Journal of Cardiology 60 (2012) 145–149

Contents lists available at SciVerse ScienceDirect

Journal of Cardiology

journal homepage: www.elsevier.com/locate/jjcc

Original article

Myocardial strain of the left ventricle in normal children

Yuko Sato (MD, PhD), Asami Maruyama (MD), Ko Ichihashi (MD, PhD, FJCC)*

Department of Pediatrics, Saitama Medical Center of Jichi Medical University, 1-847 Amanuma, Omiya, Saitama 330-8503, Japan

ARTICLE INFO

Article history:
Received 15 March 2011
Received in revised form 14 January 2012
Accepted 20 January 2012
Available online 5 April 2012

Keywords:
Myocardial strain
Children
Echocardiography

ABSTRACT

Background: There have been few reports regarding cardiac strain in children. The present study was performed to determine the reference values for circumferential and radial strains of the left ventricle in normal children and discern the relative influence of aging and cardiac growth on these left ventricular functional indices.

Methods: The study population consisted of 180 children (aged 2 months to 21 years) who had normal cardiac function and normal cardiac load. None of the patients had symptoms, and none was receiving medical therapy. 2D cine-loop recordings of short-axis views at the papillary muscle level were stored for off-line analysis. Custom acoustic-tracking software was used to measure left ventricular strain. Continuous variables are reported as mean values ± standard deviation. The correlation coefficients were calculated to identify the relative influences of aging on the strains. Tukey's test was used to assess differences in strain among the six-myocardial segments. In all analyses, $p < 0.01$ was taken to indicate statistical significance.

Results and conclusions: The strains of all segments could be analyzed in 136 of 180 children. There were no significant age-related changes in circumferential or radial strain in children, but regional heterogeneity in left ventricular strain. The circumferential and radial strains showed inverse distributions; the circumferential strain in the region with low radial strain was high, and that in the region with high radial strain was low. These observations indicated there are differences among the three-dimensional movements of the regions.

Introduction

Two-dimensional (2D) strain imaging by speckle tracking echocardiography, in contrast to tissue Doppler strain imaging, is angle-independent, and thus permits determination of all three (longitudinal, radial, and circumferential) strain components. These strains were measured in normal adults and data are available for adult patients with several cardiac diseases [1–3]. However, there have been few reports regarding cardiac strain in children [4].

The present study was performed to determine the reference values for circumferential and radial strains of the left ventricle in normal children, and to identify the relative influences of aging and cardiac growth on these left ventricular functional indices.

Methods

The study population consisted of 180 children (102 males and 78 females, aged 2 months to 21 years), including 62 cases of innocent heart murmur, 32 cases of benign chest pain, 31 cases of infrequent premature atrial contractions, 28 cases of natural closure of atrial septal defect, and 27 cases of infrequent premature ventricular contraction. All of them were judged to have normal cardiac function and normal cardiac load on echocardiac routine examination (the parameters of conventional echocardiography including end-diastolic and end-systolic dimensions, fractional shortening, and left ventricular ejection fraction were normal). None of the patients had symptoms, and none was receiving medical therapy. Their heart rates ranged from 51 to 150/min (84 ± 20/min).

All the patients were imaged in the supine position using a commercial ultrasound system (Vivid 7; GE Healthcare, Milwaukee, WI, USA). 2D cine-loop recordings of short-axis views at the papillary muscle level were stored for off-line analysis.

Custom acoustic-tracking software that allowed semiautomated strain analysis was used (EchoPac Advanced Analysis Technologies; GE Healthcare). This software utilizes B-mode grayscale images and tracks movement of stable acoustic patterns/markers, called speckles, in myocardial tissue. This tracking takes place frame by frame throughout the cardiac cycle [5]. The software is interactive, in that the endocardial-cavity interface is traced manually, while automated generation of a second epicardial tracing is created by the software.

* Corresponding author. Tel.: +81 48 647 2111; fax: +81 48 648 5188.
E-mail address: koichihashi@jichi.ac.jp (K. Ichihashi).

0914-5087/$ – see front matter
doi:10.1016/j.jjcc.2012.01.015

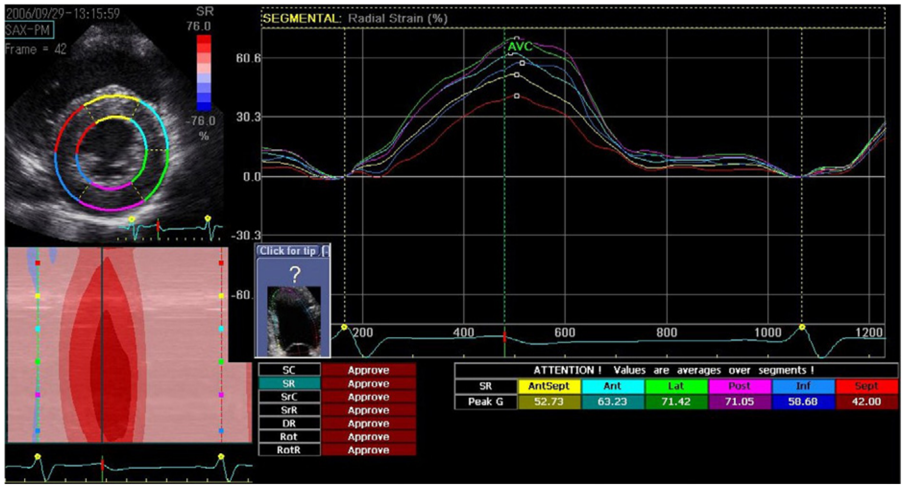

Fig. 1. Regions of interest (left) and graphic depiction of individual values of the mean transmural radial strain in a representative subject. AntSep, anteroseptal; Ant, anterior; Lat, lateral; Post, posterior; Inf, inferior; Sep, septal.

The software automatically divides the image into six segments (anteroseptal, anterior, lateral, posterior, inferior, and septal), provides automated tracking confirmation, and generates the strain values for each segment based on the spatial and temporal shift of the corresponding acoustic markers (Fig. 1).

Segments with poor image quality were rejected by the software and excluded from the analysis. The strains of all segments could be analyzed in 136 of 180 children, and data from these 136 children were included in this study.

Continuous variables are reported as mean values ± standard deviation (SD). The correlation coefficients were calculated to identify the relative influences of aging on the strains. Tukey's test was used to assess differences in strain among the six myocardial segments. In all analyses, $p < 0.01$ was taken to indicate statistical significance.

Interobserver variability was determined as the mean of differences between 10 paired strain measurements for each of the 6 segments in circumferential and radial modalities. Intraobserver variability was defined as the mean of differences between 1 measure and 10 repeated measures in all 6 segments.

Results

Peak strains were constant during childhood (Fig. 2). They were not correlated with age or heart rate. Circumferential peak strains of anteroseptal, anterior, lateral, posterior, inferior, and septal segments were −30.2 ± 5.9, −23.7 ± 5.3, −17.3 ± 4.4, −15.3 ± 4.3, −20.9 ± 5.7, and −27.6 ± 5.6, respectively (Fig. 3, upper panel). The peak strain of the anteroseptal segment was the highest, and those of septal, anterior, inferior, lateral, and posterior segments followed in descending order. Significant differences were found in the peak strains of all segments from each other ($p < 0.01$). Radial peak strains of the anteroseptal, anterior, lateral, posterior, inferior, and septal segments were 44.5 ± 10.6, 47.6 ± 11.6, 53.6 ± 15.5, 58.2 ± 16.0, 55.5 ± 16.3, and 51.6 ± 14.1, respectively (Fig. 3, lower panel). The peak strains of the anteroseptal and anterior segments were smaller than those of the lateral, posterior, inferior, and septal segments. The peak strain of the lateral segment was larger than those of the anterior and anteroseptal segments, and smaller than that of the posterior segment. The peak strain of the posterior segment was larger than those of the anteroseptal, anterior, lateral, and septal segments. The peak strain of the inferior segment was larger than those of the anteroseptal, anterior, and septal segments. The peak strain of the septal segment was larger than those of anteroseptal and anterior segments, and smaller than those of posterior and inferior segments.

The inter and intraobserver variabilities are shown on Bland–Altan plots (Fig. 4).

Discussion

There have been few reports regarding cardiac strain in children. Lorch et al. reported left ventricular longitudinal strain and

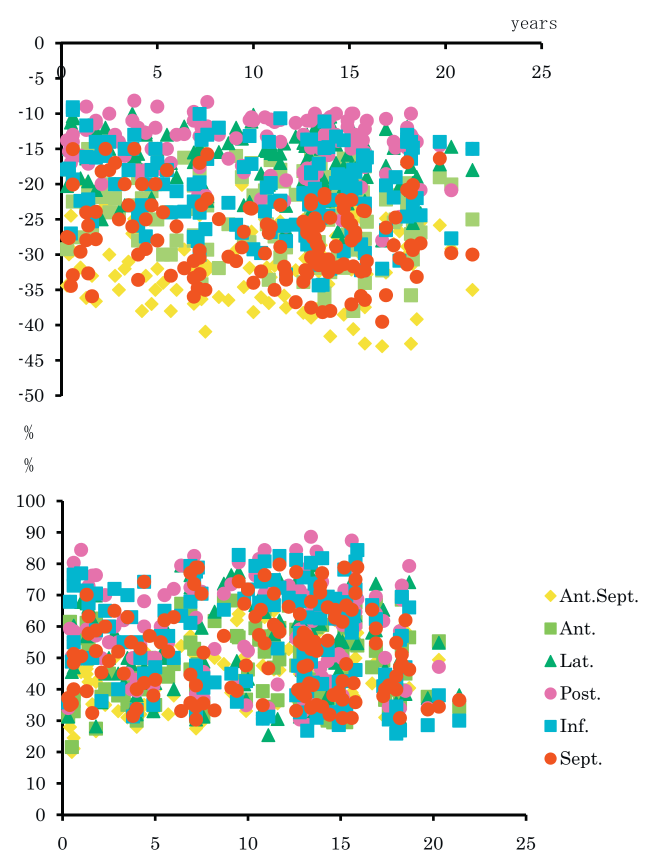

Fig. 2. Relation between circumferential strain and age (upper panel) and relation between radial strain and age (lower panel). Ant.Sept., anteroseptal; Ant., anterior; Lat., lateral; Post., posterior; Inf., inferior; Sept., septal.

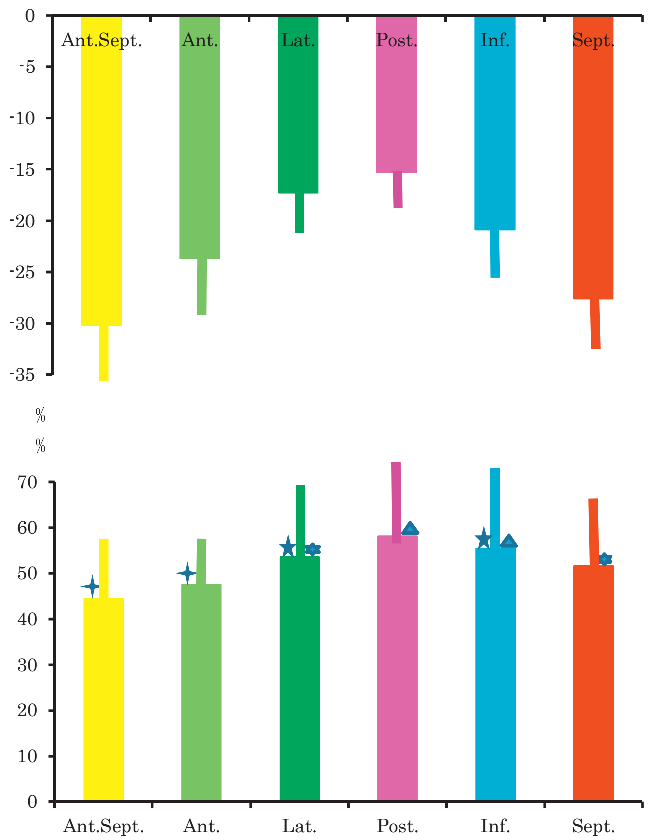

Fig. 3. Circumferential strains of regional segments (upper panel) and radial strains of regional segments (lower panel). The bars show the standard deviations. AntSept, anteroseptal; Ant, anterior; Lat, lateral; Post, posterior; Inf, inferior; Sept, septal. The pair data with the same symbol are not significantly different. The other data are significantly different from each other.

strain rate measured by 2D speckle tracking echocardiography in a healthy pediatric population, but they measured strains only at the septal and lateral attachments of the mitral valve [4]. The present study is the first report in which the strain of each segment in left ventricle was measured and compared in children.

The results of the present study showed that there were no significant age-related changes in circumferential or radial strain in pediatric subjects. It has been reported that there are no age-related changes in longitudinal systolic strain in childhood [4]. The relative invariability of systolic strain with aging in the present study is intriguing in the presence of changing loading conditions and ventricular contractility that normally occur in childhood [6]. This may be partly attributable to the fact that left ventricular geometry (represented by the left ventricular length-diameter ratio) remains constant from infancy to adulthood, leading to normalized torsion, which is considered a major mechanism underlying deformation of the myocardium [7,8].

The left ventricular myocardium consists of circumferential fibers in the mid-wall layer and longitudinal fibers in the endocardial and epicardial layers, and myofiber orientation changes continuously from right-handed helix in subendocardium to left-handed helix in subepicardium [9]. It is well known that myocardial fibrosis related to pressure overload appears frequently in the subendocardiac layer [10], and that there is negative correlation between longitudinal myocardial velocity and the interstitial fibrosis content [11]. Wang et al. [12] indicated that normal circumferential strain and torsion contribute to a preserved left ventricular ejection fraction in patients with diastolic heart failure, although longitudinal and radial strains are deteriorated. Mizuguchi et al. [13] reported that the mean peak systolic strain rates in the three directions in the concentric left ventricular hypertrophy group and those in the longitudinal and radial directions in the eccentric and normal geometric left ventricular hypertrophy groups were lower compared to the control group. From these facts, it is clear that longitudinal and circumferential strains mainly show contraction of the longitudinal and circumferential fibers, respectively, and that radial strain is affected by contractions of both fibers.

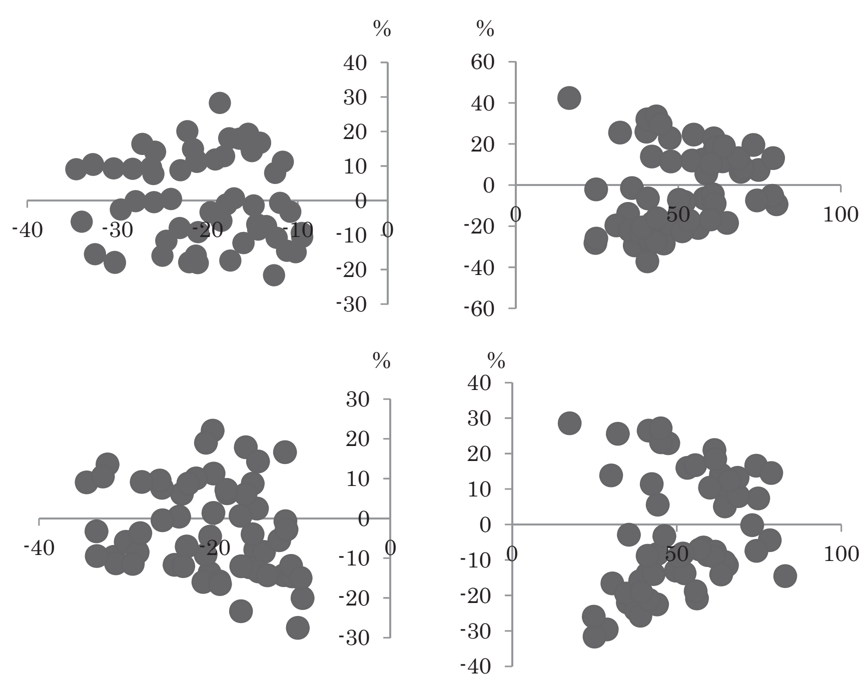

Fig. 4. Inter and intraobserver variabilities (upper and lower panels, respectively) of the circumferential (left panels) and radial (right panels) peak strains.

We observed regional heterogeneity of left ventricular strain. While circumferential strain was higher in the anteroseptal and septal regions compared to lower values in the lateral and posterior segments, radial strain was higher in the posterior and inferior regions compared to lower values in the anteroseptal and anterior segments. The circumferential and radial strains showed inverse distributions; i.e. the circumferential strain was high in regions with low radial strain, and low in regions with high radial strain. These observations indicate that there are differences in three-dimensional (3D) movements of these regions. To analyze 3D movements of the regions, we measured the longitudinal strains of the midseptal and midlateral segments in four chamber views of 40 patients by using the same software. The peak strain of the midseptal segment was significantly smaller than that of midlateral segment (-19.2 ± 4.8, -22.0 ± 4.4, respectively, Tukey's test, $p < 0.01$). In the septal region, the vectors of radial strains of left and right ventricles are the opposite, and the vectors of longitudinal strains of both ventricles were different. The vectors of circumferential strains of both ventricles were the same. The different directions of strains between right and left ventricle may be the causes of difference of strains among the segments.

There are some articles about regional nonuniformity of normal adult human left ventricle using magnetic resonance (MR) myocardial tagging. Bogaert and Rademakers [14] showed that circumferential strain in posterior wall is higher than that in septal or anterior walls, which is different from our results. They also showed that anterior wall and septum demonstrated the largest radial strain but had a smaller regional ejection fraction, which was primarily caused by the lower degree of circumferential and longitudinal strain in this part of the left ventricular wall. In that the circumferential and radial strains showed inverse distributions, their result and ours are in agreement. On the contrary, another study reported circumferential strain of lateral or anterior wall is larger than that of posterior wall [15]. We do not know the reason why these results were different, however, the pattern of the regional nonuniformity measured by ultrasonography were similar to our results [1,14].

In normal adults, no significant differences were found in regional longitudinal or radial strain [1]. Circumferential strain was slightly higher in the anteroseptal, anterior, and septal regions compared to the somewhat lower values in the posterior, lateral, and inferior regions, which were similar to our results, but the differences among the regions were smaller than in the present study. We measured the ratio of anteroseptal circumferential peak strain divided by that in the posterior segment and the ratio of the septal segment divided by that in the lateral segment. However, these ratios did not change significantly in childhood (data not shown).

There seems to be a lot of variations in normal values in this study, however, they are as much as those reported in other articles [1,4,16]. Jamel et al. reported that strain could accurately differentiate abnormally from normally contracting segments after acute infarction with a sensitivity/specificity of 85% [16]. The reference values shown in this study may be useful for detecting and monitoring regional left ventricular dysfunction in children. And we need to measure the strains of patients with cardiac diseases to decide cutoff values.

2D strain was not feasible in approximately 24% of children in the present study. This may have been due partially to the movements of the whole left ventricle in directions other than radial or circumferential, in addition to the quality of the images and also the tracking accuracy of the algorithm. In most of these cases, the strain of the lateral segment could not be analyzed due to the poor lateral resolution. Rapid improvements in technology in terms of improved tracking of the algorithm and better lateral resolution of images with higher image frame rate will enhance the results.

The limitations of the 2D approach will probably be resolved by application of the system to 3D echocardiography. Area strain by 3D echocardiography represents a promising novel automatic index that may provide an accurate and reproducible alternative to current echocardiographic standards for quantitative assessment of global and regional left ventricular function [17].

Study limitations

We only measured strains in the left ventricular short axis view at the level of the papillary muscles, because it is difficult to show an apex clearly by echocardiography for some reasons. The apex in children exists near the surface, so a part of it is sometimes not contained in the angle of the view. And the image in the near field is not so clear. However, assessment of multiple views is indispensable to detect left ventricular wall motion abnormalities. We additionally measured the longitudinal strains of the midseptal and midlateral segments to detect 3D orientation of strains. We must devise a way to measure 3D strains in all segments of left ventricle.

We exclusively used a single vendor machine. Strain measurements may be affected by the machines used [18]. It is planned in future to compare the data by using different ultrasound systems.

Conclusion

Our study showed that there were no significant age-related changes in circumferential or radial strain in children. However, the circumferential and radial peak strains of the left ventricle in normal children were different among the regions. The reference values shown in this study may be useful for detecting and monitoring regional left ventricular dysfunction in children with congenital heart disease or myopathy.

References

[1] Hurlburt HM, Aurigemma GP, Hill JC, Narayanan A, Gaasch WH, Vinch CS, Meyer TE, Tighe DA. Direct ultrasound measurement of longitudinal, circumferential, and radial strain using 2-dimensional strain imaging in normal adults. Echocardiography 2007;24:723–31.
[2] Marwick TH, Leano RL, Brown J, Sun JP, Hoffmann R, Lysyansky P, Becker M, Thomas JD. Myocardial strain measurement with 2-dimensional speckle-tracking echocardiography: definition of normal range. JACC Cardiovasc Imaging 2009;2:80–4.
[3] Wang J, Khoury DS, Yue Y, Torre-Amione G, Nagueh SF. Preserved left ventricular twist and circumferential deformation, but depressed longitudinal and radial deformation in patients with diastolic heart failure. Eur Heart J 2008;29:1283–9.
[4] Lorch SM, Ludomirsky A, Singh K. Maturational and growth-related changes in left ventricular longitudinal strain and strain rate measured by two-dimensional speckle tracking echocardiography in healthy pediatric population. J Am Soc Echocardiogr 2008;21:1207–15.
[5] Langeland S, D'hooge J, Wouters PF, Leather HA, Claus P, Bijnens B, Sutherland GR. Experimental validation of a new ultrasound method for the simultaneous assessment of radial and longitudinal myocardial deformation independent of insonation angle. Circulation 2005;112:2157–62.
[6] Colan SD, Parness IA, Spevak PJ, Sanders SP. Developmental modulation of myocardial mechanisms: age- and growth-related alterations in afterload and contractility. J Am Coll Cardiol 1992;19:619–29.
[7] Ingels Jr NB, Hansen DE, Daughters 2nd GT, Stinson EB, Alderman EL, Miller DC. Relation between longitudinal, circumferential, and oblique shortening and torsional deformation in the left ventricle of the transplanted human heart. Circ Res 1989;64:915–27.
[8] Liu W, Ashford MW, Chen J, Watkins MP, Williams TA, Wickline SA, Yu X. MR tagging demonstrates quantitative differences in regional ventricular wall motion in mice, rats, and men. Am J Physiol 2006;291: H2515–21.
[9] Sengupta PP, Krishnamoorthy VK, Korineck J, Narula J, Vannan MA, Lester SJ, Tajik JA, Seward JB, Khandheria BK, Belohlavek M. Left ventricular form and function revisited: applied translational science to cardiovascular ultrasound imaging. J Am Soc Echocardiogr 2007;20:539–51.
[10] Hittinger L, Shannon RP, Bishop SP, Gelpi RJ, Vatner SF. Subendomyocardial exhaustion of blood flow reserve and increased fibrosis in conscious dogs with heart failure. Circ Res 1989;65:971–80.

[11] Shan K, Bick RJ, Poindexter BJ, Shimoni S, Letsou GV, Reardon MJ, Howell JF, Zoghbi WA, Nagueh SF. Relation of tissue Doppler derived myocardial velocities to myocardial structure and beta-adrenergic receptor density in humans. J Am Coll Cardiol 2000;36:891–6.

[12] Wang J, Khoury DS, Yue Y, Torre-Amione G, Nagueh SF. Preserved left ventricular twist and circumferential deformation, but depressed lonitudinal and radial deformation in patterns with diastolic heart failure. Eur Heart J 2008;29:1283–9.

[13] Mizuguchi Y, Oishi Y, Miyoshi H, Iuchi A, Nagase N, Oki T. Concentric left ventricular hypertrophy brings deterioration of systolic longitudinal, circumferential, and radial myocardial deformation in hypertensive patients with preserved left ventricular pump function. J Cardiol 2010;55:23–33.

[14] Bogaert J, Rademakers FE. Regional nonuniformity of normal adult human left ventricle. Am J Physiol Heart Circ Physiol 2001;280:H610–20.

[15] Fonseca CG, Oxenham HC, Cowan BR, Occleshaw CJ, Young AA. Aging alters patterns of regional nonuniformity in LV strain relaxation: a 3-D MR tissue tagging study. Am J Physiol Heart Circ Physiol 2003;285:H621–30.

[16] Jamel F, Kukluski T, Sutherland GR, Weidemann F, D'hooge J, Bijnens B, Derumeaux G. Can changes in systolic longitudinal deformation quantify regional myocardial function after an acute infarction? An ultrasonic strain rate and strain study. J Am Soc Echocardiogr 2002;15:723–30.

[17] Kleijn SA, Aly MFA, Terwee CB, van Rossum AC, Kamp O. Three-dimensional speckle tracking echocardiography for automatic assessment of global and regional left ventricular function based on area strain. J Am Soc Echocardiogr 2011;24:314–21.

[18] Kjaergaard J, Korinek J, Belohlavek M, Oh JK, Sogaard P, Hassager C. Accuracy, reproducibility, and comparability of Doppler tissue imaging by two high-end ultrasound systems. J Am Soc Echocardiogr 2006;19:322–8.