JOURNAL OF CARDIOVASCULAR MAGNETIC RESONANCE®
Vol. 6, No. 4, pp. 855–863, 2004

ATRIAL VOLUMES

Assessment of Left Atrial Volumes in Sinus Rhythm and Atrial Fibrillation Using the Biplane Area-Length Method and Cardiovascular Magnetic Resonance Imaging with TrueFISP

Burkhard Sievers, M.D.,* Simon Kirchberg, Marvin Addo, Asli Bakan, Bodo Brandts, M.D., and Hans-Joachim Trappe, M.D.

Department of Cardiology and Angiology, University of Bochum, Germany

ABSTRACT

Objectives: To determine whether the biplane area-length method can be used for the evaluation of left atrial volumes and ejection fraction with cardiovascular magnetic resonance imaging (CMR) by TrueFISP in normal subjects and patients with atrial fibrillation. *Background:* Atrial fibrillation is the most common arrhythmia in elderly patients. Left atrial size and volumes play an important role in predicting short and long-term success after cardioversion. *Methods:* Fifteen healthy subjects (mean age 65.6±6.4 years) and 18 patients (mean age 67.2±8.8 years) with atrial fibrillation were examined by CMR (Magnetom, Siemens, Erlangen, Germany). Images were acquired by TrueFISP using the horizontal and vertical long-axis plane to measure left atrial end-diastolic and end-systolic areas and longitudinal dimensions. Volumes were determined with commercially available software. Left atrial end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV), and ejection fraction (EF) were determined by the biplane area-length method and compared to findings obtained by the standard short-axis method. Images were acquired and analyzed a second time in the patients with atrial fibrillation. *Results:* There was no difference in age between men and women ($p=0.147$) and healthy subjects and patients ($p=0.128$) included in the study. EDV and ESV were significantly higher and SV and EF significantly lower in patients with atrial fibrillation than in healthy subjects

*Correspondence: Burkhard Sievers, M.D., Duke Cardiovascular Magnetic Resonance Center, Duke University Medical Center, Duke Clinic, RM 00354, SB, Orange Zone, Trent Drive, DUMC 3934, Durham, NC 27710, USA; Fax: (919) 668-5588; E-mail: burkhard.sievers@duke.edu.

DOI: 10.1081/JCMR-200036170
1097-6647 (Print); 1532-429X (Online)

($p \leq 0.009$), regardless of the method used. The values obtained for EDV and ESV by the biplane area-length method were significantly higher in both healthy subjects ($p < 0.001$) and patients with atrial fibrillation ($p < 0.001$) than those obtained by the standard short-axis approach, whereas SV ($p \geq 0.057$) and EF ($p \geq 0.118$) did not differ significantly. In the second investigation in patients with atrial fibrillation, ESV, SV, and EF did not differ significantly between the two methods ($p \geq 0.481$). Assessment of interobserver variability revealed good agreement in the findings of the two observers, both in normal sinus rhythm and atrial fibrillation (overall variability 0.8±6.5%). *Conclusions:* The biplane area-length method can be used in CMR images obtained by TrueFISP to assess left atrial volumes and ejection fraction in normal subjects and patients with varying cardiac cycle length, as in atrial fibrillation.

Key Words: Left atrial volumes; Left atrial ejection fraction; Cardiovascular magnetic resonance imaging; Biplane-area length method; Atrial fibrillation.

INTRODUCTION

Cardiovascular magnetic resonance (CMR) allows accurate and reproducible evaluation of left and right ventricular function by the determination of left and right ventricular volumes, ejection fraction (EF), and mass (Dulce et al., 1993; Mackey et al., 1990; Matsuoka et al., 1993; Mogelvang et al., 1986, 1988; Pattynama et al., 1995; Sakuma et al., 1993, 1996; Van Rossum et al., 1988). Image acquisition can now be performed with fast gradient-echo sequences as a result of recent technical developments in the field of CMR. The advantages are a shorter breath-hold period and greater temporal and spatial resolution, resulting in better blood-myocardium contrast and greatly facilitating the identification of the ventricular endocardium and epicardium.

From echocardiographic studies, it is well known that left atrial diameter and volume are of relevance in atrial fibrillation as an increase is associated with a higher risk of developing this arrhythmia, a poorer prognosis in the presence of atrial fibrillation, and reduced long-term success rates after cardioversion (Hoglund and Rosenhamer; Ortiz De Murua et al., 2001; Tsang et al., 2001; Volgman et al., 1996). Assessment of left atrial volumes therefore plays an important role in clinical practice, as atrial fibrillation is the most common arrhythmia in elderly patients.

The standard short-axis method of volume and ejection fraction assessment by CMR is time-consuming. We therefore tested the use of the biplane area-length method for ellipsoid bodies, which enables much faster calculation (Dulce et al., 1993; Oh et al., 1999), and compared the findings with those obtained by the standard short-axis method. The aim was to evaluate whether this method is as accurate and reliable as the standard short-axis method for left atrial volume and ejection fraction assessment in normal subjects and patients with atrial fibrillation, and to determine whether measurements obtained in the presence of atrial fibrillation are reproducible, despite the varying cycle length.

METHODS

Patients

A total of 15 subjects with no cardiac pathology and history of atrial fibrillation (8 males, 7 females; mean age 65.6±6.4 years, heart rate 63±10 bpm) and 18 patients with atrial fibrillation (10 males, 8 females; mean age 67.2±8.8 years; duration of atrial fibrillation 21.4±9.2 months; heart rate 73±21 bpm) underwent CMR for the evaluation of cardiac function and the determination of left atrial volumes. Four patients had nonischemic heart disease, 7 patients had ischemic heart disease, 15 patients had hypertension, and 5 patients had diabetes.

All patients were on their routine medications, including beta-blockers, verapamil, and digoxin. No additional medications were given to drop the heart rate, prior to or during the scan. The patient population was recruited from the daily clinical practise. The normal subjects had been referred for a routine insurance medical check-up. Organic heart disease was excluded before CMR by noninvasive diagnostic techniques [electrocardiogram (ECG), 24-hour Holter ECG, chest X-ray, treadmill exercise ECG, echocardiography, thallium scintigraphy].

Left ventricular function was assessed by CMR [healthy subjects (mean±SD): end-diastolic volume

(EDV) 102.3±25 ml; end-systolic volume (ESV) 29.2±11.3 ml; stroke volume (SV) 72.8±19 ml; ejection fraction (EF) 71.4±7.2%; patients with atrial fibrillation (mean±SD): EDV, 168.3±31 ml; ESV, 73.6±19.5 ml; SV, 94.3±24.3 ml; EF 55.9±11.2%].

Informed consent was obtained before CMR in all cases. The study was conducted according to the principles of the Declaration of Helsinki. Approval of the Institutional Review Board was not considered necessary as the investigations are performed routinely in our department. All patient identifiers were removed from the images before analysis. They would have been conducted in all cases even if the study had not been performed, as they were either clinically indicated or required for insurance purposes.

CMR Image Acquisition

Imaging was performed with a Siemens 1.5 Tesla magnetic resonance imager (Magnetom, Sonata, Erlangen, Germany) using front and back surface coils (CP Body Array Flex, CP Spine Array, Siemens) and prospective electrocardiographic triggering. The anterior body array and the posterior spine array coil together give a four-element array combination. The dimensions of the coil elements are about 160 mm in the z-direction (head to feed) and about 460 mm in the x-direction (right to left). The gradient-echo sequence TrueFISP, a rapid image sequence with steady-state free precession, was employed (Brown and Semelka, 1999). On the basis of scout images, cine images were acquired in the short axis and horizontal and vertical long axes (Figs. 1 and 2). Short-axis images covering the whole left atrium were acquired with a 7-mm section thickness and a 3-mm gap during breath holding in end expiration. One section was acquired per breath hold. The number of cardiac cycles per acquisition was 80–90% of the R-R interval divided by the temporal resolution (43 msec). A total of 4 to 10 slices were necessary for imaging of the left atrium. The following parameters were employed: repetition time, 3.2 msec; echo time, 1.6 msec; section thickness, 7 mm; flip angle, 60°; in-plane pixel size, 2.3 × 1.4 mm; acquisition time, 12 heartbeats.

CMR Image Analysis

The images were evaluated with the commercially available computer software program Argus (Siemens) by two experienced investigators (BS, SK), each of whom was unaware of the findings of the other. End-diastole was defined visually as the phase with the largest volume/dimension, and end-systole as the phase with the smallest volume/dimension.

Left atrial volumes were first assessed by the standard short-axis method (Fig. 1). At the base of the atrium, slices were considered to be in the left atrium if the blood was less than half surrounded by ventricular myocardium. If the blood was half or more than half surrounded by ventricular myocardium, the slice was considered to be in the left ventricle. For the basal slice, the contours were traced up to the junction of the atrium and the ventricle. Blood volume above the level of the aortic valve was included in the left atrial volume. The endocardium of the left atrium was marked with a cursor in each end-diastolic and

Figure 1. Stack of standard short-axis gradient-echo images (TrueFISP) from the left atrial base to the apex for volume and ejection fraction assessment in a healthy subject.

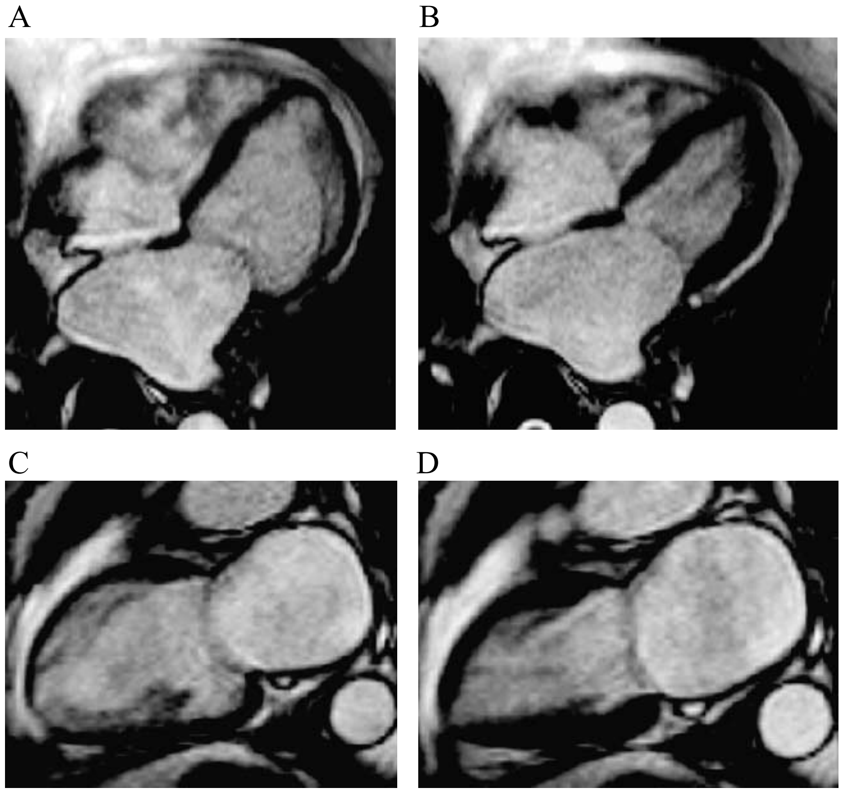

Figure 2. Gradient-echo cine magnetic resonance imaging (TrueFISP) in a patient with chronic atrial fibrillation (heart rate 92 bpm). Despite the irregular heartbeat, the image is of high quality and precise evaluation is possible. Horizontal long-axis view (A and B), vertical long axis view (C and D), (A, C = ventricular end-diastole, B, D = ventricular end-systole).

end-systolic slice and the sum of the marked areas used to calculate the total volume. Left atrial EDV and ESV were calculated from the sums of the outlined areas using a modification of Simpson's rule (Lorenz et al., 1999). Left atrial SV and EF were calculated from the formulae $SV = EDV - ESV$ and $EF = SV/EDV \times 100\%$.

The left atrial volumes and EF were then measured by the biplane area-length method in the horizontal and vertical long axes (Lester et al., 1999; Oh et al., 1999; Rodevan et al., 1999) (Fig. 2) and the values obtained compared with those obtained by the standard short axis method.

Interobserver variability was calculated for the findings for both groups of subjects.

In the patients with atrial fibrillation, images were acquired a second time (30±6 min after the first image acquisition) to evaluate the reproducibility of the measurements, in view of the fact that the cycle length varies in atrial fibrillation. Measurements were again obtained by both observers using both methods. The interobserver variability of those measurements were also assessed.

The maximum dimensions (mean±SD) of the left atrium were measured in the horizontal (left to right, cranial to caudal; Fig. 1B) and vertical (anterior to posterior; Fig. 1D) long axis view.

STATISTICAL ANALYSIS

The mean and standard deviation were derived for each of the parameters evaluated. The Mann-Whitney *U* Test was used to compare the volumes and ejection fractions of the two independent groups. The sign test was used to test for significant differences between the standard short-axis method and the biplane area-length method. The significance level (α) was set at 0.05 for all tests. To assess interobserver variability, percentage variability was calculated from the absolute difference between the two measurements divided by the mean of the two measurements (Bland-Altman method).

Table 1. Left atrial volumes and ejection fractions of healthy subjects with normal sinus rhythm (NSR) and patients with atrial fibrillation (AF).

	NSR ($n=15$)	AF ($n=18$)	p-value*
EDV [ml]–biplane	62.9±18.9	114.4±41.3	0.0004
EDV [ml]–short-axis	61.3±19	112.7±41.3	0.0005
ESV [ml]–biplane	32.1±11.3	94.2±42.5	0.0001
ESV [ml]–short-axis	31±11.2	92.8±42.3	0.0001
SV [ml]–biplane	30.9±9.1	20.2±12	0.0075
SV [ml]–short-axis	30.3±9.3	20±12.2	0.0092
EF [%] biplane	49.4±6.6	20.3±12	0.0000
EF [%] short-axis	49.8±6.7	20.3±12.2	0.0000

Values are presented as mean and standard deviation (SD).
Abbreviations: EDV=end-diastolic volume, EF=ejection fraction, ESV=end-systolic volume, SV=stroke volume.
*Two-sided Mann-Whitney *U* Test.

RESULTS

There was no difference in age between men and women ($p=0.147$) and normal subjects and patients with atrial fibrillation ($p=0.128$) included in the study.

The values obtained for left atrial volumes and ejection fractions in both groups investigated are given in Table 1. The values for EDV and ESV were significantly higher and those for SV and EF significantly lower in the patients with atrial fibrillation, regardless of the method used. In both groups, the biplane area-length method produced values for EDV and ESV that were significantly higher than those obtained by the standard short-axis approach, whereas SV and EF did not differ significantly (Table 2). In the second investigation, in the patients with atrial fibrillation, only the values for EDV showed a significant difference between the two methods ($p<0.01$; Table 3). The evaluation of interobserver variability revealed very good agreement for the measurements obtained in the first investigation in both groups (Table 4) and the second investigation (Table 5) in the patients with atrial fibrillation (overall variability 0.8±6.5%).

The biplane area-length method (3±1 min) was significantly faster than the standard short-axis method (10±3 min) in both groups ($p<0.01$).

The comparison of the results of the first and second investigations in the patients with atrial fibrillation revealed significant differences in the values obtained for EDV by both the biplane area-length method ($p=0.0075$) and the short-axis method

Table 2. Differences between the measurements obtained by the biplane area-length method (biplane) and the standard short-axis method (short axis) in normal sinus rhythm (NSR) and atrial fibrillation (AF), first investigation.

Difference (biplane − short axis)	NSR ($n=15$) mean±SD	AF ($n=18$) mean±SD
EDV [ml]	1.6±0.6 ($p<0.001$)	1.6±0.5 ($p<0.001$)
ESV [ml]	1.0±0.4 ($p<0.001$)	1.4±0.5 ($p<0.001$)
SV [ml]	0.6±0.6 ($p=0.0574$)	0.2±0.5 ($p=0.2379$)
EF [%]	−0.3±0.8 ($p=0.1185$)	−0.1±0.4 ($p=0.8145$)

The p-values obtained by the two-sided sign test are given in brackets.
Abbreviations: EDV=end-diastolic volume, EF=ejection fraction, ESV=end-systolic volume, SV=stroke volume.

Table 3. Differences between the measurements obtained by the biplane area-length method (biplane) and the standard short-axis method (short axis), second investigation in patients with atrial fibrillation (AF).

Difference (biplane − short axis)	AF ($n=18$)
EDV [ml]	1.3±0.7 ($p<0.001$)
ESV [ml]	1.0±2.0 (1.000)
SV [ml]	0.3±1.9 (0.4807)
EF [%]	0.4±2.2 (0.4807)

The p-values of the two-sided sign test are given in brackets.
Abbreviations: EDV=end-diastolic volume, EF=ejection fraction, ESV=end-systolic volume, SV=stroke volume.

Table 4. Interobserver variability in the evaluation of left atrial volumes and ejection fraction in healthy subjects in normal sinus rhythm (NSR) and patients with atrial fibrillation (AF; first investigation).

	NSR (n=15)			AF (n=18)		
	Difference	Mean	Variability	Difference	Mean	Variability
EDV biplane [ml]	0.8±0.4	62.5±18.9	1.3±0.7	0.9±0.5	113.9±41.4	1.0±0.9
EDV short axis [ml]	1.1±0.4	60.8±19.1	2.0±1.2	0.6±0.7	112.4±41.4	0.6±0.6
ESV biplane [ml]	0.8±0.3	31.7±11.3	2.9±1.5	0.2±0.4	94.1±42.5	0.3±0.6
ESV short axis [ml]	0.9±0.4	30.6±11.2	3.5±2.6	0.1±0.3	92.7±42.4	0.2±0.4
SV biplane [ml]	0±0.4	30.9±9	−0.1±1.3	0.7±0.7	19.8±12.2	8.7±12.7
SV short axis [ml]	0.2±0.4	30.2±9.3	0.7±2.0	0.4±0.8	19.7±12.3	9.0±20.3
EF biplane [%]	−0.7±0.6	49.8±6.7	−1.4±1.2	0.6±0.8	20±12	7.7±12.6
EF short axis [%]	−0.7±0.9	50.1±6.8	−1.3±1.8	0.4±0.6	20.2±12.2	8.4±20.1

Abbreviations: EDV=end-diastolic volume, EF=ejection fraction, ESV=end-systolic volume, SV=stroke volume.

(p=0.0309; Table 6). However, the differences are very small (mean difference −0.8 ml and 0.9 ml for the biplane and short-axis methods, respectively).

The maximum dimensions (mean±SD) of the left atrium measured in the horizontal and vertical long axis view are displayed in Table 7.

DISCUSSION

Atrial fibrillation is the most common arrhythmia in elderly patients and is often associated with left atrial enlargement (Kannel et al., 1998). Echocardiography is currently the gold standard for the assessment of atrial diameters. Left atrial volumes and ejection fractions might provide better information about left atrial size and function than left atrial diameters. The determination of left atrial volumes has not yet become routine, partly because there is no straightforward and easily applicable method, but would be particularly valuable in the follow-up of patients with atrial fibrillation, especially after electrical or pharmacologic cardioversion.

Few CMR studies have addressed atrial volume assessment. Both Mohiaddin and Hasegawa (1995) and Matsuoka et al. (1993) studied patients in sinus rhythm and used scanners with a lower gradient strength (0.5 Tesla). In the study of Mohiaddin and Hasegawa images were acquired with spin-echo sequences, whereas Matsuoka et al. used a former gradient-echo sequence for cine imaging. In both studies the volumes were calculated from transverse images by summing the areas outlined in the individual images.

However, both the transverse and short-axis approaches for the assessment of atrial and ventricular volumes are time-consuming. We therefore decided to

Table 5. Interobserver variability in the evaluation of left atrial volumes and ejection fraction in patients with atrial fibrillation (AF), second investigation.

AF (n=18)	Difference	Mean	Variability
EDV biplane [ml]	0.5±0.8	113.3±41.8	0.5±0.8
EDV short axis [ml]	0.4±0.9	112.1±41.7	0.6±0.9
ESV biplane [ml]	0.2±1.1	93.9±42.9	−0.2±1.3
ESV short axis [ml]	0.8±1.3	92.6±42.5	1.4±2.6
SV biplane [ml]	0.3±1.2	19.4±12.2	5.9±17.3
SV short axis [ml]	0.3±1.0	19.5±12.5	−10.8±37.7
EF biplane [%]	0.4±1.1	19.8±12.1	5.3±17.1
EF short axis [%]	−0.6±1.3	19.9±12.2	−10.3±37.6

Abbreviations: EDV=end-diastolic volume, EF=ejection fraction, ESV=end-systolic volume, SV=stroke volume.

Table 6. Comparison between first and second measurements in the patients with atrial fibrillation (AF).

AF ($n=18$)	First measurement	Second measurement	Difference	p-value*
EDV biplane [ml]	114.4±41.3	113.6±41.8	−0.8±1.0	0.0075
EDV short axis [ml]	112.7±41.3	112.3±41.6	0.9±1.0	0.0309
ESV biplane [ml]	94.2±42.5	94±43	−0.2±1.2	0.6219
ESV short axis [ml]	92.8±42.3	93±42.4	1.2±1.4	0.2379
SV biplane [ml]	20.2±12	19.6±12.1	−0.6±0.9	0.0963
SV short axis [ml]	20±12.2	19.3±12.6	−0.4±1.1	0.4807
EF biplane [%]	20.3±12	20±12.3	−0.3±0.9	0.8145
EF short axis [%]	20.3±12.2	19.6±12	−0.3±1.0	0.8145

Abbreviations: EDV=end-diastolic volume, EF=ejection fraction, ESV=end-systolic volume, SV=stroke volume.
*p-value of the two-sided sign test to test the null hypothesis that the median of the differences between the first and second measurement is zero.

investigate whether the biplane area-length method is as accurate as the standard short-axis approach for the assessment of left atrial volumes and EF, and also sought to determine whether it can be used in patients with varying heart cycle length, in this case atrial fibrillation.

We found small but significant differences between the two methods in EDV and ESV in both healthy subjects and patients with atrial fibrillation, whereas SV and EF did not differ significantly. However, the small differences in EDV and ESV may not be of clinical significance. The biplane area-length method is an accurate and reproducible method for left atrial volume and EF assessment in healthy subjects and in patients with varying heart cycle length, such as in atrial fibrillation.

The values we obtained for left atrial EDV by both the standard short-axis method and the biplane area-length method were similar to those reported by Mohiaddin et al. (62±16 ml) and marginally lower than those described by Matsuoka et al. (75.8±15.4 ml). The values for ESV (both methods) were marginally lower than those reported by Mohiaddin and Hasegawa (36±11 ml) and Matsuoka et al. (37.5±10.7 ml), and the values for left atrial EF (both methods) were higher than those measured by Mohiaddin et al. (42±9%), but similiar to those of Matsuoka et al. (50.7±8.7%). These discrepancies may be due in part to the differing approaches employed for image acquisition. In our study, we used a 1.5 Tesla magnet, a fast gradient-echo sequence with steady-state free precession (TrueFISP), and the conventional short-axis and biplane area-length methods for volume and ejection fraction calculation. With spin-echo sequences, as used by Mohiaddin et al., the identification of end-diastole and end-systole might be more difficult than in gradient-echo cine images. The use of body-axis orientated slices (transverse plane) for volume assessment is also likely to result in measurements that are different to those obtained from heart-axis orientated slices (short-axis plane, horizontal and vertical long-axis planes) (Fig. 3). The apparent shape and dimensions of the cardiac chambers differ according to the angle at which the images are obtained. In addition, it should be noted that the subjects examined by Mohiaddin and Hasegawa and Matsuoka et al. were considerably younger than those investigated in our study, although the impact of age on left atrial volumes and ejection fractions has not yet been established.

Table 7. Maximum dimensions (mean ± SD) of the left atrium measured in the horizontal (left to right, cranial to caudal) and vertical (anterior to posterior) long axis view.

Maximum dimensions/cm	NSR ($n=15$)	AF ($n=18$)	p-value
Anterior-posterior	4.1±0.6	5.0±0.9	0.0024
Left-right	3.9±0.7	4.5±1.0	0.0595
Cranial-caudal	4.8±0.9	5.9±1.2	0.0064

We have previously reported that the biplane area-length method produces significantly higher values for left ventricular EDV and ESV in sinus rhythm than the standard short-axis method, whereas EF does not differ significantly (Sievers et al., 2004). This study revealed that the two methods also produce differences in atrial volumes (Table 2).

Hundley et al. (1996) first described the use of CMR for left ventricular volume assessment in patients with atrial fibrillation using a 1.5 Tesla magnet and a gradient-echo sequence. However, there are no

A

B

Figure 3. Gradient-echo cine magnetic resonance imaging (TrueFISP) in a patient with ischemic cardiomyopathy (left ventricular ejection fraction 45%) and chronic atrial fibrillation, heart rate 87 bpm. Horizontal long-axis view (A) in ventricular end-diastole, ventrical long-axis view (B) in ventricular end-systole.

published data concerning left atrial volume and ejection fraction assessment by the standard short-axis approach and the biplane area-length method in images obtained by a fast gradient-echo sequence, either in healthy subjects with normal sinus rhythm or in patients with atrial fibrillation.

Despite the varying cycle length in atrial fibrillation, CMR with the fast gradient-echo sequence TrueFISP is able to produce high-quality images in which the endocardial and epicardial borders can be clearly distinguished (Figs. 2 and 3). Our study revealed good reproducibility for left atrial volume and EF measurements obtained from these images, even in patients with atrial fibrillation (Tables 5 and 6).

Atrial fibrillation can be caused by various diseases like hypertension, valve diseases, cardiomyopathies, myocarditis, and storage diseases. It may also be idiopathic.

However, our study did not attempt to cover patients with various diseases causing atrial fibrillation. We aimed to demonstrate that the biplane area-length method is fast and reasonably accurate for left atrial volume and ejection fraction assessment in patients with atrial fibrillation.

We used a prospectively-gated gradient-echo sequence for image acquisition. At the time, the study was performed, a retro-gated gradient-echo cine sequence was not commercially available. A recently developed retro-gated fast gradient-echo sequence with parallel imaging has been available for only a few months. Prior sequences with retrospective ECG triggering were not robust and rejected many heartbeats in patients with arrhythmias resulting in an unacceptable increase of the breath-hold duration. With prospective triggering, about 10–15% of the RR-interval is missed. However, that probably doesn't affect the data significantly and the difference in volumes and ejection fraction might not be of clinical relevance. Further studies are required to address this issue.

CONCLUSIONS

In conclusion, it can be said that the biplane area-length method can be used for the rapid assessment of left atrial volumes and EF in subjects with sinus rhythm or atrial fibrillation. However, for research purposes, the standard short-axis method should be performed. For daily clinical purposes, it might be more important to have a time-saving method than to have a most accurate method.

REFERENCES

Brown, M. A., Semelka, R. C. (1999). MR imaging abbreviations, definitions and descriptions: a review. *Radiology* 213:647–662.

Dulce, M. C., Mostbeck, G. H., Friese, K. K., Caputo, G. R., Higgens, C. B. (1993). Quantification of the left ventricular volumes and function with cine MR imaging: comparison of geometric models with three-dimensional data. *Radiology* 188:371–376.

Hoglund, C., Rosenhamer, G. Echocardiographic left atrial dimension as a predictor of maintaining sinus rhythm after conversion of atrial fibrillation. *Acta Med. Scand.* 217(4):411–415.

Hundley, W. G., Meshack, B. M., Willett, D. L., Sayad, D. E., Lange, R. A., Willard, J. E., Landau, C., Hillis, L. D., Peshock, R. M. (1996). Comparison of quantitation of left ventricular volume, ejection fraction, and cardiac output in patients with atrial fibrillation by cine magnetic resonance imaging versus invasive measurements. *Am. J. Cardiol.* 78(10):1119– 1123.

Kannel, W. B., Wolf, P. A., Benjamin, E. J., Levy, D. (1998). Prevalence, incidence, prognosis, and predisposing conditions for atrial fibrillation: population-based estimates. *Am. J. Cardiol.* 82(8A):2N–9N.

Lester, S. J., Ryan, E. W., Schiller, N. B., Foster, E. (1999). Best method in clinical practice and in research studies to determine left atrial size. *Am. J. Cardiol.* 84(7):829–832.

Lorenz, C. H., Walker, E. S., Morgan, V. L., Klein, S. S., Graham, T. P. Jr. (1999). Normal human right and left ventricular mass, systolic function, and gender differences by cine magnetic resonance imaging. *J. Cardiovasc. Magn. Reson.* 1(1):7–21.

Mackey, E. S., Sandler, M. P., Campbell, R. M., Graham, T. P. Jr., Atkinson, J. B., Price, R., Moreau, G. A. (1990). Right ventricular myocardial mass quantification with magnetic resonance imaging. *Am. J. Cardiol.* 65:529–532.

Matsuoka, H., Hamada, M., Honda, T., Kobayashi, T., Suzuki, M., Ohtani, T., Takezaki, M., Abe, M., Fujiwara, Y., Sumimoto, T. (1993). Measurement of cardiac chamber volumes by cine magnetic resonance imaging. *Angiology* 44:321–327.

Mogelvang, J., Thomsen, C., Mehlsen, J., Brackle, G., Stubgaard, M., Henriksen, O. (1986). Evaluation of left ventricular volumes measured by magnetic resonance imaging. *Eur. Heart J.* 7:1016–1021.

Mogelvang, J., Stubgaard, M., Thomsen, C., Henriksen, O. (1988). Evaluation of right ventricular volumes measured by magnetic resonance imaging. *Eur. Heart J.* 9:529–532.

Mohiaddin, R. H., Hasegawa, M. (1995). Measurement of atrial volumes by magnetic resonance imaging in healthy volunteers and in patients with myocardial infarction. *Eur. Heart J.* 16(1): 106–111.

Oh, J. K., Seward, J. B., Tajik, A. J. (1999). The Echo Manual. 2nd ed.

Submitted October 27, 2003
Accepted May 11, 2004

Ortiz De Murua, J. A., del Carmen Avila, M., Ochoa, C., de La Fuente, L., Moreno De Vega, J. C., del Campo, F., Villafranca, J. L. (2001). Independent predictive factors of acute and first year success after electrical cardioversion in patients with chronic atrial fibrillation. *Rev. Esp. Cardiol.* 54(8):958–964.

Pattynama, P. M. T., Lamb, H. J., Van der Velde, E. A., Van der Geest, R. J., van der Wall, E. E., de Roos, A. (1995). Reproducibility of magnetic resonance imaging-derived measurements of right ventricular volumes and myocardial mass. *Magn. Reson. Imaging* 13:53–63.

Rodevan, O., Bjornerheim, R., Ljosland, M., Maehle, J., Smith, H. J., Ihlen, H. (1999). Left atrial volumes assessed by three- and two-dimensional echocardiography compared to MRI estimates. *Int. J. Card. Imaging* 15(5):397–410.

Sakuma, H., Fujita, N., Foo, T. K., Caputo, G. R., Nelson, S. J., Hartiala, J., Shimakawa, A., Higgins, C. B. (1993). Evaluation of left ventricular volume and mass with breath-hold cine MR imaging. *Radiology* 188:377.

Sakuma, H., Globits, S., Boume, M. W., Shimakawa, A., Foo, T. K., Higgens, C. B. (1996). Improved reproducibility in measuring LV volumes and mass using multicoil breath-hold cine MR imaging. *J. Magn. Reson. Imaging* 1:124–127.

Sievers, B., Kirchberg, S., Bakan, A., Franken, U., Trappe, H. J. (2004). Impact of papillary muscles in ventricular volume and ejection fraction assessment by cardiovascular magnetic resonance. *J. Cardiovasc. Magn. Reson.* 6(1):9–16.

Tsang, T. S., Barnes, M. E., Bailey, K. R., Leibson, C. L., Montgomery, S. C., Takemoto, Y., Diamond, P. M., Marra, M. A., Gersh, B. J., Wiebers, D. O., Petty, G. W., Seward, J. B. (2001). Left atrial volume: important risk marker of incident atrial fibrillation in 1655 older men and women. *Mayo Clin. Proc.* 76(5):467–475.

Van Rossum, A. C., Visser, F. C., van Eenige, M. J., Valk, J., Roos, J. P. (1988). Magnetic resonance imaging of the heart for determination of ejection fraction. *Int. J. Cardiol.* 18:53–63.

Volgman, A. S., Soble, J. S., Neumann, A., Mukhtar, K. N., Iftikhar, F., Vallesteros, A., Liebson, P. R. (1996). Effect of left atrial size on recurrence of atrial fibrillation after electrical cardioversion: atrial dimension versus volume. *Am. J. Card. Imaging* 10(4):261–265.