Functional Maturation of Left and Right Atrial Systolic and Diastolic Performance in Infants, Children, and Adolescents

Shelby Kutty, MD, Asif Padiyath, MD, Ling Li, MD, PhD, Qinghai Peng, MD, PhD, Sheela Rangamani, MD, Andreas Schuster, MD, PhD, and David A. Danford, MD, *Omaha, Nebraska; Göttingen, Germany*

Background: Left atrial (LA) function is an important modulator of left ventricular filling and has a prognostic role in adult heart failure, but pediatric data are limited. The aim of this study was to characterize the normal LA and right atrial (RA) strain (ε) and strain rate (SR) in infants and children.

Methods: Atrial ε and SR were prospectively investigated in 153 subjects using two-dimensional speckle-tracking echocardiography. High–frame rate, three-beat captures of LA (15-segment model; two-chamber, three-chamber, and four-chamber views) and RA (six-segment model; four-chamber view) were analyzed (Vivid 7, EchoPAC BT11). LA and RA segmental and global peak positive ε (ε_{Pos}) and negative ε (ε_{Neg}) and peak positive SR, early negative SR, and late negative SR were measured. Linear and nonlinear regressions of ε and SR were performed with age and heart rate. Relationships of ε and SR with ventricular inflow Doppler and myocardial tissue Doppler indices were explored.

Results: The age range was 3 days to 20 years, and body surface area range from 0.17 to 2.3 m^2 for the study cohort. Mean global LA ε_{Pos}, LA ε_{Neg}, RA ε_{Pos}, and RA ε_{Neg} were 28 ± 9%, −16 ± 6%, 23 ± 9%, and −15 ± 6%, respectively. Positive correlations were found for global atrial ε_{Pos} and ε_{Neg} with age ($P < .001$). A marked rate of changes in ε and SR was seen in the first year of life, reaching normal adult values by adolescence. Peak positive SR had a strong negative correlation with age, and early negative SR had a strong positive correlation with age ($P < .001$), while late negative SR was correlated nonlinearly. Heart rate and age both influenced all LA and RA ε and SR indices.

Conclusions: Maturational changes in LA and RA ε and SR occur in normal children and are especially profound in infancy. Consequently, LA and RA performance indices must be interpreted in light of heart rate and age. Normal values and percentiles for atrial ε and SR reported here will provide a foundation for the study of pediatric atrial physiology and function in disease states. (J Am Soc Echocardiogr 2013;26:398-409.)

Keywords: Pediatric cardiology, Atrial function, Atrial strain, Atrial strain rate, Two-dimensional speckle-tracking

With improved understanding of the role of the atrium in modulating ventricular filling and performance, the assessment of atrial function has emerged as a useful tool in the evaluation of heart failure. The left atrium has three principal functions during the cardiac cycle: it serves as a reservoir that collects pulmonary venous blood during ventricular systole, a passive conduit of stored blood to the left ventricle during early diastole, and a booster during late diastole.[1] The active contractile component of the atria supplements ventricular volume in the setting of ventricular dysfunction, and this augmented atrial "booster pump" compensates for decreased early filling in patients with decreased ventricular compliance.[1,2] Diastolic dysfunction leads to left atrial (LA) remodeling and estimation of LA volume is therefore considered an important marker of the chronicity and severity of diastolic dysfunction.[3] Similar to the left atrium, three phases of function has been described for the right atrium as well. These correspond to right atrial (RA) filling during ventricular systole (reservoir function), flow from the right atrium into the right ventricle during diastole before the P wave (conduit function), and active contraction during atrial systole (contractile function).

Newer echocardiographic tools of strain (ε) and strain rate (SR) allow quantification of atrial performance and function independent of cardiac translational motion and tethering effects. Recently, two-dimensional (2D) speckle-tracking echocardiography (STE)–derived

From the University of Nebraska/Creighton University Joint Division of Pediatric Cardiology, Children's Hospital and Medical Center, Omaha, Nebraska (S.K., A.P., L.L., Q.P., S.R., D.A.D.); and the Department of Cardiology and Pulmonology, Georg-August-University and German Center for Cardiovascular Research (DZHK, Partner site Göttingen), Göttingen, Germany (A.S.).

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Reprint requests: Shelby Kutty, MD, University of Nebraska Medical Center and Children's Hospital and Medical Center, Division of Pediatric Cardiology, 8200 Dodge Street, Omaha, NE 68198-2265 (E-mail: *skutty@unmc.edu*).

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Abbreviations

ε = Strain

ε_{Neg} = Peak negative strain

ε_{Pos} = Peak positive strain

HR = Heart rate

LA = Left atrial

LV = Left ventricular

RA = Right atrial

SR = Strain rate

$SR_{EarlyNeg}$ = Peak early negative strain rate

$SR_{LateNeg}$ = Peak late negative strain rate

SR_{Pos} = Peak positive strain rate

STE = Speckle-tracking echocardiography

2D = Two-dimensional

atrial ε has been used to assess atrial function in hypertension,[4] hypertrophic cardiomyopathy,[5] and diastolic heart failure in adults.[6] LA ε may be impaired in adults with hypertension or diabetes, even in the presence of normal LA size.[3] LA ε has been proposed as a prognostic indicator in patients with atrial fibrillation[7] and after acute myocardial infarction.[8,9] A stronger association with prospective risk for atrial fibrillation was shown for LA ε than with LA size,[10] and LA ε was predictive of recurrence after ablation procedures.[11-13] Decreased LA SR was independently associated with stroke in patients with atrial fibrillation.[14] LA function by 2D STE has also been proposed as a sensitive tool for detecting abnormal left atrioventriculoarterial coupling.[15] A small number of 2D STE–based ε and SR studies have been performed for the right atrium as well,[16,17] and reference ranges have been reported for adults.[16] Abnormal RA ε was shown to be associated with pulmonary hypertension in patients with heart failure.[17]

Several pediatric heart diseases are associated with increased ventricular stiffness or decreased compliance, which in turn may lead to elevated atrial pressure and atrial remodeling.[18] Similar to the assessment of diastolic heart failure in adults, atrial ε and SR indices derived by 2D STE may provide insights into atrial function in pediatric and adolescent heart disease. Normal values for 2D STE–derived LA ε and SR are established in adults,[19,20] but pediatric data are lacking. Moreover, maturational characteristics of atrial ε and SR from infancy through childhood and adolescence have not been previously studied. The aims of the present study were (1) to investigate normal ε and SR for the left and right atria in infants and children and (2) to correlate ε and SR values with Doppler-derived indices of ventricular diastolic function.

METHODS

Patients

This was a single-center prospective investigation conducted from October 2010 to October 2011. The institutional review board approved the study protocol. Infants, children, and adolescents who underwent standard-of-care echocardiographic screening for the evaluation of heart murmur or chest pain and were found to have completely normal echocardiographic results were prospectively enrolled for the acquisition of research images. Subjects with histories of any heart disease, hypertension, or any other systemic disease were excluded even if the screening echocardiogram showed normal intracardiac structure and function. Demographic data were collected, including gender, date of birth, height, weight, heart rate (HR), and systemic blood pressure. Body surface area was calculated using the Haycock formula.

Image Acquisition

All examinations were performed using Vivid 7 systems (GE Medical Systems, Milwaukee, WI) and consisted of three-beat, high-frame rate (mean, 92 ± 30 Hz) captures in two-chamber, three-chamber, and four-chamber views acquired during quiet breathing, with special care taken to include the entire circumference of both atria in all three views. These measures were taken to optimize temporal resolution and spatial definition and thereby enhance the feasibility of frame-to-frame tracking.[21] Electrocardiograms were recorded simultaneously to time the events during subsequent analysis. Three experienced sonographers performed all acquisitions.

Measurement of Atrial ε and SR

Offline semiautomated analysis was performed using commercially available software for 2D STE (EchoPAC BT11; GE Medical Systems). The LA endocardial surfaces were manually traced in apical four-chamber, three-chamber, and two-chamber images using a point-and-click approach when the chamber was at its minimum volume after contraction. Assessment of RA deformation was based on the four-chamber acquisitions alone. The software, creating a region of interest, automatically generated an epicardial surface tracing. The region of interest was adjusted to fit the atrial wall thickness before the automated tracking algorithm was applied. Tracking performance was reviewed to ensure accurate tracking of the atrial myocardium, and adjustments were made to the region of interest width and shape manually before the algorithm was reapplied when necessary. The software divided the region of interest into six segments, and the resulting tracking quality for each segment was automatically scored as either acceptable or unacceptable, with the possibility of further manual correction. In the three-chamber view, only the inferoposterior wall indices were measured (the opposing wall that had the ascending aorta was excluded from analysis of results).[19,20] This constituted 15 equidistant regions of the left atrium, six in the apical four-chamber view, six in the apical two-chamber view, and three in the inferoposterior wall in the long axis. Velocity, ε, and SR curves for each atrial segment were obtained on the basis of a 15-segment model[19] for the left atrium and a six-segment model for the right atrium (Figure 1A).

Strain and SR time plots were displayed for manual measurements. Global and segmental values for peak positive ε (ε_{Pos}), peak negative ε (ε_{Neg}), peak early negative SR ($SR_{EarlyNeg}$), peak late negative SR ($SR_{LateNeg}$), and peak positive SR (SR_{Pos}) were measured with the start of the cardiac cycle set as the onset of the P wave on the electrocardiogram (Figure 1B). This method was described by Vianna-Pinton *et al.*[20] and has been endorsed by the American Society of Echocardiography and European Association of Echocardiography consensus statement on methodology and indications for the quantitative evaluation of cardiac mechanics.[22] Accordingly, the first negative peak atrial longitudinal ε (ε_{Neg}, corresponding to atrial systole/contractile function) and the second positive peak atrial ε (ε_{Pos}, corresponding to LA conduit function) were measured. The three SR parameters ($SR_{LateNeg}$, SR_{Pos}, and $SR_{EarlyNeg}$), corresponding respectively to atrial systole, commencement of ventricular systole, and commencement of ventricular diastole, were measured.

Measurement of Atrial Volumes and Indices of Systolic and Diastolic Function

Atrial volumes were calculated using the biplane Simpson's method for the left atrium.[23] For each cardiac cycle, the average of three