ASSESSMENT OF CARDIAC FUNCTION BY MAGNETIC RESONANCE IMAGING: SEGMENTED × REAL-TIME STEADY-STATE FREE PRECESSION SEQUENCES*

Leonardo Bernardo Bezerra[1], Edson Marchiori[2], Paulo V. Pontes[3]

Absrtract **OBJECTIVE: To compare ventricular systolic parameters on segmented and real-time steady-state free precession cine-MRI sequences and ECG-gated MRI in patients presenting or not with cardiac arrhythmias. MATERIALS AND METHODS: Ejection fraction and end-diastolic/end-systolic volumes have been compared in 31 patients, 11 presenting with cardiac arrhythmias, and 20 with regular sinus rhythm, using ECG-gated segmented and real-time sequences. The statistical analysis was performed using Pearson's correlation and Bland-Altman agreement plot, with $p < 0.01$. RESULTS: Real-time acquisitions demonstrated endocardial borders blurring effects, but both sequences presented a clear, positive correlation: ejection fraction $r = 0.94$; end-diastolic volume $r = 0.93$ and end-systolic volume $r = 0.98$. The assessment of 11 patients with arrhythmias has not demonstrated a statistically significant difference, despite the lower blood pool-myocardial contrast ratio. CONCLUSION: Real-time sequences may be utilized for cardiac function assessment, regardless the patient's cardiac rhythm.**

Keywords: Cine-RMI; Ventricular function; Steady-state free precession; Real-time; ECG-gated MRI.

Resumo *Avaliação da função cardíaca por ressonância magnética com seqüências em equilíbrio estável: segmentadas × tempo real.*

OBJETIVO: Comparar os índices de função sistólica ventricular obtidos entre as seqüências de cine-ressonância magnética em equilíbrio estável, em tempo real e acoplada ao eletrocardiograma, em pacientes com ritmo regular ou não. MATERIAIS E MÉTODOS: Foram comparados a fração de ejeção e os volumes diastólico e sistólico finais, em 31 pacientes, 11 com ritmo cardíaco irregular e 20 com ritmo cardíaco sinusal regular, utilizando-se seqüências segmentadas acopladas ao eletrocardiograma e em tempo real. O tratamento estatístico foi feito através da correlação de Pearson e a concordância de Bland-Altman, com $p <$ 0,01. RESULTADOS: As aquisições em tempo real demonstraram borramento dos contornos endocárdicos, mas ambas as seqüências tiveram forte correlação positiva entre os valores obtidos: fração de ejeção, r = 0,94; volume diastólico final, r = 0,93; volume sistólico final, r = 0,98. A análise dos 11 pacientes com ritmo irregular não demonstrou diferença estatisticamente significativa, apesar da menor relação de contraste sangue-miocárdio. CONCLUSÃO: Seqüências em tempo real podem ser utilizadas para a análise da função cardíaca, independente do ritmo cardíaco dos pacientes.

Unitermos: Cine-RM; Função ventricular; Equilíbrio estável; Tempo real; Acoplamento de imagens.

INTRODUCTION

Currently, magnetic resonance imaging (MRI) is the gold-standard for assessing the ventricular function[(1,2)]. Notwithstanding, the complexity of the cyclic heart motion has posed a challenge to this imaging method[(3)], and the long acquisition time as well as the frequent presence of respiratory movement artifacts have restricted its widespread use in clinical practice[(4–6)]. The ECG-gated MRI[(6)] has been an alternative method for acquisition of images free from motion artifacts, while respiratory control techniques have reduced diaphragmatic motion artifacts[(7)].

Currently, cine-MRI steady-state sequences, TrueFISP (free steady-state precession), segmented and ECG-gated sequences are the methods of choice for cardiac function evaluation, because of the high contrast between blood pool and myocardium[(5,6,8)]. These sequences utilize the ECG R-R interval regularity to perform the images acquisition. Another significant factor in the implementation of this method has been the introduction of true fast imaging with steady-state precession sequences, reducing the acquisition time within a single breath-hold[(7)].

Notwithstanding this reduction in acquisition time, there are cases where complex arrhythmias inherent to some ventricular dysfunctions complicate the MRI evaluation. This difficulty only could be overcome when images acquisition could be performed independently of the cardiac rhythm. Then, real-time sequences are introduced[(7)], allowing images acquisition independently of the cardiac cycle rhythmicity, differently from segmented acquisition.

This study has the objective of comparing ventricular systolic function parameters in patients submitted to cardiac MRI

* Study developed at Clínica Multimagem – Ipanema, Rio de Janeiro, RJ, Brazil.

1. Master in Radiology by Universidade Federal do Rio de Janeiro, Assistant Professor at Disciplina de Imagenologia da Universidade Federal do Rio Grande do Norte.

2. Titular Professor of Radiology at Universidade Federal Fluminense, Adjunct Coordinator for Course of Post-Graduation in Radiology at Universidade Federal do Rio de Janeiro.

3. Master in Cardiology by Universidade Federal Fluminense.

Mailing address: Dr. Leonardo Bernardo Bezerra. Rua dos Tororós, 420, Ed. Therra Mater, ap. 1203, Bloco B, Lagoa Nova. Natal, RN, Brazil, 59054-550. E-mail: warrenhellwind@yahoo.com.br

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studies with ECG-gated TrueFISP (segmented) and real-time sequences and, also, to observe if the presence of arrhythmias may affect the analysis of such ventricular systolic function parameters.

MATERIALS AND METHODS

Thirty-one patients were retrospectively evaluated by cardiac MRI for investigating possible myocardial viability, myocarditis and arrhythmogenic morphological alterations, in the period between August 2003 and March 2004. Regardless the indication and the presence or not of cardiovascular dysfunctions, all the patients had their ventricular function studied by means of left ventricular volumetric analysis by cine-MRI.

MR images were acquired in a Magneton Symphony 1.5 T scanner equipped with a high-performance gradient system (40 mT/m; slew rate – 125 mT/m/s), using TrueFISP sequences. Short cardiac axis views were acquired in cine-MRI segmented and real-time sequences, all of them under expiratory apnea. The repetition time (TR) was reduced to a minimum possible for both sequences and magnetization angle was the maximum possible, in compliance with the workstation predetermined protocol aiming at the sequence maximum effectiveness.

TrueFISP sequences (TR/TE = 1.4/1.2; flip angle = 65° and 8 mm section thickness) obtained the highest number possible of segments per heartbeat according to the size of R-R interval for each patient The software utilized predetermined 28 segments as a basis for each heartbeat, this number being increased or reduced according the R-R variation in milliseconds (msec) (Figure 1), resulting in a mean temporal resolution of 39 msec. Acquisition matrix was 192 × 82, with a mean acquisition time of 14 heartbeats. Each apnea at the moment of the data acquisition resulted in a slab (a set o slices) with three slices (multislice technique). This slab was repeated for two or three times up to the whole imaging of left ventricle long axis was completed without any gap between slabs. Therefore, for ventricular function data acquisition, two or three breath-hold periods were necessary.

Real-time sequences (TR/TE = 3.5/0.9; flip angle = 40° and 8 mm section thickness) had a 128 × 72 acquisition matrix, with 72 segments per slice (Figure 2), an effective total TR of 2.300 msec.

Single-shot acquisitions were utilized in real-time sequences, optimizing the temporal resolution, allowing the study of the whole heart during a single breath-hold period. The number of sections was similar to the number of segmented acquisitions (six to nine sections for real-time and two or three slabs for segmented acquisitions) Total acquisition time (estimated in heartbeats) of real-time sequences ranged between 12 and 18 heart-beats.

Parallel acquisition (multichannel) protocols were utilized with an iPAT factor 2 in both sequences.

The initial FOV was of 350 mm, but varied among patients, aiming at offering a better spatial resolution at each acquisition, ranging between 280 and 420 mm.

For images acquisition, six leads were placed: four anterior and two on the dorsum.

For real-time acquisitions, the ECG-gating served for the purpose of synchronizing the start signal for data acquisition, while in segmented images it was utilized for triggering pulse sequences.

The short cardiac axis was studied from the base to the apex with a 2 mm gap.

Ventricular function parameters were calculated with the Argus software (Siemens Medical Systems) through semi-automatic endocardial cavity volume rendering on the several sections of the short cardiac axis, with manually corrected data. All the patients had their parameters for analysis of the left ventricular function measured: end-systolic (ESV) and end-diastolic (EDV) volumes, and ejection fraction.

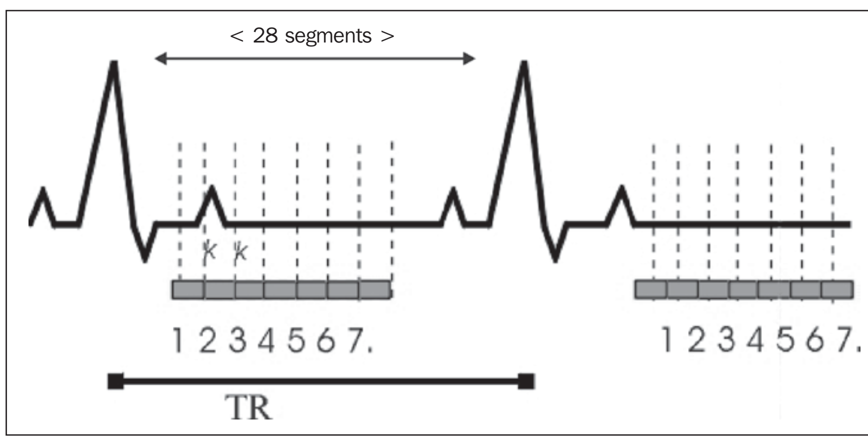


Figure 1. Schematic diagram showing segmented TrueFISP sequences ECG-gating and TR-gating, demonstrating *k*-spaces and mean number of segments. Figure idealized by the author.

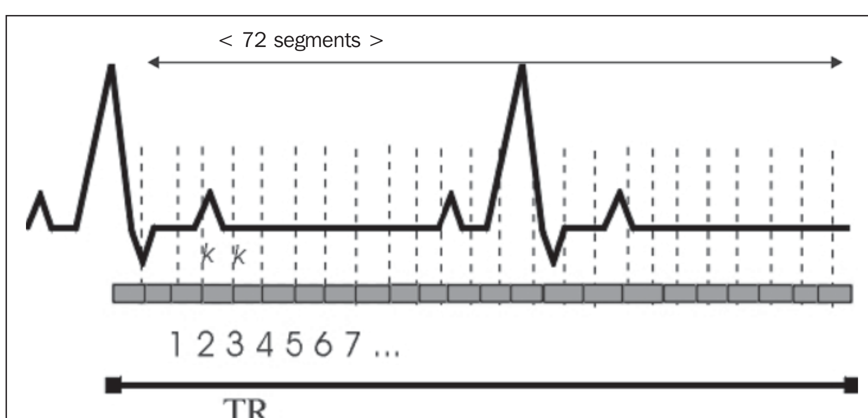


Figure 2. Schematic diagram showing real-time TrueFISP sequences ECG-gating and TR-gating, demonstrating *k*-spaces and mean number of segments. Figure idealized by the author.

All the analyses were performed by a single observer in both sequences.

Pearson's correlation and *t*-Student test were employed for statistical analysis. The concordance between the sequences was analyzed by means of the Bland-Altman plot with $p < 0.01$ as an indicator of statistically significant difference. The analyses were performed with the aid of the softwares Analyse-it for Excel^{TM}, version 1.71, and MedCalc®, version 7.6.0.0.

RESULTS

The epidemiological analysis of the sample included in the present study demonstrated a female predominance (18 women and 13 men) and an age range between 7 and 77 years (mean age 47 years), with a standard deviation of ± 19 years.

The analysis of the cardiac rhythm during examinations demonstrated that 11 patients presented with irregular cardiac rhythm due the presence of frequent ventricular extra-systoles and other arrhythmias such as tachyarrhythmias, bigeminy and atrial fibrillation. The remaining 20 patients presented with regular sinusal rhythm.

Steady-state, real-time and segmented MRI acquisitions were performed for all the patients, from the base to the apex, as per Figures 3 and 4, with temporal resolution of 39 msec and 126 msec respectively in cine-MR segmented and real-time acquisitions.

Real-time images showed lower spatial resolution than segmented images, a fact demonstrated by a slight blurring of contours on acquired images (Figure 5), which complicated the myocardial contour delineation. At the moment of the endocardial contour delineation, the papillary muscles were added to this contour if contacting the ventricular wall, otherwise, they were added to the ventricular cavity volume.

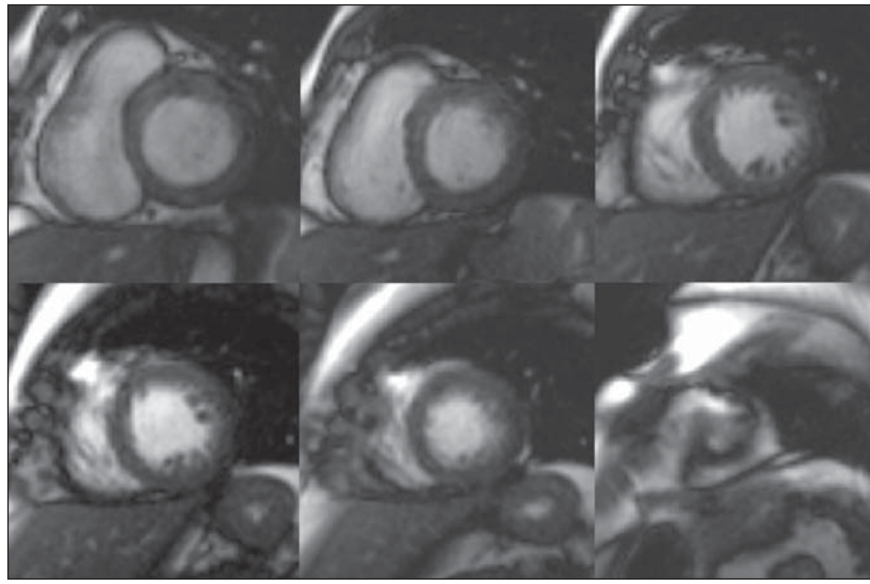


Figure 3. Short cardiac axis views acquired in segmented TrueFISP sequences, from the base to the apex.

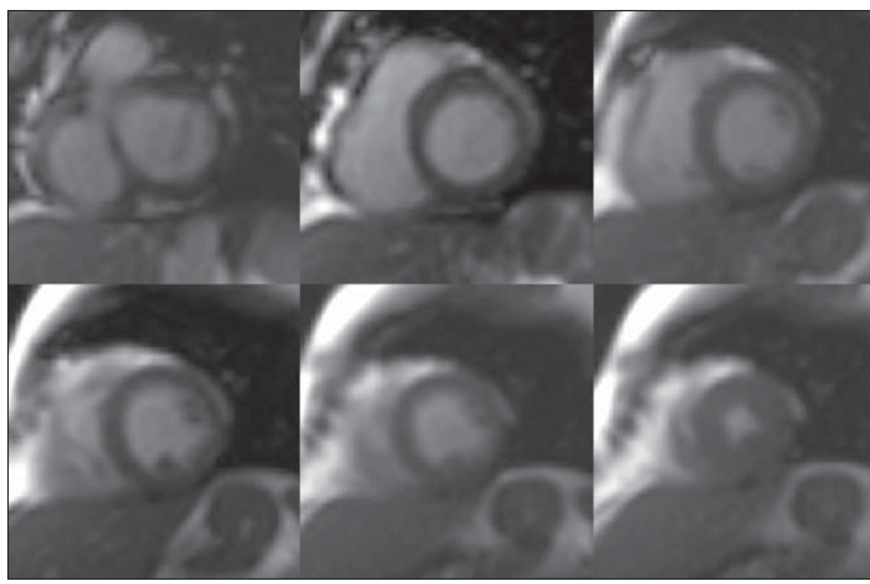


Figure 4. Short cardiac axis views acquired in real-time TrueFISP sequences, from the base to the apex.

Volumetric parameters

There was no statistically significant difference ($p < 0.01$) between values obtained from both sequences. The mean values obtained from real-time and segmented acquisitions were, respectively 55.7% and 53.8% for ejection fraction, 44 ml and 45 ml for ESV and 96.4 ml and 94.2 ml for EDV. These functional parameters presented a strong positive correlation *r*, as per Table 1.

The concordance between methods was tested by means of the Bland-Altman plot updated by NCCLS, with mean differences of respectively –2.1%, –2.2 ml and 1.7 ml for ejection fraction, EDV and ESV. The proposed graphic analysis (NCCLS guideline EP9-A[9]) plotted the difference between the sequences values compared with values obtained from segmented acquisitions, demonstrating only two patients falling out of the confidence interval of agreement for ejection fraction and one patient for EDV and ESV (Graph 1).

Cardiac rhythm influence

A comparison also has been performed between data obtained for both sequences — real-time and segmented — in patients with irregular cardiac rhythm due the presence of arrhythmias, with a strong correlation and establishing the absence of statistically significant difference between values by means of the *t*-Student test (Table 2)

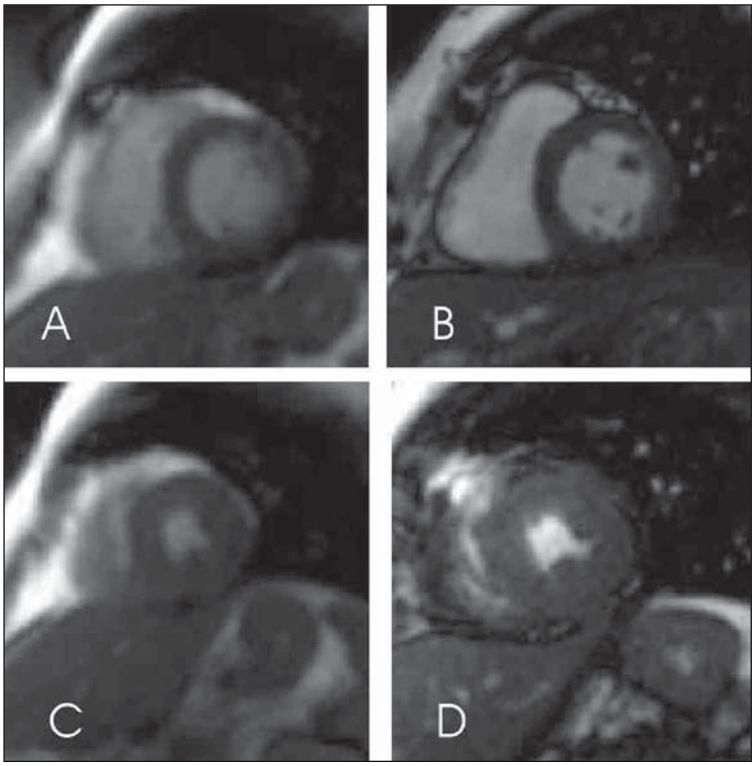


Figure 5. Short axis TrueFISP MR images of one of the patients included in the present study, demonstrating endocardial contour blurring. **A:** Heart base real-time image. **B:** Heart base segmented image. **C:** Heart apex real-time image. **D:** Heart apex segmented image.

Table 1 Result of comparison between averages of measurements for evaluation of ventricular function and respective correlation rates (*r* value), obtained in segmented and real-time TrueFISP sequences.

Parameter	Segmented	Real-time	Correlation coefficient
Ejection fraction	55.7%	53.8%	0.94
End-diastolic volume	96.4 ml	94.2 ml	0.93
End-systolic volume	44.0 ml	45.0 ml	0.98

Table 2 Values calculated according to Pearson's correlation, t-Student test and *p* demonstrating the inexistence of difference between parameters for 11 patients with irregular cardiac rhythm.

Parameter	Value *t* calculated	*p*	Pearson's correlation
Ejection fraction	1.56	0.147	0.94
End-diastolic volume	1.146	0.278	0.82
End-systolic volume	0.037	0.971	0.94

and the concordance between values obtained in both sequences of those 11 patients.

Volumetric parameters acquired from patients with irregular cardiac rhythm demonstrated mean differences of respectively 2%, 5.2 ml and –0.1ml for ejection fraction, EDV and ESV (Graph 2), with only one patient falling out of the confidence interval for EDV. This was the parameter which presented a high confidence interval in the whole studied population.

DISCUSSION

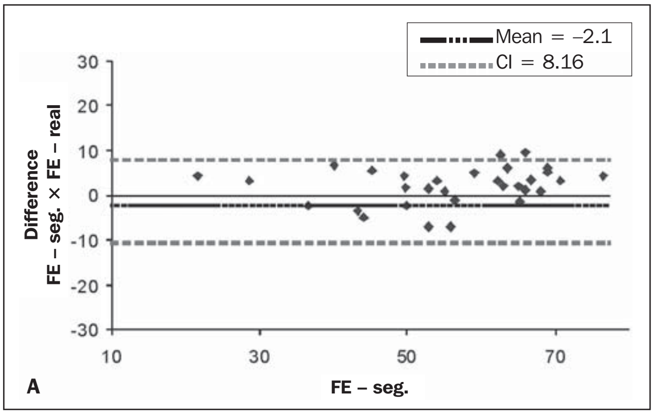
Cardiovascular MRI with steady-state precession, presents high-contrast resolution and currently is the gold standard for evaluation of the cardiac function. ECG-gating, besides regular cardiac rhythm (sinusal rhythm) is necessary for appropriate image acquisition in cardiac MRI. This is not always feasible due the frequent presence of cardiac rhythm disorders in patients with cardiopathy. The introduction of real-time MRI sequences has allowed the acquisition of cardiovascular images independently from the ECG regularity. Manning and Pennell[10] consider that ECG-gating and regular cardiac cycle are essential for an appropriate quality RM image, assertion that we consider real although, in our opinion the absence of these factor does not impede the performance of cardiac MRI. Real-time sequences utilize the cardiac gating as a start signal for data acquisition, however they do not depend on a normal R-R interval for images acquisition.

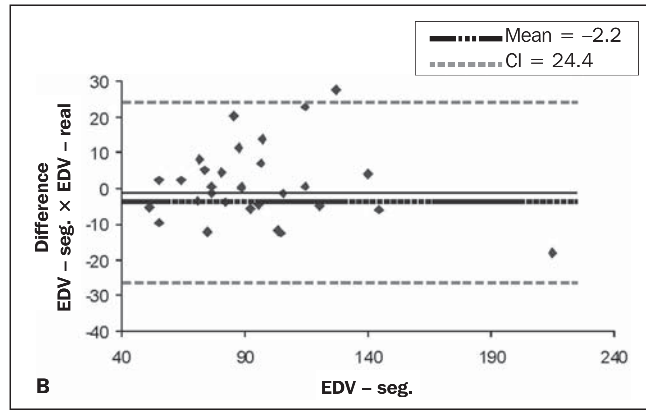
In this study we compared cardiac ECG-gated MRI steady-state sequences (segmented) with real-time sequences (multichannel). Systolic ventricular function parameters were utilized as a tool to indicate the existence of concordance between both sequences. Also, one has investigated if the presence of cardiac rhythm disorder affected the concordance between ventricular systolic function parameters in both sequences.

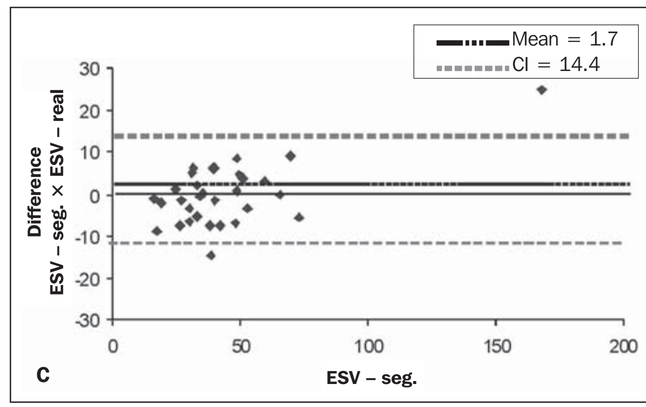
This is one of few studies to include, in the systolic parameters evaluation, patients presenting an irregular cardiac rhythm with arrhythmias (bigeminy, ventricular and supraventricular extra-systoles). These cardiac rhythm alterations affect the R-R interval causing irregularity and difficulting the EGC-gating. Barkhausen *et al.*[8] have developed a similar study including a lower number of patients, but they have not reported any potential cardiac rhythm disorder although they have discussed the presence of already existent cardiac diseases.

Images quality

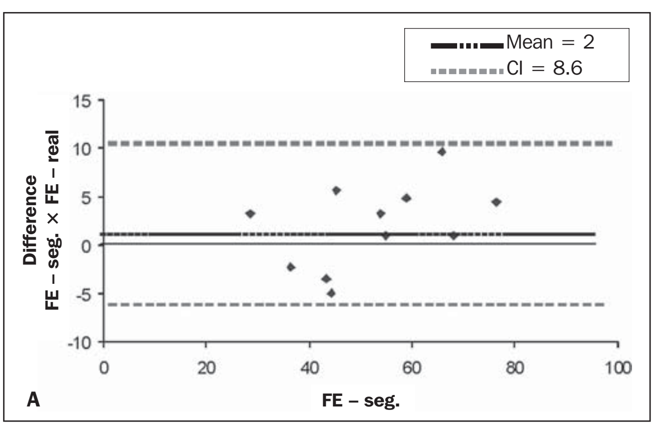
Systolic function parameters from two cine-MRI sequences (segmented and real-time acquisition) were utilized to determine the concordance between them. The determination of such parameters required endocardial contour delineation aiming at the quantitation of ventricular volumes. Such delineation is related to the level of clearness distinguishing myocardium from blood. Therefore, spatial and contrast resolution (images quality) was an essential attribute in the present study.

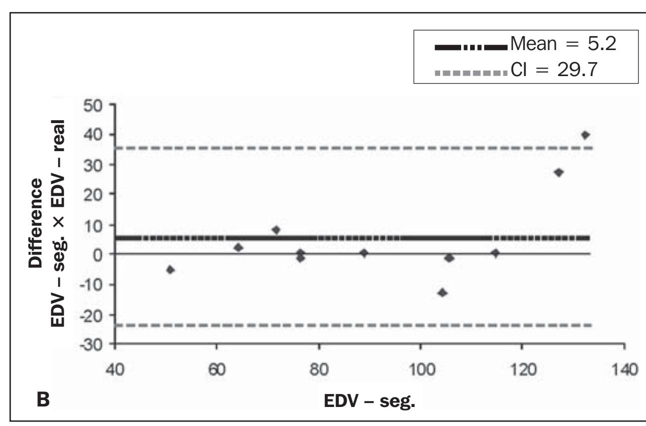


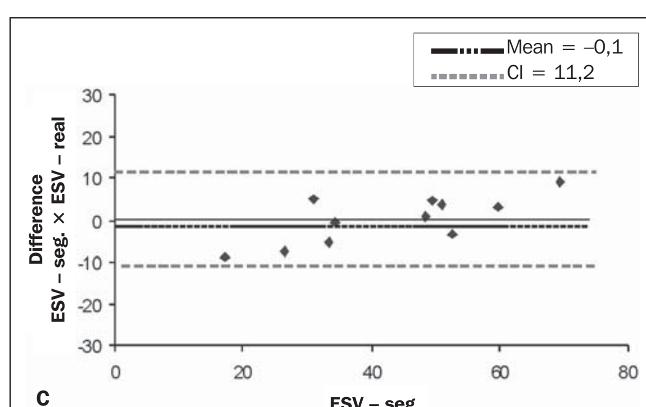




Graph 1. Graphic representation of concordance as proposed by NCCLS EP9-A guideline updating Bland-Altman plot. A comparison was utilized between methods difference and segmented sequences. **A:** Concordance between ejection fraction in real-time sequences (FE – real) and segmented (FE – seg.). **B:** Concordance between end-diastolic volume for data obtained in real-time (EDV – real) and segmented (EDV – seg.) sequences. **C.** Concordance between end-systolic volume for data obtained in real-time (ESV – real) and segmented (ESV – seg.) sequences.







Graph 2. Graphic representation of concordance as proposed by NCCLS EP9-A guideline updating Bland-Altman plot. A comparison was utilized between methods difference and segmented sequences. **A:** Concordance between ejection fraction in real-time sequences (FE – real) and segmented (FE – seg.). **B:** Concordance between end-diastolic volume for data obtained in real-time (EDV – real) and segmented (EDV – seg.) sequences. **C.** Concordance between end-systolic volume for data obtained in real-time (ESV – real) and segmented (ESV – seg.) sequences.

The balance between spatial resolution (images quality) and temporal resolution (images acquisition time) is necessary for appropriate images acquisition.

The ability of patients to maintain breath-hold periods is directly related with his/her clinical condition, especially in cases of patients with cardiopathy. The breath-hold significance is paramount, since cardiac images acquisition with high-field MR equipment is performed within this temporal window.

Segmented acquisitions required two or three breath-hold periods to cover the whole left ventricle, while real-time acquisitions do it within just one apnea. This gain in the examination time resulted in loss of spatial resolution evidenced by the comparison between levels of images detailing in both sequences, particularly regarding the delimitation of the blood-endocardium interface. Such loss of spatial resolution has already been reported by other authors[4,11–13].

For comparison between parameters utilized in images segmented and real-time acquisitions, the following factors will affect the spatial resolution: images matrix, pixels and voxels size, acquisition time duration and images reconstruction software utilized.

In the present study, the matrix utilized in real-time sequences provided a mean pixel size of 3 mm., which is slightly larger than those reported in the study of Barkhausen *et al.*[4], while segmented sequences resulted in mean pixels size of 2.3 mm, contributing to a low contrast resolution in real-time sequences. Miller *et al.*[12] report that a pixel size of 1-2 mm may be obtained with high magnetic field (1.5 T) equipment with good temporal resolution and that alterations in cardiac volumetric parameters, especially the EDV, only would be observed on images with >3-mm pixels. These authors also say that section thickness >10 mm affect the values of acquired cardiac parameters. The slight blurring of real-time images has not evidenced any significant interference on the ventricular function analysis, even making the delineation a little difficult, especially in patients with extra-systoles, as a result of the difficulty in determining systole and diastole in the slices sequence..

The multichannel or integrated parallel imaging techniques (iPAT) have favored the temporal resolution of both sequences, reducing acquisition time, since they utilize simultaneous data acquisition because of variation of MR equipment coil sensitivity.

Lee *et al.*[14] have evaluated cardiac volumes with segmented and real-time TrueFISP sequences, obtaining similar spatial resolution, but they suggest that this similarity could inexist in case of an increase in the patient cardiac frequency. In the present study, real-time and segmented sequences presented different spatial resolutions, but with no statistical significance for volumetric evaluations, even in the 11 patients presenting with irregular cardiac rhythm.

Steady-state sequences present a better contrast resolution because they do not depend on the blood flow and their images formation is based on the relation between T1 and T2 or, more specifically, the tissues composition, differently from FLASH sequences previously utilized to study the heart and which depended on the presence of blood flow to generate cine-MR images.

The present study has utilized steady-state sequences for both for segmented and real-time acquisition methods, facilitating the endocardial contour delineation due the better contrast resolution. With steady-state (TrueFISP), real-time sequences present a lower signal intensity (signal noise)[8]. This fact has been observed in the comparison between short-axis views in both sequences included in our study.

The post-processing analysis of real-time and segmented TrueFISP sequences for endocardial contour delineation is a process that takes considerable time to be accomplished. Segmented sequences took, on average, less time than the real-time sequences, which is explained by the best contras resolution of the first ones. This analysis was extended in cases where patients presented with irregular cardiac rhythm, since the presence of extra-systoles and other arrhythmias complicated the organized disposition of sections for volumetric quantitation by the Simpson's technique. Our data do not indicate a significant difference between parameters obtained, but this analysis was more prolonged, especially for the patients with irregular cardiac rhythm, in agreement with the current literature[9,15–17].

The utilization of a modified Bland-Altman graphic plotting for statistical concordance comparison has not demonstrated any significant variation between ventricular systolic function parameters. The mentioned plotting fitted effectively in the present study, since it compares a gold-standard method, which is closest to real values, with a new method. In the present study, the graphic analysis has shown only two patients with values falling out of the confidence interval for ejection fraction, and only one for EDV and another for ESV, with no common factor between them. This reflects an excellent concordance between sequences.

When separately analyzed, the 11 patients with arrhythmias demonstrated a strong correlation and a good concordance between both sequences, even in the presence of an irregular cardiac rhythm, with only one patient with EDV falling out of the confidence interval. However, a 7 ml increase has been identified in the analysis of EDV in these 11 patients with arrhythmias and of the mean EDV in the study population. This may represent a deterioration of the measurement accuracy due the presence of an irregular cardiac rhythm. The high confidence interval demonstrated by volumetric parameters graphs for EDV is compatible with this parameter variability, and previous studies have demonstrated absence of concordance for both sequences, as explained by Miller *et al.*[12].

Cine-MRI has progressed with potential to become a supplementary method for providing a higher number of data for cardiovascular evaluation. However, cardiac rhythm alterations present in patients with cardiopathy affect the images quality. The present study, comparing TrueFISP segmented sequences (currently the gold-standard in cardiac evaluation) with real-time TrueFISP sequences, has concluded that the latest may be safely utilized for ventricular function assessment and determination, independently from the presence of an irregular cardiac rhythm.

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REFERENCES

1. Higgins CB. What standard has the gold? J Am Coll Cardiol 1992;19:1608–1609.
2. Lladó GP, Costa FC, Beiras AC, *et al*. Guías de práctica clínica de la Sociedad Espanõla de Cardiología en resonancia magnética. Rev Esp Cardiol 2000;53:542–559.
3. Boxt LM. Cardiac MR imaging: a guide for the beginner. RadioGraphics 1999;19:1009–1025.
4. Barkhausen J, Ruhm SG, Goyen M, Buck T, Laub G, Debatin JF. MR evaluation of ventricular function: true fast imaging with steady-state precession versus fast low-angle shot cine MR imaging – feasibility study. Radiology 2001;219:264–269.
5. Bellenger NG, Francis JM, Davies CL, Coats AJ, Pennell DJ. Establishment and performance of a magnetic resonance cardiac function clinic. J Cardiovasc Magn Reson 2000;2:15–20.
6. Lanzer P, Botvinick EH, Schiller NB, *et al*. Cardiac imaging using gated magnetic resonance. Radiology 1984;150:121–127.
7. Sakuma H, Fujita N, Foo TKF, *et al*. Evaluation of left ventricular volume and mass with breath-hold cine MR imaging. Radiology 1993;188: 377–380.
8. Barkhausen J, Goyen M, Ruhm SG, Eggebrecht H, Debatin JF, Ladd ME. Assessment of ventricular function with single breath-hold real-time steady-state free precession cine MR imaging. AJR Am J Roentgenol 2001;178:731–735.
9. Lelieveldt BPF, van der Geest RJ, Lamb HJ, Kayser HWM, Reiber JHC. Automated observer-independent acquisition of cardiac short-axis MR images: a pilot study. Radiology 2001;221:537–542.
10. Manning WJ, Pennell DJ. Cardiovascular magnetic resonance. 1st ed. Philadelphia: Churchill Livingstone; 2002.
11. Kaji S, Yang PC, Kerr AB, *et al*. Rapid evaluation of left ventricular volume and mass without breath-holding using real-time interactive cardiac magnetic resonance imaging system. J Am Coll Cardiol 2001;38:527–533.
12. Miller S, Simonetti OP, Carr J, Kramer U, Finn JP. MR imaging of the heart with cine true fast imaging with steady-state precession: influence of spatial and temporal resolutions on left ventricular functional parameters. Radiology 2002; 223:263–269.
13. Setser RM, Fischer SE, Lorenz CH. Quantification of left ventricular function with magnetic resonance images acquired in real-time. J Magn Reson Imaging 2000;12:430–438.
14. Lee US, Resnick D, Burdy JM, Simonetti OP, Lee P, Weinreb JC. Cardiac function: MR evaluation in one breath hold with real-time true fast imaging with steady-state precession. Radiology 2002; 222:835–842
15. Graves MJ, Dommett DMT. Comparison of cardiac stroke volume measurement determined using stereological analysis of breath-hold cine MRI and phase contrast velocity mapping. Br J Radiol 2000;73:825–832.
16. Lima JAC, Milind Y, Desai MD. Cardiovascular magnetic resonance imaging: current and emerging applications. J Am Coll Cardiol 2004;44: 1164–1671.
17. Sievers B, Brandts B, Franken U, Trappe HJ. Single and biplane TrueFISP cardiovascular magnetic resonance for rapid evaluation of left ventricular volumes and ejection fraction. J Cardiovasc Magn Reson 2004;6:593–600.