

FUNCTION

Single and Biplane TrueFISP Cardiovascular Magnetic Resonance for Rapid Evaluation of Left Ventricular Volumes and Ejection Fraction

**Burkhard Sievers, M.D.,* Bodo Brandts, M.D., Ulrich Franken, M.D.,
and Hans-Joachim Trappe, M.D.**

Department of Cardiology and Angiology, University of Bochum,
Herne, Germany

ABSTRACT

Introduction. Cardiovascular magnetic resonance (CMR) allows very accurate, but time-consuming, volume assessment by the short-axis slice summation technique. The single and biplane methods of volume assessment are used less, partly because FLASH cine imaging provides poor blood-myocardium contrast in long-axis views. TrueFISP gives excellent blood-myocardium contrast, even in patients with heart failure. We hypothesized that the single plane and biplane methods of volume assessment in TrueFISP images might provide an acceptable degree of accuracy and be quicker than the short axis method, and that single and biplane left ventricular volume assessment would be more accurate with TrueFISP than with FLASH in patients with impaired ventricular function. *Methods.* Short- and long-axis CMR images were obtained by FLASH and TrueFISP with a 1.5-T scanner. We determined the accuracy of both single and biplane long-axis methods for left ventricular volume and ejection fraction (EF) measurements compared with the conventional short-axis method in 10 heart failure patients using both FLASH and TrueFISP and in 9 healthy subjects using TrueFISP. *Results.* No difference in volumes and EF was found between the single plane method, the biplane method, and the short-axis method using TrueFISP for image acquisition, in both patients and healthy subjects. The same was

*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@gmx.de.

true of the results obtained by FLASH in the patients with heart failure. *Conclusions.* The single and biplane methods, regardless of whether TrueFISP or FLASH is used, are a reasonable and rapid alternative to the conventional short-axis approach for left ventricular volume and EF assessment in patients with heart failure and impaired ventricular function.

Key Words: Single plane method; Biplane method; TrueFISP; FLASH; Cardiovascular magnetic resonance; Left ventricular volumes; Ejection fraction.

INTRODUCTION

Cardiovascular magnetic resonance (CMR) is currently the most accurate and reproducible technique for the measurement of left ventricular volumes and ejection fraction (EF) (Barkhausen et al., 2001; Bellenger et al., 2000a,b; Grothues et al., 2002; Pattynama et al., 1993; Romminger et al., 1999; Sakuma et al., 1993; Semelka et al., 1990a,b; Shapiro et al., 1989). This is partly due to the image quality but is also related to the fact that, with the short-axis technique, volume measurements can be made without the use of any geometric assumptions about the shape of the left ventricle. However, the short-axis technique is time-consuming, and with the increasing clinical use of CMR, a more rapid but nevertheless accurate method of assessment of left ventricular volumes would be of great value.

The single and biplane methods of volume assessment, while making some mathematical assumptions about ventricular geometry, are standard techniques in x-ray and echocardiographic evaluation of left ventricular function and may be used in CMR. However, gradient-echo cine imaging using FLASH (fast low angle shot) relies on through-plane flow for blood-myocardium contrast and may give poor results in the long axis, particularly if ventricular function is impaired (Fig. 1).

In the course of recent advances in scanner technology, new cine techniques have been introduced. These steady-state free precession (SSFP) sequences (TrueFISP: fast imaging with steady state precession; bFFE: balanced fast field echo imaging; or Fiesta (fast imaging employing steady-state acquisition) (Brown and Semelka, 1999) do not rely on through-plane flow

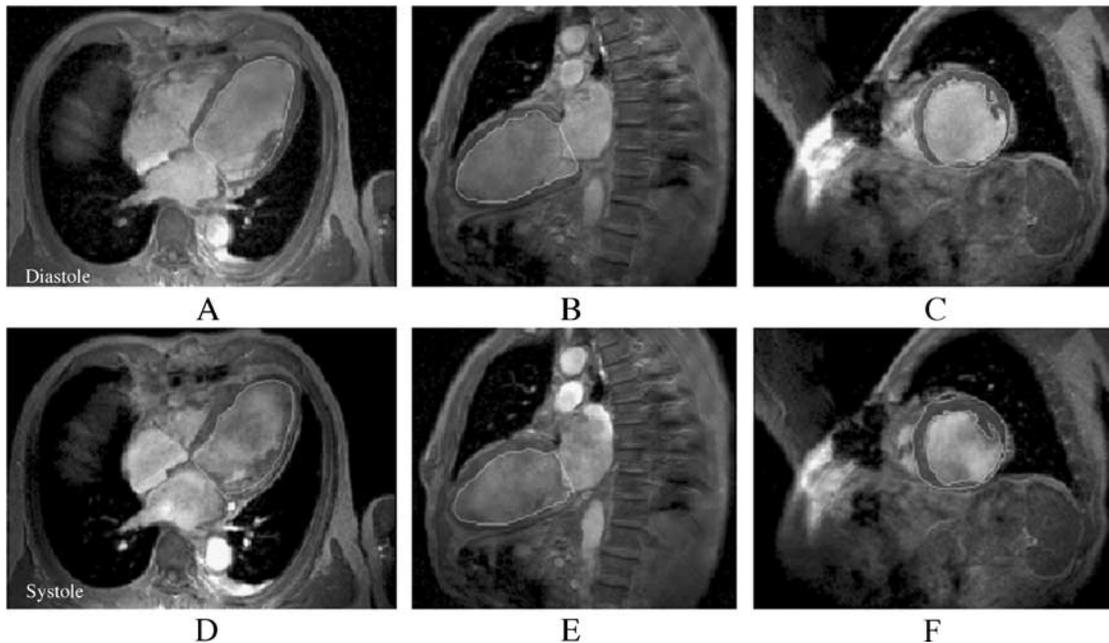


Figure 1. FLASH images from a patient with ischemic cardiomyopathy. Horizontal long axis (A and D), vertical long axis (B and E), and short axis (midventricular slice; C and F) views in end diastole (upper panel) and end systole (lower panel). It is difficult to differentiate between the blood pool and myocardium, especially in end systole (lower panel).

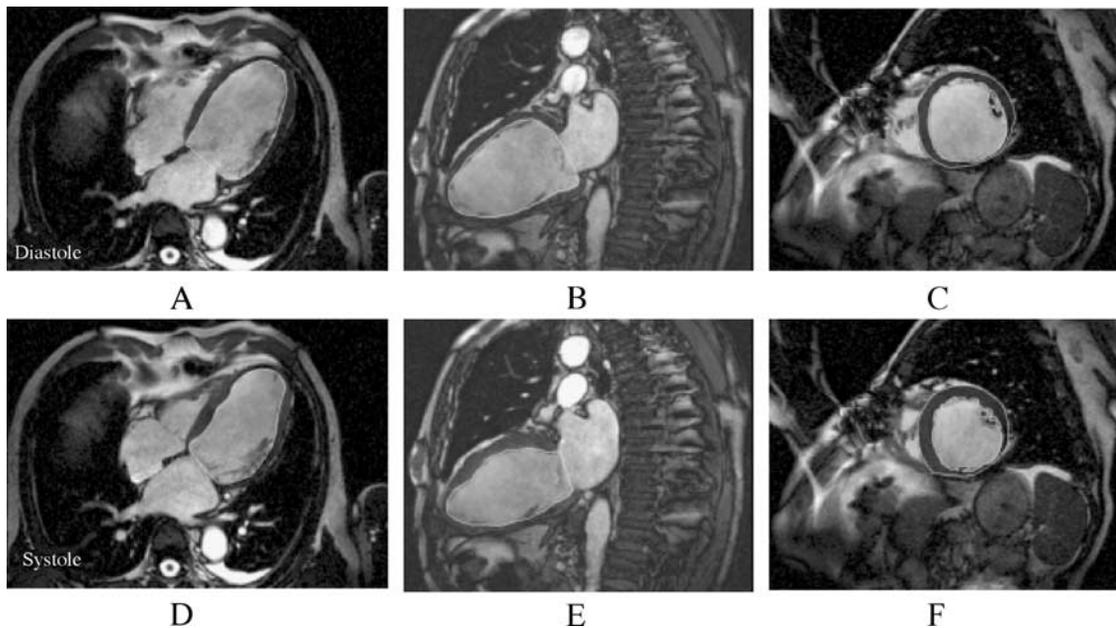


Figure 2. TrueFISP images from a patient with ischemic cardiomyopathy. Same views as in Fig. 1. The endocardial and epicardial borders can easily be differentiated.

for blood-myocardium contrast (Barkhausen et al., 2001; Fig. 2), which is excellent, regardless of ventricular function and slice orientation. We hypothesized that the single plane and biplane methods of volume

assessment in TrueFISP images might provide an acceptable degree of accuracy and be quicker than the short-axis method and that single and biplane left ventricular volume assessment would be more accurate

Table 1. Values for left ventricular end systolic and end diastolic volume and ejection fraction obtained by various approaches (single plane, biplane, and short axis) with different imaging techniques (TrueFISP and FLASH) in patients and healthy subjects.

Technique	EDV (mL)	ESV (mL)	EF (%)
TrueFISP patients (n=10)			
SA	207±68	125±65	41±17
HLA	197±74 (0.24)	113±72 (0.07)	47±20 (0.22)
VLA	208±76 (0.88)	134±90 (0.57)	40±22 (0.65)
HLA+VLA	205±72 (0.92)	125±80 (0.96)	43±19 (0.57)
FLASH patients (n=10)			
SA	199±80	115±63	44±15
HLA	197±71 (0.68)	120±72 (0.57)	43±18 (0.72)
VLA	214±95 (0.20)	134±96 (0.14)	42±20 (0.76)
HLA+VLA	210±81 (0.36)	129±83 (0.17)	42±18 (0.68)
TrueFISP normals (n=9)			
SA	156±39	58±19	63±5
HLA	154±48 (0.44)	55±19 (0.51)	64±4 (0.59)
VLA	161±46 (0.26)	59±23 (0.77)	64±5 (0.55)
HLA+VLA	160±47 (0.47)	58±21 (1.00)	64±4 (0.44)

Abbreviations: EDV = end diastolic volume; ESV = end systolic volume; EF = ejection fraction; HLA = horizontal long axis for single plane method; VLA = vertical long axis for single plane method; VLA + VLA = biplane long axis method; SA = short-axis method.

Data displayed as mean±standard deviation (*p* values of the two-sided Wilcoxon matched-pairs signed-rank test to test the null hypothesis of identical distributions of the parameter measured by the HLA, VLA, and HLA+VLA compared to the standard SA).

Table 2. The *p*-values of the comparisons between TrueFISP and FLASH with respect to volume measurements obtained by various different approaches in patients with heart failure.

	Patients (<i>n</i> = 10)		
	EDV	ESV	EF
SA	0.2026	0.0050	0.2017
HLA	0.7213	0.3326	0.1392
VLA	0.6098	0.7983	0.5738
HLA+VLA	0.4142	0.3586	0.8383

For abbreviations, see Table 1.

The *p* values of the two-sided Wilcoxon matched-pairs signed-rank test.

with TrueFISP than with FLASH in patients with impaired ventricular function.

METHODS

Nine healthy adult volunteers (4 male, 5 female; mean age 32, range 27–44 years) and 10 patients with cardiac failure (7 male, 3 female; 5 with dilated cardiomyopathy and 5 with ischemic dysfunction; mean age 58, range 19–84 years) underwent CMR. All the subjects were informed of the investigational nature of the study and gave written informed consent.

CMR

CMR was performed with a 1.5-Tesla Siemens Sonata scanner (Erlangen, Germany) using TrueFISP (echo time 1.6 ms; repetition time 3.2 ms; flip angle 60°; in plane pixel size 2.3 × 1.4 mm; slice thickness 7 mm; and acquisition in 12 heartbeats) and FLASH (echo time 6.1 ms; repetition time 11 ms; flip angle 20°; in plane pixel size 2.1 × 1.4 mm; slice thickness 7 mm; and acquisition in 15 heartbeats).

Cine images were acquired in a single breath-hold in the short axis (SA) and in the horizontal long axis (HLA) and vertical long axis (VLA) planes. The SA imaging was repeated at 1-cm intervals to cover the left ventricle. The number of cardiac phases per acquisition was 80%–90% of the RR interval divided by the temporal resolution (56 ms with FLASH: 43 ms with TrueFISP). In the 10 patients, both FLASH and TrueFISP gradient-echo images were acquired, but only TrueFISP images were acquired for the 9 healthy volunteers. Values obtained by the standard SA technique from TrueFISP images were taken as the gold standard for left ventricular volume assessment.

Image Analysis

Analysis was performed offline by using commercially available software (ARGUS, Siemens Medical Solutions, Erlangen, Germany) by two experienced

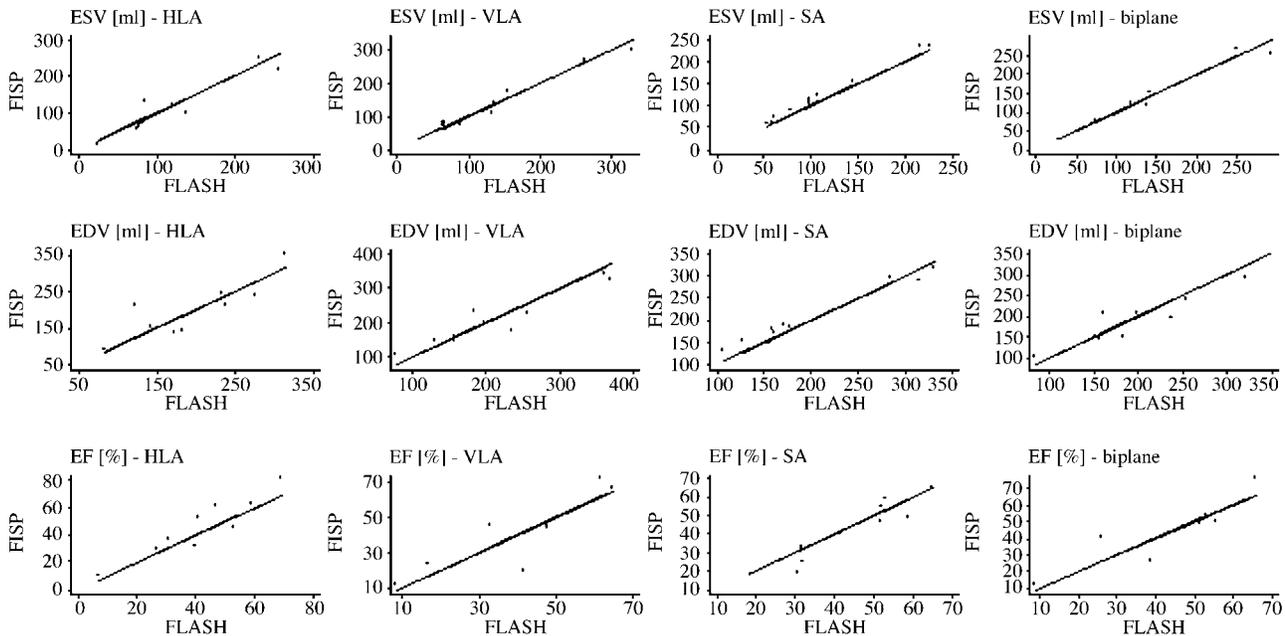


Figure 3. Data displayed as regression plots (TrueFISP vs. FLASH) for identical patients and across the methods.

Table 3. Inter- and intraobserver variability (%) of TrueFISP and FLASH measurements.

	ESV	EDV	EF
Interobserver variability (%)			
HLA	-0.9±5.9 (3.1)	-0.8±2.3 (-1.7)	-0.7±3.1 (1.5)
VLA	-1.4±5.3 (-3.6)	-0.8±2.6 (-2.0)	-0.3±3.8 (1.2)
HLA+VLA	-1.1±5.3 (-2.9)	-0.9±2.5 (-1.7)	-0.1±6.4 (0.9)
SA	-1.0±4.9 (-2.8)	-0.8±2.4 (-1.8)	0.1±3.0 (1.4)
Intraobserver variability (%)			
HLA	-0.4±3.8 (-1.6)	-0.4±1.8 (-0.8)	-0.1±2.8 (0.9)
VLA	-0.6±5.2 (-2.3)	-1.8±9.8 (-1.0)	-1.8±11.5 (0.6)
HLA+VLA	-0.3±5.2 (-1.7)	-0.4±1.8 (-1.0)	-0.6±5.6 (0.7)
SA	-0.8±3.1 (-1.3)	-0.3±1.6 (-0.6)	0.3±2.1 (0.8)

The values are expressed as the means±standard deviation and median (in brackets). For abbreviations, see Table 1.

observers. For the single and biplane methods, the endocardial and epicardial contours were drawn manually in end diastole and end systole in the HLA and VLA views. The ventricular length was measured from the atrioventricular ring to the apex of the left ventricle. End diastolic volume (EDV), end systolic volume (ESV), and EF were calculated by using the area-length method (Simpson’s rule) in the HLA and VLA planes separately (single plane method) and together (biplane method) (Figs. 1A and B), the trabeculae and papillary muscles being included in the ventricular volume. For the short-axis method, the endocardial and epicardial contours were traced from the basal end diastolic and end systolic slice up to the apex of the left ventricle (Fig. 1C) and left ventricular EDV, ESV, and EF computed, the trabeculae and papillary muscles being excluded from the ventricular volume. Analysis could not be performed blind with regard to the acquisition technique because of obvious differences in appearance between the images produced.

To investigate intraobserver variability, the same observer repeated the measurements. To assess inter-observer variability, each observer measured the left ventricular volumes and EF on all data sets independently and unaware of the findings of the other.

Statistical Analysis

The mean and standard deviation were derived for the left ventricular volumes and EF of the healthy subjects and patients obtained by the various methods. Differences between the distribution of TrueFISP and FLASH measurements were analyzed by the two-sided Wilcoxon matched-pairs signed rank test. The single, biplane, and short-axis methods were compared by

using the two-sided Friedman test. A p-value ≤0.05 was considered significant.

RESULTS

The results are summarized in Table 1. The left ventricular volumes and EF obtained by the single and biplane long-axis methods did not differ significantly from those obtained by the short-axis method using TrueFISP for image acquisition in the heart failure patients or normal subjects. The same was true of the results obtained by FLASH in the heart failure patients.

With the exception of ESV calculated by the standard short axis method, no significant difference in the values obtained for left ventricular volumes and EF was found between TrueFISP and FLASH, regardless of the method used (standard short-axis method or area-length method; Table 2).

The regression analysis of the data (TrueFISP vs. FLASH) is displayed as plots in Fig. 3. Reproducibility, as assessed by inter- and intraobserver variability, was excellent for both techniques (Table 3).

DISCUSSION

To our knowledge, the question of whether the single and biplane long-axis methods for the assessment of left ventricular volume and EF in SSFP images from patients with impaired left ventricular function are as reliable as the short-axis method and whether the values are more accurate than those obtained by FLASH has not been examined previously.

Until recently, the gold standard for the evaluation of ventricular volumes and EF was short-axis FLASH,

because of high accuracy and reproducibility with short TE, TR, and acquisition times, excellent spatial resolution, and reasonable temporal resolution (Sakuma et al., 1993). With TrueFISP, the endocardial and epicardial borders can be delineated accurately, even at the ventricular apex in the long axis, because blood-myocardium contrast is greater than with FLASH (Figs. 1 and 2). The mean signal intensity and the mean contrast-to-noise ratio of the left ventricular cavity are significantly better with TrueFISP than with FLASH (Barkhausen et al., 2001). The reasons for this are the dependence on T1/T2 tissue properties and less signal intensity of the sequence from flowing blood (Plein et al., 2001a; Scheffler, 1999). It is likely that voxels at the blood-myocardium border contain myocardium and blood and appear as blood in TrueFISP, due to the bright signal of the blood pool, and as myocardium in FLASH (Ibrahim et al., 1999).

We did not find any significant differences between the values obtained by the long-axis and standard short axis methods with TrueFISP in healthy subjects and patients with heart failure. Our results are consistent with the findings of other authors: Benjelloun et al. (1991) compared the results of the biplane method and the conventional short-axis method in healthy subjects, whereas Schröder et al. (2000) and Lawson et al. (1996) focused on heart failure patients with impaired left ventricular function. All these investigators used FLASH for image acquisition. Lawson et al. (1996) found that the biplane long-axis method gave slightly higher values for EDV in patients with regional ventricular dysfunction, but overall the two methods gave similar results in patients with regional and global ventricular dysfunction. We also found the biplane method to produce slightly higher values for EDV than the short-axis method in FLASH images, but the difference was not significant. Their conclusion was that the biplane method exhibits reasonable accuracy and reproducibility for left ventricular volume assessment.

Single and biplane volume assessment with FLASH is often considered problematic because of the poor blood-myocardium contrast in poorly functioning ventricles, especially in the long axis plane (Fig. 1).

Because TrueFISP provides better blood-myocardium contrast than FLASH, it might be expected to give more accurate values for left ventricular volumes. However, neither the volumes measured by the single plane method nor those determined by the biplane method differed significantly between TrueFISP and FLASH in the patients with heart failure in our study.

Our findings are consistent with data published by Moon et al. (2002), who compared TrueFISP and FLASH for the determination of left ventricular volumes

and EF in patients with heart failure and found a significant difference only in ESV, which was larger with TrueFISP than with FLASH using the standard short-axis method ($p = 0.03$). Like Moon et al., we found the only significant difference between TrueFISP and FLASH to be in left ventricular ESV. Both EDV and ESV obtained by the standard short-axis method were larger with TrueFISP than with FLASH, but the difference in EDV was not significant (Table 1).

Thiele et al. (2002) and Plein et al. (2001b) compared TrueFISP and FLASH in healthy subjects and found higher values for left ventricular EDV and ESV and lower values for left ventricular EF with TrueFISP than with FLASH using the standard short-axis method. Neither of these studies included patients with impaired left ventricular function.

Thiele et al. (2002) concluded that, because of the improved blood-myocardium contrast, TrueFISP is associated with higher accuracy and reproducibility in the assessment of left ventricular volumes and EF in healthy subjects using various different geometric models. In our patients with heart failure, however, the only significant difference between TrueFISP and FLASH lay in ESV as calculated by the short-axis method. With the area-length approach, the values we obtained by TrueFISP were slightly lower than those obtained by FLASH, but the differences were very small and were not of statistical or clinical significance (Table 1). The differences between our findings and those of Thiele et al. might be related to the fact that with FLASH our measurements were obtained by repeated viewing of the cine film to obtain the most accurate delineation of the endocardial border, especially in patients with low blood-myocardium contrast due to impaired ventricular function. It is possible that the extra care taken in this detailed scrutiny could, in fact, have overcompensated for the slightly greater difficulty involved in defining the endocardial border in the FLASH images. However, the reason ultimately remains unclear. The discrepancies may encourage others to address this issue in further studies with a larger number of patients.

The trabeculae and papillary muscles were included in the ventricular volume with the area-length method and excluded with the standard short-axis method. If the trabeculae and papillary muscles were to be taken into account, their volume derived on this basis would be overestimated and the blood volume therefore underestimated. It is difficult and time-consuming to exclude the trabeculae and papillary muscles by delineating them on the long-axis images, and exact delineation is sometimes impossible in long-axis slices obtained by FLASH because of the poor



blood-myocardium contrast. This is also sometimes a problem with TrueFISP. Only the exact delineation of the trabeculae and papillary muscles in the short axis in TrueFISP and FLASH allows exact calculation of the blood volume. However, short-axis volumetric assessment is still very time-consuming.

Automated contour detection would be of great practical value, but it has not yet been perfected and is still unreliable for the analysis of gradient-echo images (Plein et al., 2001b). Manual correction of automatically detected contours often takes as long as drawing the contours manually in the first place. It should also be borne in mind that automated contouring is currently unable to exclude the papillary muscles from the volumes (Baldy et al., 1994; Lalande et al., 1999; Plein et al., 2001b).

Because automated contour detection still has some technical limitations and is not yet commercially available, the single plane and biplane methods, regardless of the gradient-echo sequence used, appear to present a reasonable and rapid alternative to the conventional short-axis approach for left ventricular volume and ejection fraction assessment in daily clinical practise in patients with impaired ventricular function, where accuracy and reproducibility are of major clinical importance.

REFERENCES

Baldy, C., Douek, P., Croisille, P., Magnin, I. E., Revel, D., Amiel, M. (1994). Automated myocardial edge detection from breath-hold cine-MR images: evaluation of left ventricular volumes and mass. *Magn. Reson. Imaging* 12:589–598.

Barkhausen, J., Ruehm, S. G., Goyen, M., Buck, T., Laub, G., Debatin, J. F. (2001). MR evaluation of ventricular function: true fast imaging with steady-state precession versus fast low-angle shot cine MR imaging: feasibility study. *Radiology* 219: 264–269.

Bellenger, N. G., Davis, L. C., Francis, J. M., Coats, A. J. S., Pennell, D. J. (2000a). Reduction in sample size for studies of remodeling in heart failure by the use of cardiovascular magnetic resonance. *J. Cardiovasc. Magn. Reson.* 2:271–278.

Bellenger, N. G., Burgess, M. I., Ray, S. G., Lahiri, A., Coats, A. J., Cleland, J. G., Pennell, D. J. (2000b). Comparison of left ventricular ejection fraction and volumes in heart failure by echocardiography, radionuclide ventriculography and cardiovascular magnetic resonance; are they interchangeable? *Eur. Heart J.* 21:1387–1396.

Benjelloun, H., Cranney, G. B., Kirk, K. A., Blackwell, G. G., Lotan, C. S., Pohorst, G. M. (1991). Interstudy reproducibility of biplane cine nuclear magnetic resonance measurements of left ventricular function. *Am. J. Cardiol.* 67:1413–1420.

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

Grothues, F., Smith, G. C., Moon, J. C., Bellenger, N. G., Collins, P., Klein, H. U., Pennell, D. J. (2002). Comparison of interstudy reproducibility of cardiovascular magnetic resonance with two-dimensional echocardiography in normal subjects and in patients with heart failure or left ventricular hypertrophy. *Am. J. Cardiol.* 90(1): 29–34.

Ibrahim, T., Weniger, M., Schwaiger, M. (1999). Effect of papillary muscles and trabeculae on left ventricular parameters in cine-magnetic resonance images (MRI). *J. Cardiovasc. Magn. Reson.* 1:319.

Lalande, A., Legrand, L., Walker, P. M., Guy, F., Cottin, Y., Roy, S., Brunotte, F. (1999). Automatic detection of left ventricular contours from cardiac cine magnetic resonance imaging using fuzzy logic. *Invest. Radiol.* 34:211–217.

Lawson, M. A., Blackwell, G. G., Davis, N. D., Roney, M., Dell’Italia, L. J., Pohost, G. M. (1996). Accuracy of biplane long axis left ventricular volume determined by cine magnetic resonance imaging in patients with regional and global dysfunction. *Am. J. Cardiol.* 77(12): 1098–1104.

Moon, J. C., Lorenz, C. H., Francis, J. M., Smith, G. C., Pennell, D. J. (2002). Breath-hold FLASH and FISP cardiovascular MR imaging: left ventricular volume differences and reproducibility. *Radiology* 223(3):789–797.

Pattynama, P. M., Lamb, H. J., Van der Velde, E. A., van der Wall, E. E., de Roos, A. (1993). Left ventricular measurements with cine and spin echo MR imaging: a study of reproducibility with variance component analysis. *Radiology* 187: 261–268.

Plein, S., Bloomer, T., Ridgway, J. P., Jones, T. R., Bainbridge, G. J., Sivananthan, M. U. (2001a). Measurements of left ventricular dimensions and function using steady-state free precession imaging: comparison with turbo gradient echo imaging. *Proc. Int. Soc. Magn. Reson. Med.* 9:9.

Plein, S., Bloomer, T. N., Ridgway, J. P., Jones, T. R., Bainbridge, G. J., Sivananthan, M. U. (2001b). Steady-state free precession magnetic resonance

- imaging of the heart: comparison with segmented k-space gradient-echo imaging. *J Magn. Reson. Imaging* 14(3):230–236.
- Rommingner, M. B., Bachmann, G. F., Geuer, M. (1999). Accuracy of the right and left ventricular heart volume and left muscle mass determination with cine MRI in breath holding technique. *Rofo, Fortschr. Geb. Rontgenstrahlen Neuen Bildgeb. Verfahr.* 170:54–60.
- 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* 188:377–380.
- Scheffler, K. (1999). A pictorial description of steady states in rapid magnetic resonance imaging. *Concepts Magn. Reson.* 11:291–304.
- Schröder, A. P., Houliand, K., Pederson, E. M., Nielsen, T. T., Egeblad, H. (2000). Biplane long-axis magnetic resonance imaging. Survey projections for rapid estimation of left ventricular mass and global function. *SCJ, Scand. Cardiovasc. J.* 35(6):385–393.
- Semelka, R. C., Tomei, E., Wagner, S., Mayo, J., Kondo, C., Suzuki, J., Caputo, G. R., Higgins, C. B. (1990a). Normal left ventricular dimensions and function: interstudy reproducibility of measurements with cine MR imaging. *Radiology* 174:763–768.
- Semelka, R. C., Tomei, E., Wagner, S., Mayo, J., Caputo, G., O’Sullivan, M., Parmley, W. W., Chatterjee, K., Wolfe, C., Higgins, C. B. (1990b). Interstudy reproducibility of dimensional and functional measurement between cine magnetic resonance imaging studies in the morphologically abnormal left ventricle. *Am. Heart J.* 119:1367–1373.
- Shapiro, E. P., Rogers, W. J., Beyar, R., Soulen, R. L., Zerhoumi, E. A., Lima, J. A., Weiss, J. L. (1989). Determination of left ventricular mass by MRI in hearts deformed by acute infarction. *Circulation* 79:706–711.
- Thiele, H., Paetsch, I., Schnackenburg, B., Bornstedt, A., Grebe, O., Wellnhofer, E., Schuler, G., Fleck, E., Nagel, E. (2002). Improved accuracy of quantitative assessment of left ventricular volume and ejection fraction by geometric models with steady-state free precession. *J. Cardiovasc. Magn. Reson.* 4(3):327–339.

Request Permission or Order Reprints Instantly!

Interested in copying and sharing this article? In most cases, U.S. Copyright Law requires that you get permission from the article's rightsholder before using copyrighted content.

All information and materials found in this article, including but not limited to text, trademarks, patents, logos, graphics and images (the "Materials"), are the copyrighted works and other forms of intellectual property of Marcel Dekker, Inc., or its licensors. All rights not expressly granted are reserved.

Get permission to lawfully reproduce and distribute the Materials or order reprints quickly and painlessly. Simply click on the "Request Permission/Order Reprints" link below and follow the instructions. Visit the [U.S. Copyright Office](#) for information on Fair Use limitations of U.S. copyright law. Please refer to The Association of American Publishers' (AAP) website for guidelines on [Fair Use in the Classroom](#).

The Materials are for your personal use only and cannot be reformatted, reposted, resold or distributed by electronic means or otherwise without permission from Marcel Dekker, Inc. Marcel Dekker, Inc. grants you the limited right to display the Materials only on your personal computer or personal wireless device, and to copy and download single copies of such Materials provided that any copyright, trademark or other notice appearing on such Materials is also retained by, displayed, copied or downloaded as part of the Materials and is not removed or obscured, and provided you do not edit, modify, alter or enhance the Materials. Please refer to our [Website User Agreement](#) for more details.

[Request Permission/Order Reprints](#)

Reprints of this article can also be ordered at

<http://www.dekker.com/servlet/product/DOI/101081JCMR120038081>