure and to monitor for pulmonary vein stenosis after the procedure (Dill et al., 2003; Moak et al., 2000; Robbins et al., 1998; Scanvacca et al., 2000; Seshadri et al., 2002; Sohn and Schiller, 2000; Wittkampf et al., 2003; Yang et al., 2001). Contrast-enhanced MRA also visualizes the LA. It may be advantageous for clinical as well as investigative follow-up to determine the LA volume in these patients with AF. However, the CE-MRA images routinely obtained in examining these patients are not gated and therefore subject to artifacts from cardiac motion. Moreover, it is uncertain whether the resulting LA measurements would reflect the LA volume at its maximal size or during some other portion of the cardiac cycle.

We first examined whether the LA volume determined by CE-MRA was related to the maximal LA volume during the cardiac cycle. The CE-MRA LA volume was strongly associated with the maximal LA volume determined by cine MR, but the limits of agreement were relatively wide, and there was a significant bias.

We hypothesized that the CE-MRA LA volume would represent the LA volume at atrial end-diastole. Contrast-enhanced MRA produces a nongated, time-averaged image that reflects mean LA volume. Left atrial time-volume curves demonstrate that mean LA volume is approximated by end-diastolic volume and that the LA volume is close to end-diastolic volume for about one-third of the cardiac cycle. In contrast, the LA volume is at its maximal and minimal (atrial end-systolic) values only briefly ($\leq$10% of the cardiac cycle) (Jarvinen et al., 1994; Putanen et al., 2000; Tseng et al., 2002).

We found that the CE-MRA LA volume was more closely associated with the cine MR end-diastolic LA volume. The regression line had a minimal offset and a slope very close to 1. In addition, the limits of agreement were narrow with a minimal bias. Thus, the CE-MRA LA volume measure is closely correlated with the end-diastolic LA volume, a value not analogous to LA measurements performed during echocardiography.

Although CE-MRA LA volume does not correlate as well with maximal cine MR LA volume, we found that these measures were more strongly associated than previously reported for comparisons of M-mode dimension measures to 2D echocardiography LA volume

estimates (Lester et al., 1999) or comparisons of 2D and 3D echocardiography LA volume estimates to cine MR volume estimates (Rodevand et al., 1999). Our findings suggest that CE-MRA LA volume may be a useful measure of mean LA size. The potential clinical significance of this measure requires assessment in future clinical studies.

Reproducibility of CE-MRA LA Volume Measurements

We found that CE-MRA LA volume measurements were very reproducible. There was minimal variability with repeated measurements by the same observer and by a second observer. There was also minimal variability between measurements performed in the axial and four-chamber orientations, suggesting that LA volume measurement using modified Simpson's rule (disk summation) is relatively independent of image orientation. Three-dimensional CE-MRA datasets allow reconstruction of images in any orientation. Because we acquired the images in the axial plane, we measured the LA volume in the axial orientation as this provides the highest in-plane resolution.

Limitations

Our study cohort consisted of a relatively small cohort of patients with a history of paroxysmal AF, and the results may not necessarily apply to a broader population. Although CE-MRA can be performed during AF, all patients in our cohort were imaged during sinus rhythm to determine the relationship of CE-MRA LA volumes to cine MR LA volumes at distinct phases of the cardiac cycle. Very large LA volumes were relatively underrepresented in our cohort. As with other noninvasive measurements of LA volume, both methods used require some judgment by the interpreter for delineation of LA borders, particularly at the LA appendage and the mitral valve. We did not validate LA volume measurements against gross anatomical, echocardiographic, or angiographic findings; rather we used a validated and generally accepted noninvasive standard (cine MR) (Jarvinen et al., 1994; Rodevand et al., 1999; Tseng et al., 2002).

CONCLUSION

Contrast-enhanced MRA LA volumes correspond most closely to cine MR LA end-diastolic volumes and may be a useful measure of LA size.

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