Supine Exercise Echocardiographic Measures of Systolic and Diastolic Function in Children

Rajesh Punn, MD, Derek Y. Obayashi, MD, Inger Olson, MD, Jeffrey A. Kazmucha, MS, CES, Anne DePucci, RDCS, Michael P. Hurley, BS, and Clifford Chin, MD, *Palo Alto, California; Tacoma, Washington; Cincinnati, Ohio*

Background: Echocardiography has been used to determine ventricular function, segmental wall motion abnormality, and pulmonary artery pressure before and after peak exercise. No prior study has investigated systolic and diastolic function using echocardiography at various phases of exercise in children. The aim of this study was to determine the fractional shortening (FS), systolic-to-diastolic (S/D) ratio, heart rate–corrected velocity of circumferential fiber shortening (VCFc), circumferential wall stress (WS), ratio of mitral passive inflow to active inflow (E/A), ratio of passive inflow by pulsed-wave to tissue Doppler (E/E′), and right ventricular–to–right atrial pressure gradient from tricuspid valve regurgitation jet velocity (RVP) and time duration at various phases of exercise in children.

Methods: In an 8-month period (December 2007 to July 2008), 100 healthy children were evaluated, and 97 participants aged 8 to 17 years who performed complete cardiopulmonary exercise stress tests using supine cycle ergometry were prospectively enrolled. The participants consisted of 48 female and 49 male subjects with various body sizes, levels of exercise experience, and physical capacities. The cardiopulmonary exercise stress test consisted of baseline pulmonary function testing, continuous gas analysis and monitoring of blood pressure and heart rate responses, electrocardiographic recordings, and oxygen saturation measurement among participants who pedaled against a ramp protocol based on body weight. All participants exercised to exhaustion. Echocardiography was performed during exercise at baseline, at a heart rate of 130 beats/min, at a heart rate of 160 beats/min, at 5 min after exercise, and at 10 min after exercise. FS, S/D ratio, VCFc, WS, E/A, E′, E/E′, and RVP at these five phases were compared in all subjects.

Results: All echocardiographic parameters differed at baseline from 160 beats/min ($P < .0001$) except E/E′, which remained at 5.4 to 5.8. Specifically, FS (from 37% to 46%), S/D ratio, VCFc (from 1.1 to 1.6), WS (from 200 to 258 g/cm^2), E′ (from 0.2 to 0.3), and RVP (from 18 to 35 mm Hg) increased from baseline to 160 beats/min and then subsequently decreased to at or near baseline, while tricuspid valve regurgitation duration decreased (from 370 to 178 msec).

Conclusions: Normal values for systolic and diastolic echocardiographic measurements of function are now available. FS, VCFc, WS, and RVP increase with exercise and then return to near baseline levels. The E/E′ ratio is unaltered with exercise in normal subjects. (J Am Soc Echocardiogr 2012;25:773-81.)

Keywords: Exercise, Echocardiography, Function

Exercise echocardiography has been used to quantify ventricular function, segmental wall motion abnormalities, and pulmonary artery pressure before and at peak exercise.[1-19] These measurements have also been obtained at various phases of exercise. In the pediatric patient population, however, there is a concern that echocardiographic data may not represent the true peak measurement because of heart rate recovery. No prior study has investigated the parameters of systolic and diastolic function during physical exertion at different phases of exercise. In this initial, prospective investigation, we endeavored to determine the feasibility of obtaining two-dimensional and spectral Doppler imaging during exercise. Additionally, we sought to determine functional changes during different phases of exercise in normal, healthy children. This study provides echocardiographic function measurements for children during exercise.

From Stanford University (A.D.), Lucile Packard Children's Hospital, Palo Alto, California (R.P., I.O., J.A.K.); Northwest Children's Heart Care, Pediatrix Cardiology of Washington, Tacoma, Washington (D.Y.O.); Stanford University School of Medicine, Palo Alto, California (M.P.H.); and the Heart Institute, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio (C.C.).

Reprint requests: Rajesh Punn, MD, Stanford University, Lucile Packard Children's Hospital, Division of Pediatric Cardiology, 750 Welch Road, Suite 325, Palo Alto, CA 94304 (E-mail: *rpunn@stanford.edu*).

0894-7317/$36.00

doi:10.1016/j.echo.2012.03.007

METHODS

Patient Population

Healthy volunteers aged 8 to 17 years were enrolled prospectively from December 2007 to July 2008 at the Lucile Packard Children's

Abbreviations

FS = Fractional shortening

RER = Respiratory exchange ratio

S/D = Systolic-to-diastolic ratio

TR = Tricuspid valve regurgitation

TRTD = Tricuspid valve regurgitation duration

VCFc = heart rate–corrected Velocity of circumferential fiber shortening

WS = Wall stress

Hospital Heart Center at Stanford University as a part of an internal grant. The following data were collected from each subject: date of birth, gender, body surface area (Haycock formula), height, weight, baseline blood pressure, and an exercise activity questionnaire. Inclusion criteria were a structurally normal heart and normal sinus rhythm, established at baseline echocardiography. Exclusion criteria were body mass index > 35 kg/m^2, developmental delay, moderate to severe pulmonary limitations assessed by pulmonary function tests, short leg length, submaximal effort during exercise test, inability to perform exercise on a cycle ergometer, drop in systolic blood pressure during exercise, pathologic ST-segment changes during exercise, and any significant childhood disease. This study was approved by the Stanford University Institutional Review Board; informed consent and assent were obtained.

Exercise Protocol

All 97 participants performed baseline pulmonary function testing to assess forced vital capacity, forced expiratory volume in 1 sec, forced expiratory flow at 25% to 75% of forced vital capacity, and maximum voluntary ventilation. A complete cardiopulmonary exercise stress test was also performed on a supine cycle ergometer (Medical Positioning, Minneapolis, MN) that used a Medical Graphics Ultima Cardio2 system to analyze breath-by-breath metabolic measures, assessed continuous electrocardiographic recordings and oxygen saturation, and collected blood pressure measurements every 2 min. Participants pedaled at a rate of 50 to 60 rpm and performed against a ramp protocol based on body weight (0.25 × body weight [kg]), reported exercise experience, and physical abilities and tolerance. All participants began with pulmonary function testing before the cardiopulmonary exercise test. The cardiopulmonary exercise test consisted of an initial warm-up in which participants pedaled for 2 min at 0 W before pedaling against increased workloads. Participants exercised to exhaustion followed by a 5-min cool-down period. Before the onset of the cardiopulmonary exercise test, the participants had baseline heart rates < 100 beats/min and respiratory exchange ratios (RERs) < 1.00. They exercised to exhaustion and were considered to have met maximal exercise parameters by reaching an RER > 1.00 and a target heart rate ≥ 160 beats/min. The RER is the ratio of the net output of carbon dioxide to the simultaneous net uptake of oxygen and an indicator of substrate utilization. During exercise, this is directly related to lactic acid accumulation in muscle and is used to objectively quantify effort. The following parameters were measured at each protocol point: blood pressure, heart rate, and ventilatory equivalents. There were five protocol points: (1) baseline before exercise (rest), (2) a heart rate of 130 beats/min during exercise, (3) a heart rate of 160 beats/min during exercise, (4) 5 min after exercise in recovery, and (5) 10 min after exercise in recovery. Notably, all echocardiographic measurements at heart rates of 130 and 160 beats/min were obtained while cycling (Figure 1).

Figure 1 Setup for simultaneous exercise supine cycle ergometry. The sonographer imaged subjects during exercising.

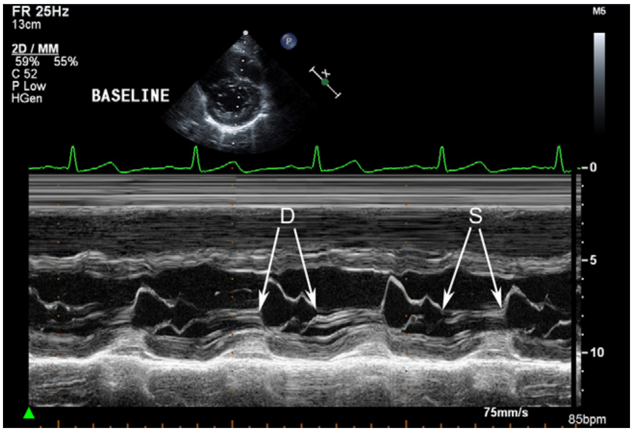

Figure 2 Parasternal short-axis view of the heart at the level of the mitral valve to examine closure (S) and opening (D) times in milliseconds to perform the S/D calculation. In this example, the patient is at baseline before exercise (rest).

Table 1 Patient characteristics (n = 97)

Variable	Value
Age (y)	12.7 ± 2.4 (8.1–17.8)
Female/male	48/49
Weight (kg)	47.3 ± 14.2 (24.0–103.0)
Body surface area (m^2)	1.4 ± 0.3 (0.9–2.2)

Data are expressed as mean ± SD (range) or as numbers.

Echocardiographic Data

Echocardiographic studies were performed using a Phillips iE33 (Philips Medical Systems, Bothell, WA). The syngo Dynamics workstation (Siemens Medical Solutions USA, Inc., Mountain View, CA) was used to perform offline analysis of M-mode and Doppler-derived velocities. All echocardiographic imaging was performed at the five protocol points using standard imaging techniques.[20] A parasternal short-axis image was obtained at the mitral valve leaflets and at the papillary muscle level to calculate a systolic-to-diastolic ratio (S/D)