Published in final edited form as:
Int J Cardiovasc Imaging. 2012 June ; 28(5): 995–1001. doi:10.1007/s10554-011-9915-1.

Right Ventricular Volume Analysis by Angiography in Right Ventricular Cardiomyopathy

Julia H. Indik, MD, PhD[1], **William J. Dallas, PhD**[2], **Kathleen Gear, RN**[1], **Harikrishna Tandri, MRCP (UK)**[3], **David A. Bluemke, MD, PhD**[4], and **Frank I. Marcus, MD**[1]

[1]Sarver Heart Center, University of Arizona, Tucson, Arizona [2]Department of Radiology, University of Arizona, Tucson AZ [3]Johns Hopkins University School of Medicine, Baltimore, Maryland [4]Radiology and Imaging Sciences, National Institutes of Health Clinical Center, and National Institute for Biomedical Imaging and Bioengineering, Bethesda, Maryland

Abstract

Introduction—Imaging of the right ventricle (RV) for the diagnosis of arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D) is commonly performed by echocardiography or magnetic resonance imaging (MRI). Angiography is an alternative modality, particularly when MRI cannot be performed. We hypothesized that RV volume and ejection fraction computed by angiography would correlate with these quantities as computed by MRI.

Methods and Results—RV volumes and ejection fraction were computed for subjects enrolled in the North American ARVC/D Registry, with both RV angiography and MRI studies. Angiography was performed in the 30° right anterior oblique (RAO) and 60° left anterior oblique (LAO) views. Angiographic volumes were computed by RAO view and two-view (RAO and LAO) formulae. 17 subjects were analyzed (11 men and 6 women), with 15 subjects classified as affected, and 2 as unaffected by modified Task Force criteria. The correlation coefficient of MRI to the two-view angiographic analysis was 0.76 for end-diastolic volume and 0.79 for ejection fraction. Angiographically derived volumes were larger than MRI derived volume ($p=0.006$) and with the slope in a linear relationship equal to 0.8 for end diastolic volume, and 0.9 for RV ejection fraction ($p<0.001$), computed by the two view formula. The RAO view formula was significantly related to the MRI derived quantities, but with lower correlation coefficients (0.36 for volume and 0.73 for ejection fraction).

Conclusion—End-diastolic volume and ejection fraction of the RV can be obtained by angiography and correlates with these quantities as obtained by MRI.

Keywords

cardiomyopathy; right ventricle; magnetic resonance imaging; angiography; right ventricular volume

Introduction

Imaging of the right ventricular (RV) to detect abnormal function and/or structural changes of this chamber is a key element in the diagnosis of ARVC/D (1). Generally, 2-D echocardiography (echo) or Magnetic Resonance Imaging (MRI) are selected to evaluate the right ventricle since these techniques are non invasive and readily available (2,3,4).

Corresponding Author: Julia H. Indik, MD, PhD, Sarver Heart Center, The University of Arizona College of Medicine, 1501 N. Campbell Ave. Tucson, AZ 85724-5037, Phone: 520-626-1416, Fax: 520-626-4333, jindik@email.arizona.edu.

However the irregular shape of the RV makes it difficult to assess the presence of minor abnormalities of this chamber. In particular, it is difficult to distinguish minor wall motion abnormalities from normal by all of the imaging methods. It has been shown that there is considerable lack of agreement of interpretation of RV imaging studies by physicians at referring centers as compared to those of expert core laboratory investigators (5). Also, even multiple aneurysms may not be detected by echocardiography (6). For ARVC/D patients, RV angiography is typically performed in conjunction with biopsy, and as a confirmation of noninvasive imaging results for RV function and structure. It is thus of interest to determine what correlation is present between quantitative analysis of RV using invasive and noninvasive approaches.

RV volume analysis by angiography has been reported previously and validated by RV cast post mortem (7, 8, 9, 10) The present study was done to compare angiographic RV volumes and RVEF calculated by a computer based program (11, 12) by single or dual plane projections (30° RAO and 60° LAO) or both with right ventricular volumes and ejection fraction determined in the same17 patients with ARVC/D by MRI. Quantitative analysis of RV volume and ejection fraction by MRI was selected as the standard of reference since the excellent accuracy of MRI for these parameters is well established (13). We found that there was a good correlation between RV volumes and RV ejection fractions assessed by either single plane 30° RAO or 60° LAO projection or both.

Methods

Patient Population

Patients were enrolled in the North American ARVC/D Registry as part of the Multidisciplinary Study of Right Ventricular Cardiomyopathy/Dysplasia (5) The design of this study, including core laboratories in the United States and Europe, has been previously described (14). Patients were 12 years or older with newly diagnosed ARVC/D, and classified as affected, borderline or not affect by the principal investigator of the Multidisciplinary Study (FM) using the original Task Force Criteria (15) Patients were also classified as affected or unaffected based on modified task force criteria (1). All subjects provided signed informed consent, per institutional review board approvals.

Patients were evaluated by standardized tests including a 12 lead ECG, signal averaged ECG, 24 hour Holter monitor, electrophysiologic study for the induction of ventricular tachyarrhythmias and RV free wall biopsy. Imaging studies included echocardiography, magnetic resonance imaging (MRI) and RV angiography. Testing was performed according to protocols, available at the website www.arvd.org.

Calculation of RV volumes and Ejection Fraction

MRI was performed according to previously described methods (16). Right ventricular volumes were computed (inner cavity) from axial cine images at the RV inflow level. Volumes were calculated by summation of volumes from individual image slices, using Simpson’s rule. Qmass software (Media, The Netherlands) was used for this analysis.

For calculation of angiographic volumes, the thirty-degree right anterior oblique (RAO) and sixty-degree left anterior oblique (LAO) views were utilized. A cardiac cycle was analyzed that had good contrast opacification of the right ventricle and not immediately proceeded by a premature ventricular contraction. The diastolic and systolic images were selected, and a contour drawn (Figure 1). The area within the contour was then calculated. The length-scale was calibrated by measuring the projected size of the magnified angiocatheter shaft within the right ventricle, which was either a pigtail 5Fr catheter or Berman 6 or 7 Fr catheter, to allow an accurate and reproducibly consistent measurement. The right ventricular volume

was then assessed by using both the RAO and LAO projections ($V_{TWO-VIEW}$) or by using the RAO projection alone (V_{RAO}).

$V_{TWO-VIEW}$ was calculated according to the model by Ferlinz (10) as

$$V_{TWO-VIEW} = 0.6^{*} A_{RAO}{}^{*} A_{LAO} / L_{RAO} + 3.9\,(mL), \quad \text{(eq. 1)}$$

where A_{RAO} was the projected area within the drawn contour in the RAO view, A_{LAO} was the projected area in the LAO view, and L_{RAO} was the projected distance in the RAO view from the pulmonic valve to the point that bisected the inferior wall (see Figure 1).

The ejection fraction was then computed as follows:

$$RVEF_{TWO-VIEW} = (V_{TWO-VIEW-DIA} - V_{TWO-VIEW-SYS}) / V_{TWO-VIEW-DIA}, \quad \text{(eq. 2)}$$

where $V_{TWO-VIEW-DIA}$ was the volume computed at end diastole and $V_{TWO-VIEW-SYS}$ was the volume computed at end systole of the chosen cardiac cycle by equation 1.

Using the RAO view alone the volume was calculated as (8):

$$V_{RAO} = (0.4^{*} A_{RAO}{}^{*} A_{RAO} / L_{RAO} + 3.9)^{*} 0.88 + 7.71\,mL \quad \text{(eq. 3)}$$

The ejection fraction was then computed using the RAO computed volumes at end-diastole and end – systole as follows

$$RVEF_{RAO} = (V_{RAO-DIA} - V_{RAO-SYS}) / V_{RAO-DIA}, \quad \text{(eq. 4)}$$

where $V_{RAO-DIA}$ was the volume computed at end-diastole and $V_{RAO-SYS}$ was the volume computed at end-systole of the chosen cardiac cycle, by the RAO volume formula (eq. 3). Body surface area (BSA) was computed and all volumes were adjusted for BSA.

Statistics

Data is presented as mean ± standard deviation. Correlation was assessed between MRI derived volumes and ejection fraction and angiographically derived volumes and ejection fraction by a Pearson correlation coefficient. A regression analysis was performed between MRI and angiographically derived volumes and ejection fraction, with the intercept forced to zero. A paired T test was performed to assess the difference in mean volumes computed by angiography or MRI. The p value was set to 0.05 for significance.

Results

A total of 17 subjects (11 men and 6 women) from the North American ARVC/D Registry had adequate MRI and angiography studies that were suitable for this analysis. The range of ages of subjects was 16 to 64 years, with a mean of 43 years. Of the 17 subjects, 9 were classified as affected, 7 as borderline and 1 as unaffected, by original Task Force criteria (15) and 15 subjects as affected and 2 subjects as unaffected by the modified Task Force criteria (1).

Computed volumes and ejection fraction by MRI and angiography, using the two-view and RAO view formulae are shown in Table 1. Using the two-view formula, MRI and angiography showed a high correlation with a correlation coefficient of 0.76 for volume and

0.79 for ejection fraction. For the RAO view formula the correlation coefficient compared to MRI was 0.36 for volume and 0.73 for ejection fraction.

The angiographic two view end-diastolic volume, $V_{TWO\text{-}VIEW\text{-}DIA}$, was larger than the MRI derived end diastolic volume, (mean ± SEM of 118 ± 12 versus 92 ± 9 ml/m^2, p=0.006).

We found the following relationship by linear regression between two-view angiographically and MRI derived end-diastolic volumes (Figure 2a):

$$V_{MRI-DIA}/BSA = V_{TWO-VIEW-DIA}/BSA * 0.8, \text{ with } P<0.001.$$

The two-view angiographically derived ejection fraction ($RVEF_{TWO\text{-}VIEW}$) was related to the MRI derived ejection fraction by the following linear relationship (Figure 2b):

$$RVEF_{MRI} = RVEF_{TWO-VIEW} * 0.9, \text{ with } P<0.001.$$

For the RAO view angiographically derived end-diastolic volume we found the following linear relationship to MRI (Figure 3a):

$$V_{MRI-DIA}/BSA = V_{RAO-DIA}/BSA * 0.9, \ (P<0.001),$$

and for the RAO view angiographically derived ejection fraction the following relationship was found (Figure 3b):

$$RVEF_{MRI} = RVEF_{RAO} * 0.8, \text{ with } P<0.001.$$

Discussion

This study demonstrates that RV volume and RVEF can be accurately determined by RV angiography, in particular for abnormal hearts for patients with ARVD. The present study using a computer based program is consistent with the good correlation reported from similar analysis with a commercial software program (17, 18). This data when combined with the previous report of computer analysis of wall motion using our computer based system allows an accurate assessment of wall motion, right ventricular volume, RVEF and RV from angiography. RV angiography can be done in conjunction with an EP study or RV biopsy; therefore it may not require an additional procedure. We found the best correlation to MRI for the two-view (RAO and LAO) angiographically derived volume and ejection fraction, but a single view (RAO) derived volume and ejection fraction were also correlated. Angiographically derived volumes were generally larger than MRI derived volumes.

When doing a right ventricular angiogram it is important to avoid inducing premature ventricular beats by positioning the catheter near the apex but not touching the right ventricular muscle. Proper positioning of the catheter can be tested following a hand injection of contrast dye before the rapid infusion in order to sure that PVCs are not induced and to indicate that the inferior portion of the right ventricle particularly the apex is well visualized. When analyzing the angiograms it is important not to evaluate right ventricular contraction for at least 2 beats after a PVC episode. Analysis of right ventricular function by angiography is in close agreement with the data obtained by MRI in the same 17 patients with ARVC/D; therefore this technique can be used for assessment of imaging abnormalities for the assessment of ARVC/D.

Acknowledgments

This study was supported by grant U01-HL65594 from the National Heart, Lung, and Blood Institute, Bethesda, Maryland.

References

1. Marcus FI, McKenna WJ, Sherrill D, Basso C, Bauce B, Bluemke DA, Calkins H, Corrado D, Cox MGPJ, Daubert JP, Fontaine G, Gear K, Hauer R, Nava A, Picard MH, Protonotarios N, Saffitz JE, Yoerger Sanborn DM, Steinberg JS, Tandri H, Thiene G, Towbin JA, Tsatsopoulou A, Wichter T, Zareba W. Diagnosis of arrhythmogenic right ventricular cardiomyopathy/dysplasia. Proposed modification of the Task Force Criteria. Circulation. 2010:121. In press. [PubMed: 21191093]
2. Yoeger D, Marcus F, Sherrill D, Calkins H, Towbin JA, Zareba W, Picard MH. Echocardiographic findings in patients meeting Task Force Criteria for arrhythmogenic right ventricular dysplasia. J Am Coll Cardiol. 2005; 45:860–865. [PubMed: 15766820]
3. Tandri H, Macedo R, Callkins H, Marcus F, Cannom D, Scheinman M, Daubert J, Estes M, Wilber D, Talajic M, Duff H, Krahn A, Sweeney M, Garan H, Bluemke DA. Role of magnetic resonance imaging in arrhythmogenic right ventricular dysplasia: Insights from the North American arrhythmogenic right ventricular dysplasia (ARVD/C) study. Am Heart J. 2008; 155:147–153. [PubMed: 18082506]
4. Jain A, Tandri H, Calkins H, Bluemke DA. Role of cardiovascular magnetic resonance imaging in arrhythmogenic right ventricular dysplasia. J Cardiovasc Magnetic REsosnance. 2008; 10:32.
5. Marcus FI, Zareba W, Calkins H, Towbin JA, Basso C, Bluemke DA, Estes M III, Picard MH, Sanborn D, Thiene G, Wichter T, Cannom D, Wilber DJ, Scheinman M, Duff H, Daubert J, Talajic M, Krahn A, Sweeney M, Garan H, Sakaguchi S, Lerman BB, Kerr C, Kron J, Steinberg JS, Sherrill D, Gear K, Brown M, Severski P, Polonsky S, McNitt S. Arrhythmogenic right ventricular cardiomyopathy/dysplasia and diagnostic evaluation: results from the North American Multidisciplinary Study. Heart Rhythm. 2009; 6:984–992. [PubMed: 19560088]
6. Ly S, Marcus FI, Xu T, Towbin JA. A woman with incidental findings of ventricular aneurysms and a desmosomal cardiomyopathy. Heart Rhythm. 2008; 5:1455–1457. [PubMed: 18672408]
7. Baudouy M, Guivarch JC, Guarino L, Gibelin P, Camous JP, Leborgne L. Methode d'exploitation infromatique de la cine-angiographie du ventricule droit. Arch Mal Coeur. 1985; 3:386–392. [PubMed: 3923969]
8. Ferlinz J. Measurements of right ventricular volume in man from single plane cineangiograms. Am Heart J. 1977; 94:87–90. [PubMed: 868748]
9. Boak JG, Bove AA, Kreulen T, Spann JF. A geometric basis for calculation of right ventricular volume in man. Catheter Cardiovasc Diagn. 1977; 3:217–230.
10. Ferlinz J, Gorlin R, Cohn PF, Herman MV. Right ventricular performance in patients with coronary artery disease. Circulation. 1975; 52:608. [PubMed: 1157272]
11. Indik JH, Wichter T, Gear K, Dallas WJ, Marcus FI. Quantitative assessment of angiographic right ventricular wall motion in arrhythmogenic right ventricular dysplasia cardiomyopathy (ARVD/C). J Cardiovasc Electrophysiol. 2008; 19:39–45. [PubMed: 17900252]
12. Indik JH, Dallas WJ, Ovitt T, Wichter T, Gear K, Marcus FI. Do patients with right ventricular outflow tract ventricular arrhythmias have a normal right ventricular wall motion? Cardiology. 2005; 104:10–15. [PubMed: 15942177]
13. Sechtem U, Pflugfelder PW, Gould RG, Cassidy MM, Higgins CB. Measurements of right and left ventricular volume in healthy individuals with Cine MR imaging. Radiology. 1987; 163:697–702. [PubMed: 3575717]
14. Marcus F, Towbin J, Zareba W, Moss A, Calkins H, Brown M, Gear K. for the ARVD/C Investigators. Arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARVD/C) a multidisciplinary study: Design and protocols. Circulation. 2003; 107:2975–2978. [PubMed: 12814984]
15. McKenna WJ, Thiene G, Nava A, Fontaliran F, Blomstrom-Lundquist C, Fontaine G. Camerini Fon behalf of the Europen Society of Cardiology and ofthe Scientific Council on Cardiomyopathies of the International Society and Federation of Cardiology. Diagnosis of

arrhythmogenic right ventricular dysplasia/cardiomyopathy. Task Force of the Working Group Myocardial and Pericardial Disease of the European Society of Cardiology and of the Scientific Council on Cardiomyopathies of the International Society and Federation of Cardiology. Br Heart J. 1994; 71:215–218. [PubMed: 8142187]

16. Tandri H, Friedrich MG, Calkins H, Bluemke DA. MRI of arrhythmogenic right ventricular cardiomyopathy/Dysplasia. J Cardiovascular Magnetic Resonance. 2004; 6:557–563.
17. Wellnhofer E, Ewert P, Hug J, Hui W, Kretschmar O, Chavengsuk D, Kuhne T, Abdul-Khaliq H, Nagel E, Lange PE, Fleck E. Evaluation of new software for angiographic determination of right ventricular volumes. Int J of Cardiovasc Imaging. 2005; 21:575–585. [PubMed: 16322915]
18. Ector J, Ganame J, van der Merwe N, Adriaenssens B, Pison L, Willems R, Gewillig M, Heidbuchel H. Reduced right ventricular ejection fraction in endurance athletes presenting with ventricular arrhythmias: a quantitative angiographic assessment. Eur Heart J. 2007; 28:345–353. [PubMed: 17242015]

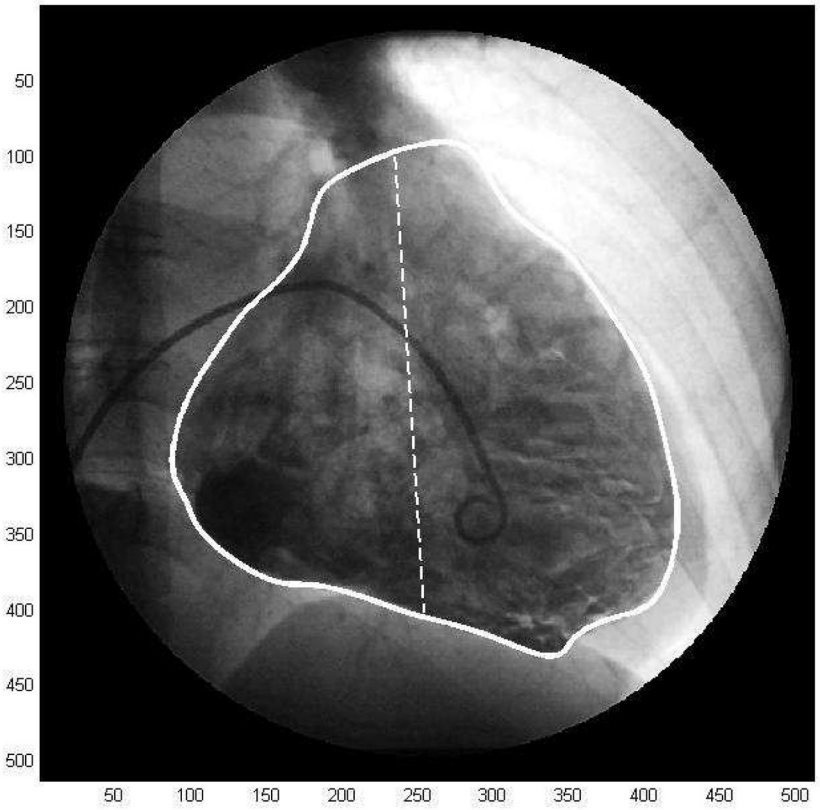

Figure 1a

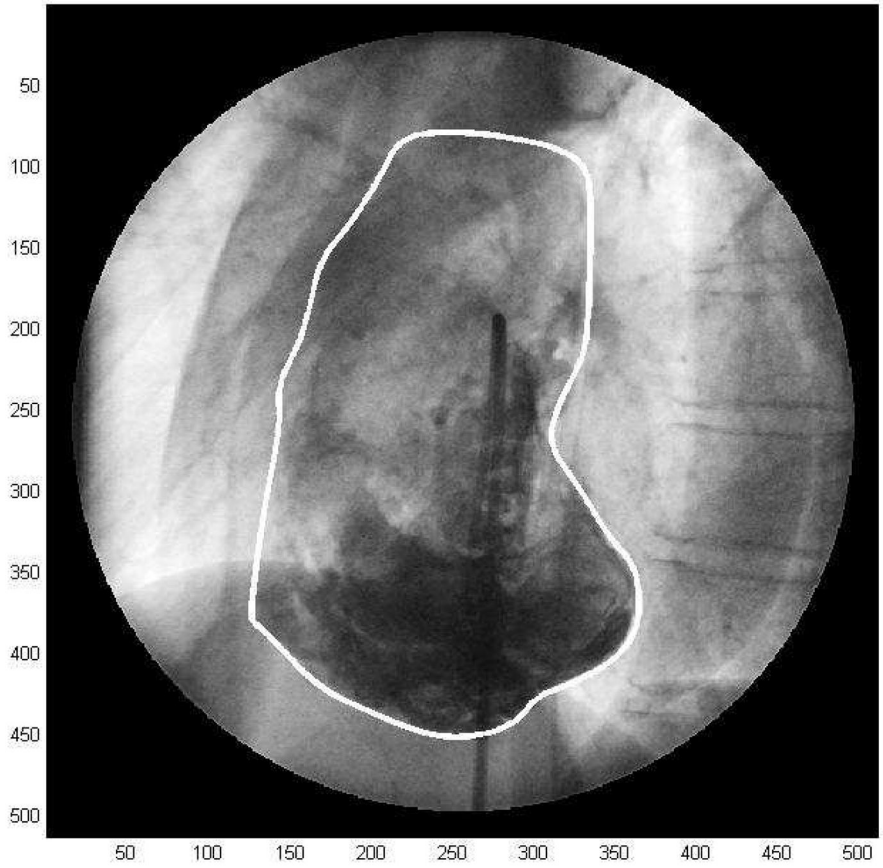

Figure 1b

Figure 1.

Angiographic image of the end-diastolic frame in the 30 degree right anterior oblique (RAO) view (a) and 60 degree left anterior oblique (LAO) view. A contour is drawn around the projected area in each view, and the length in the RAO view is measured (dashed line) from the pulmonic valve to the bisected inferior wall.

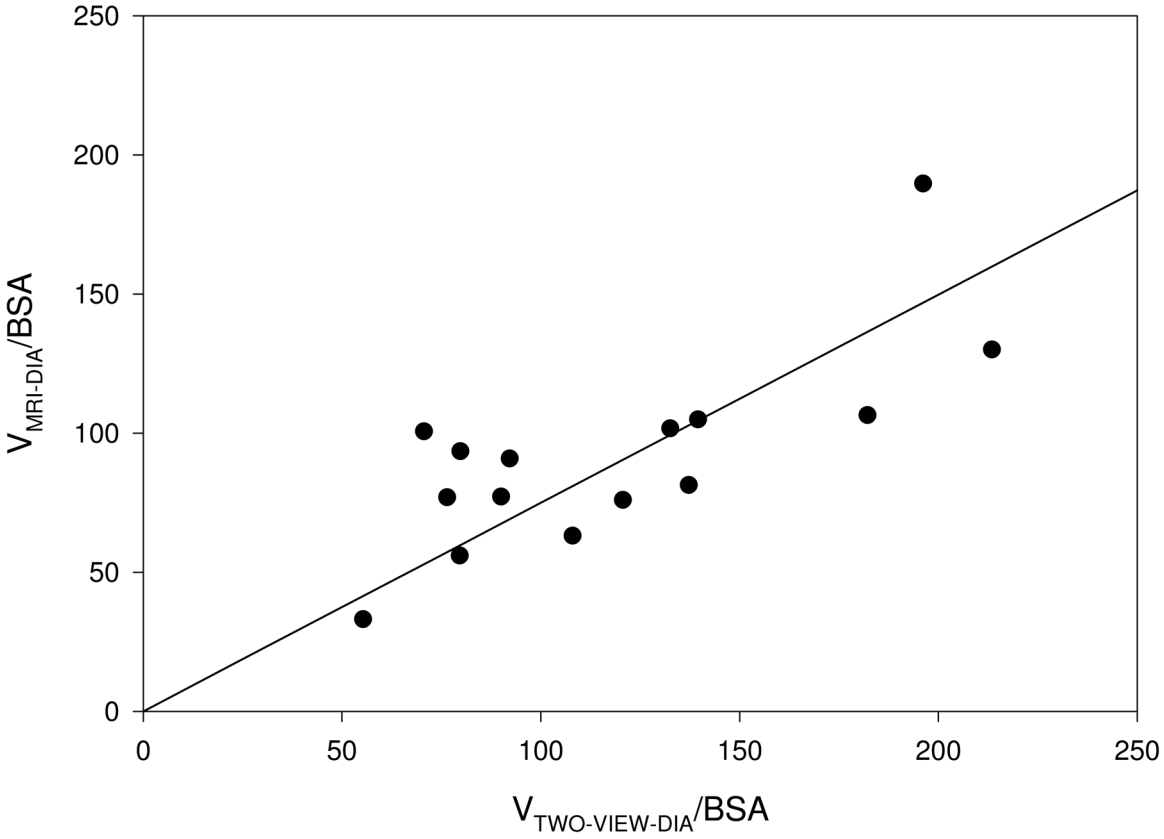

Figure 2a

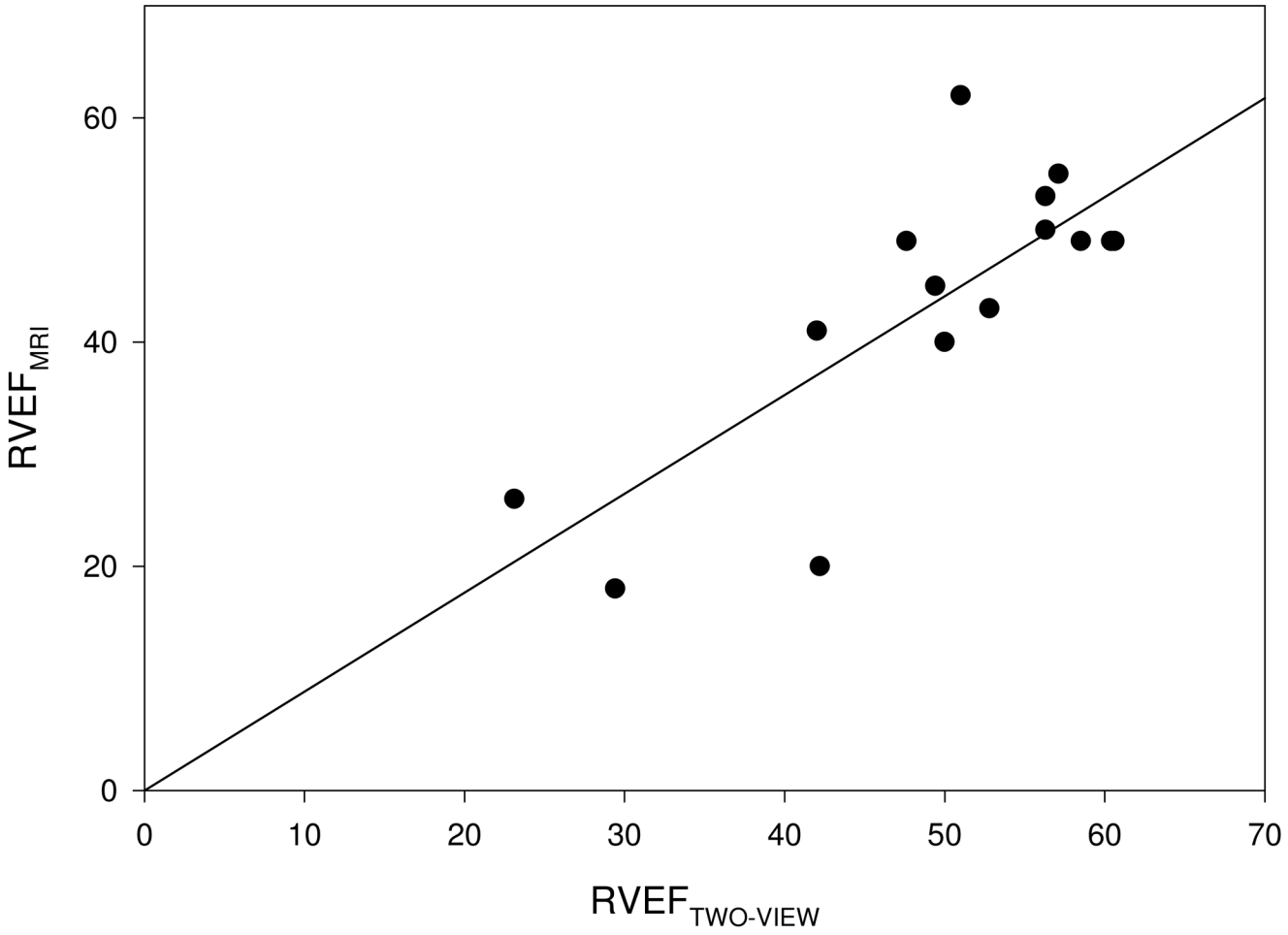

Figure 2b

Figure 2.
Comparison of MRI derived and angiographically derived end diastolic volume divided by body surface area (a) and ejection fraction (b), using the two-view angiographic formula (equations 1 and 2). There was a high correlation of both volumes and ejection fraction between angiography and MRI, with linear regression showing a significant relationship ($P<0.001$ for both volumes and ejection fraction, see text).

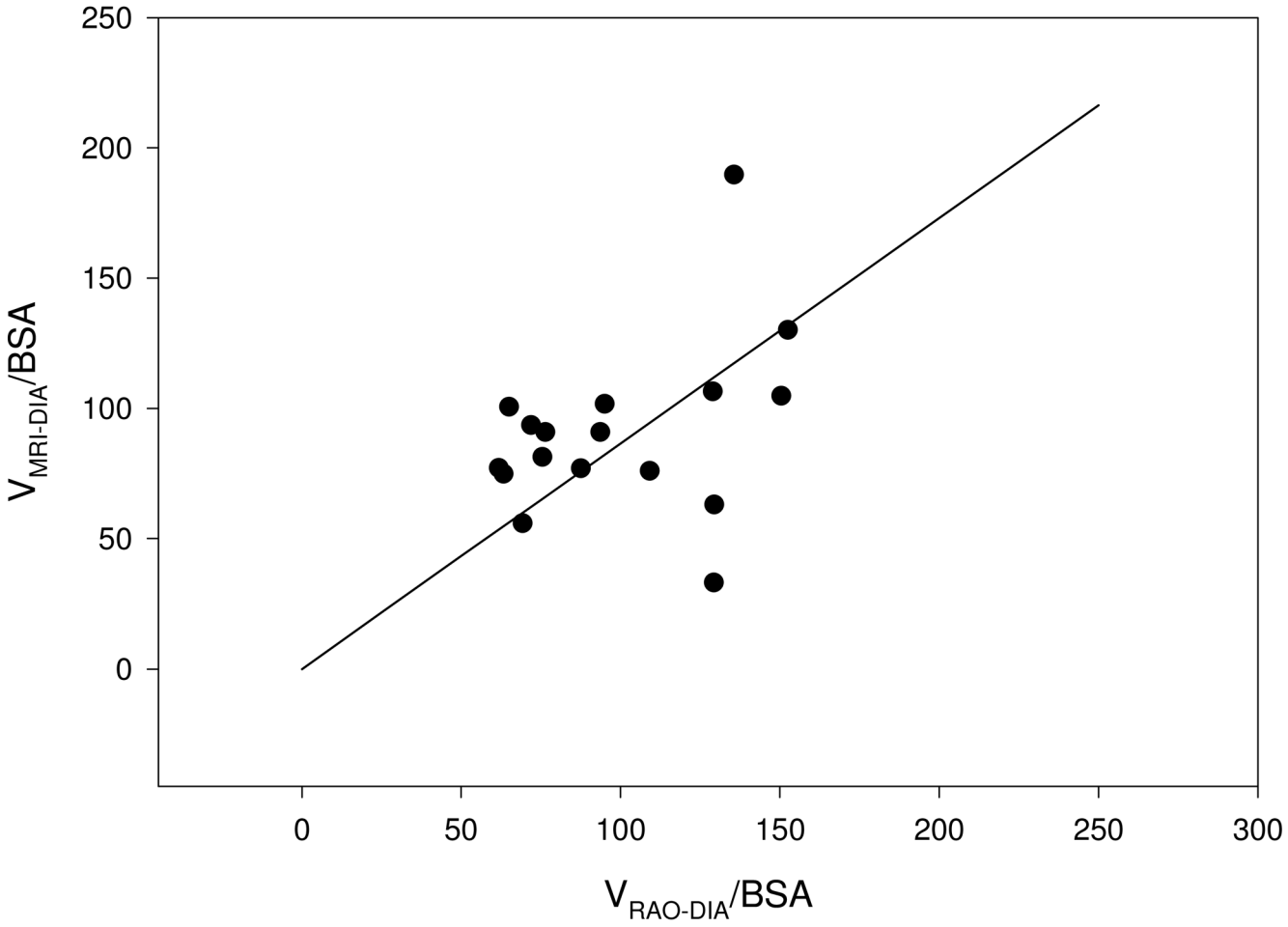

Figure 3a

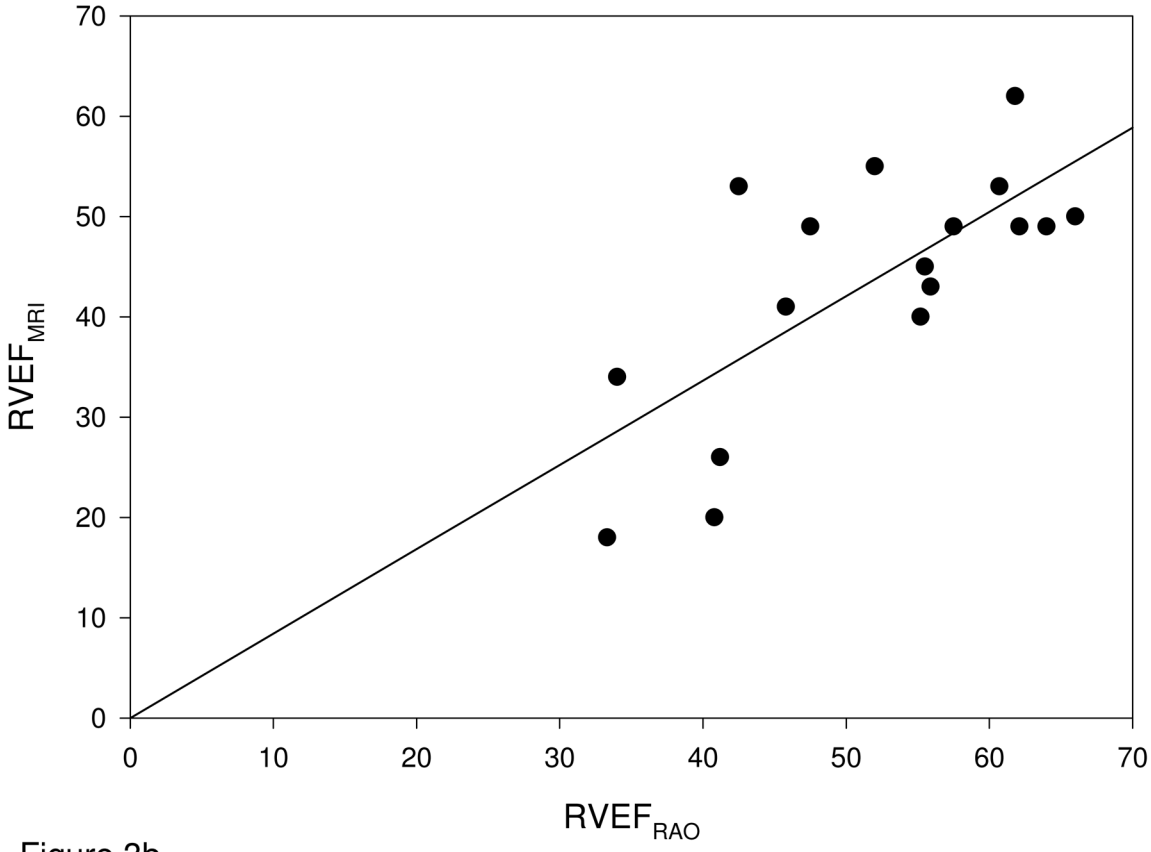

Figure 3b

Figure 3.
Comparison of MRI derived and angiographically derived end diastolic volume divided by body surface area (a) and ejection fraction (b), using the RAO angiographic formula (equations 3 and 4). By linear regression there was a significant relationship between angiographically derived and MRI derived volumes and ejection fraction ($P<0.001$ for both volumes and ejection fraction, see text for details).

Table 1

MRI and Angiographically Derived End-Diastolic Volume and Ejection Fraction*

Subject	Gender	Age at enrollment	Angio $RVEF_{RAO}$ (%)	Angio $RVEF_{TWO-VIEW}$ (%)	MRI $RVEF_{MRI}$ (%)	Angio $V_{RAO-DIA}$/BSA (ml/m^2)	Angio $V_{TWO-VIEW-DIA}$/BSA (ml/m^2)	MRI $V_{MRI-DIA}$/BSA (ml/m^2)
1	Male	48	52	57.1	55	69.3	79.6	55.9
2	Male	54	66	56.3	50	129.5	108.0	63.1
3	Male	61	45.8	42	41	109.2	120.7	76.0
4	Male	59	33.3	29.4	18	135.6	196.2	189.6
5	Male	23	40.8	42.2	20	95.1	132.6	101.7
6	Male	45	34		34	93.7		90.9
7	Male	26	42.5		53	63.3		74.9
8	Female	16	55.5	49.4	45	150.5	139.6	104.8
9	Female	21	55.2	50.0	40	71.9	79.8	93.5
10	Male	46	41.2	23.1	26	152.6	213.5	130.0
11	Male	64	61.8	51.0	62	87.6	76.5	76.9
12	Male	63	57.5	58.5	49	75.5	137.2	81.3
13	Male	43	60.7	56.3	53	76.4	92.2	90.8
14	Female	36	47.5	47.6	49	61.8	90.0	77.1
15	Female	47	64	60.4	49	129.3	55.3	33.1
16	Female	46	62.1	60.6	49	129.0	182.2	106.4
17	Female	32	55.9	52.8	43	65.0	70.6	100.6

*BSA = body surface area; RVEF = right ventricular ejection fraction; $V_{RAO-DIA}$ = end diastolic volume from the RAO view; $V_{TWO-VIEW-DIA}$ = end diastolic volume from the LAO and RAO views; $V_{MRI-DIA}$ = end diastolic volume from MRI