European Journal of Echocardiography (2009) **10**, 499–502
doi:10.1093/ejechocard/jen315

EUROPEAN SOCIETY OF CARDIOLOGY®

Two-dimensional strain and strain rate imaging of the right ventricle in adult patients before and after percutaneous closure of atrial septal defects

Smita R. Jategaonkar[1], Werner Scholtz[1]*, Thomas Butz[2], Nikola Bogunovic[1], Lothar Faber[1], and Dieter Horstkotte[1]

[1]*Department of Cardiology, Heart and Diabetes Center North Rhine-Westphalia, Ruhr University Bochum, Georgstrasse 11, D-32545 Bad Oeynhausen, Germany; and* [2]*Marienhospital Herne, Germany*

Received 19 August 2008; accepted after revision 16 November 2008; online publish-ahead-of-print 20 January 2009

KEYWORDS
Atrial septal defect;
Percutaneous closure;
Strain rate imaging;
Two-dimensional strain

Aims Echocardiographic speckle tracking or two-dimensional (2D) strain analysis is a new tool to assess myocardial function. This prospective controlled study evaluates systolic right ventricular (RV) function by 2D strain in adult patients with atrial septal defect (ASD) before and 3 months after percutaneous closure.
Methods and results Assessment of global longitudinal strain (GLS), global longitudinal strain rate (GLSR), and regional peak systolic strain (PSS) of right ventricle was performed in 33 ASD patients. The data were compared with those from 34 age-matched adults with patent foramen ovale. Before percutaneous closure, mean GLS was significantly increased in comparison to control group, and significantly reduced after closure. Analysis of regional PSS showed significant decrease in the lateral apical, lateral mid, and septal apical segments. GLSR was not influenced by ASD closure.
Conclusion Two-dimensional strain appears to be helpful also for the assessment of RV function and its response to correction of volume overload.

Introduction

Novel echocardiographic methods have been developed to quantify global and regional left ventricular (LV) function. Its major importance for diagnostic and prognostic evaluation in various cardiovascular diseases is well established. In contrast, quantitative assessment of right ventricular (RV) function is still challenging due to its complex anatomy and thin wall structure, and therefore not incorporated into daily clinical practice. However, its assessment is becoming of increasing interest in certain cardiac diseases that affect the right ventricle, e.g. pulmonary hypertension, pulmonary stenosis, atrial, or ventricular septal defects.[1] Myocardial function is traditionally assessed by visual estimation of wall motion, ventricular volumes, and calculation of ejection fraction (EF). Echocardiographic assessment of RV-EF is difficult and underlies several limitations.[2] In addition, tissue-Doppler-based techniques allow for quantification of myocardial function. Myocardial strain is a dimensionless index of tissue deformation expressed as a fraction or per cent change. Myocardial lengthening gives a positive and myocardial shortening a negative strain value. Strain rate (SR) measures the local rate of deformation per time unit. Strain and SR imaging so far was hitherto on tissue-Doppler techniques.[3,4]

Two-dimensional (2D) strain and SR analyses are novel Doppler-independent techniques to obtain these measurements of myocardial movement and deformation.[5] Standard grey scale images are analysed with a dedicated software package that focuses on specific speckle patterns and follows them on a frame-by-frame basis during a cardiac cycle. While this method has been frequently used to assess LV function,[6] it has yet rarely been used to examine RV function. Since RV function is an important prognostic factor in patients with congenital heart disease, the objective of the present study was to quantify RV function in patients with chronic RV volume overload due to an atrial septal defect (ASD) before and after its percutaneous closure. Additionally, these data were compared with RV function parameters in 34 age-matched patients with isolated patent foramen ovale (PFO), which were otherwise healthy and hence considered suitable as control group.

* Corresponding author. Tel: +49 5731 97 1258; fax: +49 5731 97 2194.
E-mail address: wscholtz@hdz-nrw.de

Methods

Patients

Patients with ASDs admitted to our centre for percutaneous closure between September 2005 and March 2007 were included in this prospective controlled study. Overall, 33 consecutive patients (20 women and 13 men, mean age 44.7 $\pm$ 18.5) were prospectively enrolled into the study after giving their informed consent. Clinical indication for ASD closure was haemodynamically significant left-to-right shunt ($>$40% of pulmonary blood flow) or echocardiographic signs of right heart dilation or shunt related symptoms. None of them had a previous stroke. Thirty-four age-matched adults with PFO and otherwise no signs of structural heart disease were also enrolled prospectively after obtaining informed consent. Echocardiography was performed on the day before and 3 months after percutaneous closure of the ASD.

Echocardiographic examination

Echocardiographic examinations were performed according to the ASE guidelines[7] using an ultrasound system (Vivid 7, General Electric, Horten, Norway) equipped with a multifrequency transducer and tissue harmonic imaging capability. Standard echocardiography included parasternal long, parasternal short, apical four-chamber, apical three-chamber, and apical two-chamber views. One cardiac cycle of each view was stored in cineloop format with a frame rate of 40–80 Hz. LV and RV end-diastolic diameters and left atrial diameters were registered by M-mode in the parasternal long-axis view. For assessment of systolic RV function, we measured tricuspid annular plane systolic excursion (TAPSE) by conventional M-mode, strain, and SR. Strain and SR analysis using customized computer software (EchoPAC, Vingmed, General Electric, Horten, Norway) was performed offline. In the apical four-chamber view, the endocardium of the right ventricle was manually drawn in end-systole, thereafter the endocardial borders were automatically tracked throughout the cardiac cycle. The RV myocardium was then automatically divided into six segments (basal, mid, and apical segment of the septum and the RV free wall). Once approved by the reading analyst, the software displayed longitudinal strain [peak systolic strain (PSS)] and SR for the respective segments and the global longitudinal strain (GLS) and global longitudinal strain rate (GLSR) (*Figure 1*).

Atrial septal defect closure

Percutaneous closure of the ASD was performed under local anaesthesia utilizing fluoroscopic and multiplane transoesophageal echocardiographic (TEE) guidance. Shunt volumes were determined oxymetrically prior to ASD closure. Native and balloon-stretched (stop-flow technique) diameters of the ASD were measured by TEE and Amplatzer ASD occluders (AGA Medical Corp., Golden Valley, MN, USA) of suitable sizes were implanted. Post-interventional treatment included 100 mg/d of acetylsalicylic acid for 6 months, and 75 mg/d of clopidogrel for 2 months. Three months after closure, all patients were re-examined echocardiographically including a contrast TEE (Echovist –300, Bayer Schering) for detection of residual shunting.

Statistics

Statistical analysis was carried out with the SPSS statistical package (Version 14.0; SPSS Inc.). In the following sections, continuous variables are expressed as mean and SD after checking for normality of distribution. Intra- and inter-observer variability was calculated as absolute difference between the two measurements in per cent of their mean.

Differences between baseline and follow-up were analysed by the paired sample *t*-test. Differences between study and control group

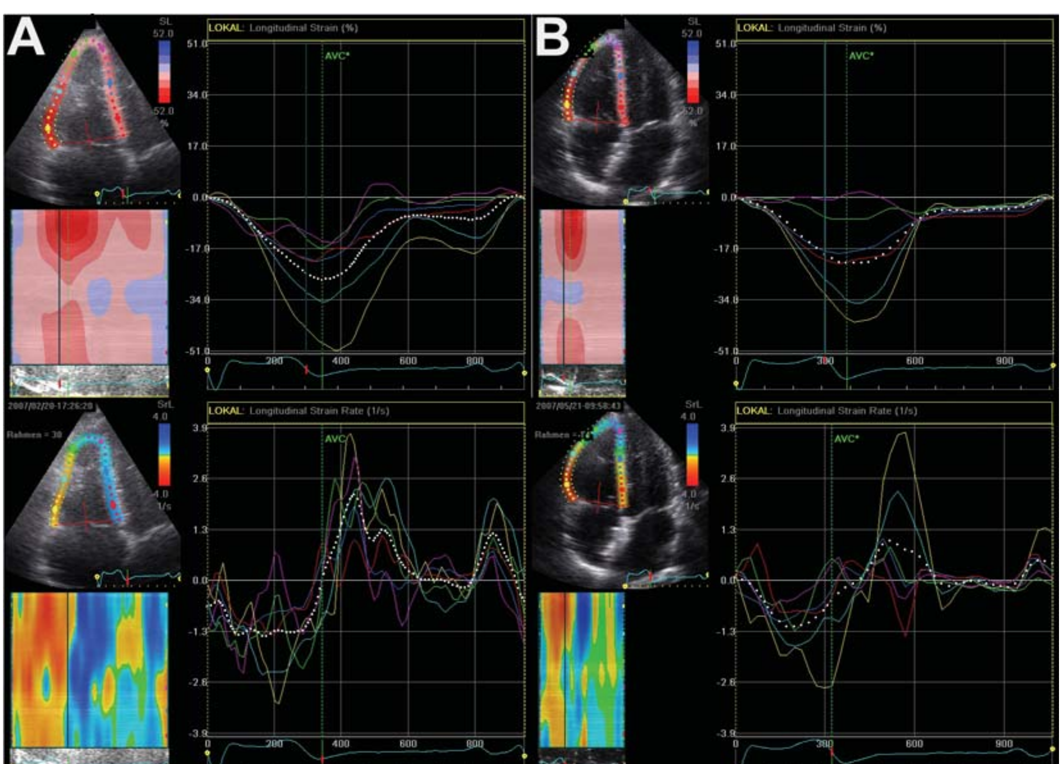

Figure 1 Global and regional strain imaging. Example of a two-dimensional strain (above) and strain rate (below) measurement of the right ventricle in a patient with atrial septal defect before (*A*) and after (*B*) percutaneous closure. Apical four-chamber view is shown. Red, dark blue, and lilac curves represent septal segments. Yellow, light blue, and green curves represent the lateral basal, mid, and apical segments. The dotted curve is the global longitudinal strain and strain rate.

were analysed by unpaired t-test. A P-value <0.05 was considered statistically significant.

Results

Patient characteristics, clinical, and haemodynamic data for study and the control groups are listed in *Table 1*. The mean native defect diameter was 15.2 ± 5.3 mm and the stretched diameter was 18.9 ± 5.2 mm. The mean shunt volume was $51.3 \pm 11.7\%$ of the pulmonary blood flow. Percutaneous ASD closure was performed successfully in all 33 patients. After 3 months, complete occlusion of the ASD was demonstrated by TEE in 31 patients, insignificant residual shunting through the device in colour flow Doppler was detected in two patients (6%). The baseline characteristics by standard echocardiographic measurements are given in *Table 2*, and the PSS of the six segments and global SR are listed in *Table 3*.

Compared with the matched control groups, RV end-diastolic diameters were significantly larger and decreased significantly after ASD closure (36.4 ± 8.9 vs. 29.3 ± 7 mm, $P < 0.05$). LV diameters (45.0 ± 6.6 vs. 49.8 ± 5.5 mm, $P < 0.05$) increased significantly after the intervention, whereas LA diameters (41.0 ± 6.9 vs. 42.1 ± 7.4 mm, n.s.) remain unchanged. TAPSE decreased significantly (21.5 ± 9.0 vs. 18.7 ± 6.1 mm, $P < 0.05$) (*Table 2*).

Global longitudinal strain of the right ventricle was significantly higher than in the control group (-23.4 ± 4.5 vs. $-21.4 \pm 4.3\%$, $P < 0.05$). After interventional closure of the defect, we observed a significant reduction of the global RV strain and the PSS of the lateral mid, the lateral apical, and the septal apical segment. There was no significant change in the global RV SR (*Figure 2*). As expected, intra-observer variability ($4.8 \pm 3.4\%$ for GLS and $6.5 \pm 4.4\%$ for SR) was lower than for inter-observer variability ($6.2 \pm 4.3\%$ for GLS and $10.4 \pm 7.9\%$ for SR).

Table 1 Characteristics of atrial septal defect patients and healthy control subjects

	ASD	Control group
Gender (male/female)	13 /20	21/13
Age (years)	44.7 ± 18.5	46.8 ± 9.2
Height (cm)	171 ± 9.8	177 ± 7.7
Weight (kg)	77.6 ± 15.4	80 ± 15.2
Native ASD diameter (mm)	15.2 ± 5.3	–
Stretched ASD diameter (mm)	18.9 ± 5.2	–
Shunt volume (% of pulmonary blood flow)	51 ± 12	–
PA pressure (mean, mmHg)	19.9 ± 5.2	$15.1. \pm 4.1$
LA pressure (mean, mmHg)	9.3 ± 3.3	7.0 ± 3.4

Table 2 Echocardiographic diameters and TAPSE (tricuspid annulus plane systolic excursion) in the control group and in atrial septal defect patients before and 3 months after closure

	Control group	ASD		P-value
		Pre	Post	
LA (mm)	38.5 ± 5.0	41.0 ± 6.9	42.1 ± 7.4	n.s.
RVEDD (mm)	25.6 ± 3.9	36.4 ± 8.9	29.3 ± 7	<0.05
LVEDD (mm)	52.6 ± 5.3	45.0 ± 6.6	49.8 ± 5.5	<0.05
TAPSE (mm)	18.6 ± 6.4	21.5 ± 9.0	18.7 ± 6.1	<0.05

Discussion

Quantification of the RV function is an important prognostic factor especially in patients with intracardiac shunts or other RV diseases. Transthoracic echocardiography is the most frequently used technique for routine examination of RV function. However, defining by visual assessment of RV is limited in practice. This paper is the first study to use 2D strain and SR analysis for the assessment of the systolic RV function in adult patients with RV volume overload secondary to ASDs and change after percutaneous ASD closure.

To our knowledge, no reference values have been defined for strain and SR of the right ventricle by 2D strain until now. Several papers[8,9] have presented normal values of myocardial velocity, strain, and SR derived by tissue-Doppler imaging (TDI). These are comparatively higher than the values of the control group in the present study that may be explained by the different approach of calculation by 2D strain and TDI. TDI measures deformation rate and derives strain by integration, whereas 2D strain measures deformation (strain) directly. Another influence on the normal values may be that the control group consisted of PFO patients whom we considered to be otherwise healthy.

The end-diastolic RV diameters decreased significantly after ASD closure by abolishment of the left-to-right shunt. The consecutive improvement of LV filling resulted in an increase in LV end-diastolic diameter. This study demonstrates that patients with chronic RV volume overload due to an ASD have increased strain values when compared with age-matched healthy adults. The increased myocardial strain values return to normal after ASD closure. Accordingly, we observed a significant reduction of the TAPSE as well. The global strain of the RV also includes the three septal segments that include RV as well as LV fibres. Though its change was statistically significant after ASD closure, the parameter does not represent the pure RV function. For assessment of the RV function, the changes in lateral segments are more important and have been shown to be significant in the mid and apical lateral segments.

Cardiac remodelling is an early post-interventional effect and appears during the first months after ASD closure,[10,11] so a 3-month follow-up period seems to be sufficient to reflect the major part of remodelling of the right ventricle.

Other studies have assessed RV function under various loading conditions. Increased afterload created by partial pulmonary artery constriction and reduced preload created by inferior vena cava occlusion both resulted in a significant decreased strain.[12] Further studies showed that patients with increased afterload due to pulmonary arterial hypertension have an impaired RV function with lower strain values in comparison to control subjects which increase after medical vasodilator therapy.[13,14]

Study limitations

In theory, myocardial strain and SR can be measured in all dimensions (longitudinal, radial, and circumferential). We only quantified the longitudinal strain and SR assuming that the contraction of the right ventricle is predominantly

Table 3 Global, regional peak right ventricular strain (%) and global right ventricular strain rate (1/s) in control group and in atrial septal defect patients before and 3 months after percutaneous closure

	Control group	Pre	Post	*P*-value
Global strain	−21.6 ± 4.9	−23.4 ± 4.5	−21.4 ± 4.3	<0.05
Lateral basal	−28.7 ± 8.8	−28.2 ± 9.8	−25.7 ± 7.7	n.s.
Lateral mid	−28.6 ± 7.8	−29.4 ± 7.7	−26.6 ± 6.3	<0.05
Lateral apical	−23.6 ± 7.6	−27.0 ± 6.7	−24.3 ± 6.4	<0.05
Septal apical	−15.7 ± 7.7	−21.2 ± 7.4	−17.9 ± 7.1	<0.05
Septal mid	−17.9 ± 3.7	−20.2 ± 4.7	−18.7 ± 4.8	n.s.
Septal basal	−18.7 ± 3.5	−18.5 ± 3.8	−17.7 ± 4.6	n.s.
Global strain rate	−1.11 ± 0.18	−1.25 ± 0.18	−1.23 ± 0.20	n.s.

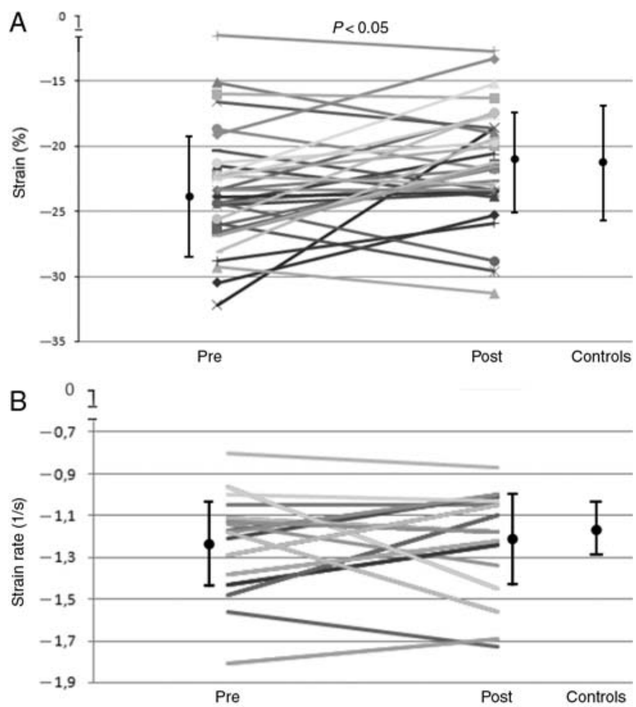

Figure 2 Global systolic strain (*A*) and global systolic strain rate (*B*) of the right ventricle before and after percutaneous atrial septal defect closure and their comparison with normal controls.

longitudinal. This partial approach, however, does not image the complex 3D RV contraction. Especially in situations where volume and/or pressure overload exists, the RV contraction may become more complex and tortuous. In this study, only one cardiac cycle is analysed and therefore some beat-to-beat and respiratory variations may be source of sample error.

In the present study, the 2D strain analysis software that was originally designed for the left ventricle was applied to the right ventricle assuming that the algorithm can be transferred. Further studies about reproducibility and feasibility are necessary to validate this method.

Conclusion

Two-dimensional strain and SR measurements are a novel approach to quantitatively assess myocardial wall motion, which can also be applied to the right ventricle. This method allows exact and objective assessment of global and regional myocardial function. Volume overload is associated with increased strain values, which return to normal after abolishment of the volume overload. SR seems to be less dependent on load of the right ventricle.

Conflict of interest: none declared.

References

1. Dambrauskaite V, Delcroix M, Claus P, Herbots L, D'hogge J, Bijnens B *et al*. Regional right ventricular dysfunction in chronic pulmonary hypertension. *J Am Soc Echocardiogr* 2007;**20**:1172–80.
2. Jiang L. Right ventricle. In: Weyman AE eds. Baltimore, MD: Lippincott Williams & Wilkins; 1994. p901–21.
3. Heimdal A, Stoylen A, Torp H, Skjaerpe T. Real-time strain rate imaging of the left ventricle by ultrasound. *J Am Soc Echocardiogr* 1998;**11**:1013–9.
4. Marwick T. Measurement of strain and strain rate by echocardiography. Ready for prime time? *J Am Coll Cardiol* 2006;**47**:113–27.
5. Perk G, Tunick PA, Kronzon I. Non-Doppler two-dimensional strain imaging by echocardiography—from technical considerations to clinical applications. *J Am Soc Echocardiogr* 2007;**20**:234–43.
6. Leitman M, Lysyansky P, Sidenko S, Shir V, Peleg E, Binenbaum M *et al*. Two-dimensional strain—a novel software for real-time quantitative echocardiographic assessment of myocardial function. *J Am Soc Echocardiogr* 2004;**17**:1021–9.
7. Cheitlin MD, Armstrong WF, Aurigemma GP, Beller GA, Bierman FZ, Davis JL *et al*. ACC/AHA/ASE 2003 guideline update for the clinical application of echocardiography: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASE Committee to Update the 1997 Guidelines for the Clinical Application of Echocardiography). 2003. American College of Cardiology Web Site. Available at: www.acc.org/clinical/guidelines/echo/index.pdf.
8. Kowalski M, Kukulski T, Jamal F, D'Hooge J, Weidemann F, Rademakers F *et al*. Can natural strain and strain rate quantify regional myocardial deformation? A study in healthy subjects. *Ultrasound Med Biol* 2001;**27**:1087–97.
9. Kjaegaard J, Sogaard P, Hassager C. Quantitative echocardiographic analysis of the right ventricle in healthy individuals. *J Am Soc Echocardiogr* 2006;**19**:1365–72.
10. Thilén U, Persson S. Closure of atrial septal defect in adult. Cardiac remodeling is an early event. *Int J Cardiol* 2006;**108**:370–5.
11. Bettencourt N, Salomé N, Carneiro F, Gonçalves M, Ribeiro J, Braga JP *et al*. Atrial septal closure in adults: surgery versus amplatzer—comparison of results. *Rev Port Cardiol* 2003;**22**:1203–11.
12. Jamal F, Bergerot C, Argaud L, Loufouat J, Ovize M. Longitudinal strain quantitates regional right ventricular contractile function. *Am J Physiol Heart Circ Physiol* 2003;**285**:H2842–H2847.
13. Borges AC, Knebel F, Eddicks S, Panda A, Schattke S, Witt C *et al*. Right ventricular function assessed by two-dimensional strain and tissue Doppler echocardiography in patients with pulmonary arterial hypertension and effect of vasodilator therapy. *Am J Cardiol* 2006;**98**:530–4.
14. Pirat B, McCulloch ML, Zoghbi WA. Evaluation of global and regional right ventricular systolic function in patients with pulmonary hypertension using a novel speckle tracking method. *Am J Cardiol* 2006;**98**:699–704.