

Normal Value of Left Ventricular End-Systolic Elastance in Infants and Children

A. Kiani, J. Gilani Shakibi

Abstract

Background: In certain conditions, there is a need for a specific and improved measure of cardiac performance. Routine methods for assessing left ventricular (LV) function are based on image-analysis or right heart monitoring which do not allow evaluation of ventriculo-arterial interaction. Chen et al presented a noninvasive method allowing measurement of end-systolic pressure-volume relation and its slope, the so-called end-systolic elastance (Ees), which is a major determinant of LV systolic performance and heart interaction with the systemic vasculature.

Objective: To determine the normal values of LV elastance in infants and children based on Chen *et al's* method.

Methods: The method involves measurement of the LV Ees using the equation $Ees(sb) = [Pd - (End(est) \times Ps \times 0.9)] / [SV \times End(est)]$ in 114 normal children: Group 1; 24 infants 1 to 12 months of age. Group2; 26 children aged between 1 and 5 years. Group3; 55 children 5 to 16 years of age and Group 4; 9 young adults aged between 16 and 20 years.

Results: The mean±SD of the LV Ees in the 4 groups were 10.16±4.7 mm Hg/ml for group 1, 5.44±1.36 for group 2, 3.29±0.94 for group 3, and 2.76±0.68 mm Hg/ml for group 4.

Conclusion: There are significant inter-group differences which make the use of the provided normal values essential for assessment of LV function.

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Keywords • End-systolic elastance • heart failure • left ventricle • systolic performance

Department of Pediatrics Cardiology,
Day Hospital,
Tehran, Iran

Correspondence: A Kiani, MD,
Department of Pediatric Cardiology,
Day Hospital, Vali Asr Ave,
Abbaspoor St, Tehran, Iran

Tel: +98-21-888-8742

Fax: +98-21-8797353

E-mail: kiani@sina.tums.ac.ir

Introduction

The effectiveness of a treatment for heart failure depends on correct evaluation of the underlying pathophysiology and close monitoring and individualized treatment. Some therapeutic measures may stabilize acute exacerbation, reduce re-admission rate, and improve quality of life and survival.¹⁻³ However, variability in the disease presentation, its response to treatment and

development of complex treatment measures^{3,4} have made the need for more specific and better assessment of cardiac function necessary. Routine assessment of left ventricular (LV) function largely depends on image-analysis and right heart monitoring.

Although, both measures are helpful, they give limited information on LV function and provide no information on ventriculo-arterial interaction, which can be crucial for optimizing the treatment.⁴⁻⁷ With this goal in mind, the end-systolic pressure-volume relation (ESPVR) and its slope, the so-called end-systolic elastance (Ees), have been proven soon very useful, since it is a major determinant of LV systolic function and its interaction with the systemic vasculature.⁶⁻¹¹ However, determination of Ees, generally, needs invasive measurement of LV pressure and volume recording over a range of cardiac loading. This has prevented the widespread use of this parameter for clinical diagnosis of heart failure and its optimum management. Several approaches have been suggested for estimating Ees without loading interventions.¹²⁻¹⁴ These methods are generally referred to as single-beat methods (Ees(sb)). The usefulness of these noninvasive methods was doubtful, because there were no validating data to show that these approaches are comparable with data obtained by invasive methods. Although there were some previous attempts¹⁵, Chen *et al.*,¹⁶ recently presented a modified technique with comparison of data from noninvasive measurements and data obtained directly from catheterization laboratory which can measure Ees(sb) noninvasively. Ees is a major determinant of cardiac performance, its interaction with systemic vasculature, and can be used clinically for assessing treatment of heart failure. Herein, we would like to report the normal values for Ees in infants and children. These values could be used for objective evaluation of response to treatment in pediatric patients with heart failure.

Patients and Methods

Study population:

The study group consisted of those children who were referred for cardiac evaluation. After a complete clinical examination, and taking an ECG, chest x-ray, and color Doppler echocardiography, normal individuals were included into the study. A total of 114 normal children thus, collected and were divided into four groups:

Group 1: 24 infants 1 to 12 months of age.

Group 2: 26 infants aged between 1 and 5 years

Group 3: 55 children 5 to 16 years of age, and

Group 4: 9 young adults aged 16 to 20 years.

Infants less than 1 month of age were excluded from the study, because of their particular cardiovascular state. The normal neonatal Ees will be reported separately.

Study protocol:

Measurements consisted of

- 1-Measurement of the brachial systolic and diastolic pressures using a cuff of suitable size in supine position.
- 2-Echocardiography: Standard method was used to calculate LV ejection fraction with M-mode echocardiography in parasternal long-axis view of two-dimensional echocardiogram.¹⁷
- 3-Measurement of LV outflow tract diameter at the base of aortic leaflet using a parasternal long-axis view. Using this value, the cross-sectional area was calculated.
- 4-Stroke volume (SV) was measured using an apical 4-chamber view. Sample volume was placed above the aortic valve and proximal aortic pulse-wave Doppler flow was recorded. Time-velocity integral of the flow was measured. SV was measured by the following equation:

$$5-SV=(DAo/2)^2 \times TVI \ Ao \times p$$

Where D designates diameter of the aortic valve and TVI is the time-velocity integral.

- 5-Two time intervals were measured:
 - a-the pre-ejection period (PEP), *i.e.*, the time interval from Q or R of ECG to the onset of the aortic Doppler flow (onset of ejection).
 - b-The time interval from Q or R of ECG to the end of aortic Doppler flow.

Then, the Ees(sb) was calculated using the following formula:

$$Ees(sb)=[Pd(E \ Nd(est) \times Ps \times 0.9)]/[SV \times E \ Nd(est)]$$

Where, Ees(sb) is the single-beat LV end-systolic elastance, Pd designates diastolic blood pressure, ENd(est) is noninvasive estimated normalized elastance at the onset of ejection, Ps represents systolic blood pressure, and SV is the stroke volume. More detail is mentioned in report of Chen, *et al.*¹⁶ Data were presented as mean±SD.

Results

The results of the study are summarized in Table 1. As noted Ees(sb) is quite different in group 1, *i.e.*, in children less than one year of age as compared with the children of the older groups ($p < 0.001$). Moreover, statistically significant difference exists between other groups as well (see Table 1).

Discussion

Heart failure (HF) in children though presenting in similar ways, may be due to various etiologies.

Left ventricular end-systolic elastance in infants and children

	EF (%)	SV (ml)	Ao root (cm)	BP (syst) (mm Hg)	BP (diast) (mmHg)	Ao TVI (cm)	T onset (msec)	T offset (msec)	HR/min	Ees (sb) (mmHg/ml)
Group 1	77 ±5	10 ±4	0.9 ±0.16	90 ±10	60 ± 5	14.65 ±2.8	40 ±10	250 ±30	136 ±27	10.16 ±4.7 † Δ ‡
Group 2	76 ±5	24 ± 8	1.28 ± 0.24	100 ± 9	60 ±13	19.55 ± 3.9	47 ± 12	293 ±26	106 ±14	5.44 ±1.63 * **
Group 3	76 ± 6	49 ± 21	1.64 ±0.34	107 ± 9	72 ± 7	22.15 ± 4	48 ±12	310 ± 30	87 ±23	3.29 ± 0.94
Group 4	78 ± 8	103 ±16	1.96 ± 0.34	115 ± 20	70 ±10	23.03 ± 5	50 ± 10	330 ±30	86 ±16	2.76 ± 0.68

† p<0.001 group 1 vs group 2

Δ p<0.001 group 1 vs group 3

‡ p<0.001 group 1 vs group 4

* p <0.001 group 2 vs group 3

** p <0.001 group 2 vs group 4

The clinical manifestations include difficulty in feeding, labored respiration, nausea, orthopnea, paroxysmal nocturnal dyspnea, tachycardia, increased precordial activity, gallop rhythm, cool and mottled extremities, tachypnea, wheezing, hepatomegaly, and peripheral edema.¹⁸

Treatment of HF consists of several strategies including decreased activity, fluid restriction, drug administration, *i.e.*, inotropic support (*e.g.*, digoxin), diuretics (*e.g.*, furosemide, spironolactone), ACE inhibitor (*e.g.*, captopril, enalapril), and sometimes β-blockers.

To assess the success of the treatment, the conventional methods used include repeated physical examination and chest x-ray study. These methods, however, are inadequate and more evaluation is needed with echocardiography (M-mode, 2-D, color Doppler).

These methods provide more data about HF and its response to the treatment. However, these are mostly subjective and do not provide objective and quantitative values. Chen *et al.*,¹⁶ introduced an objective and quantitative method for evaluation of LV systolic function and its relation to the arterial resistance and capacitance, which is simple, reproducible and noninvasive. His method can be used clinically, especially in patients with HF under therapy. Using his formula, one can predict the LV systolic function objectively and change the therapeutic strategy, if necessary. In the study of Chen *et al.*,¹¹ Ees was reported to be 2.3±1 mm Hg/ml in normal adults, <1 in those with dilated failing heart, and around 4 mm Hg/ml in those with hypertrophied heart.¹⁹ In this paper we report the normal

values of LV elastance for infants and children (Table 1). These data provide baseline values for following the course of patients with HF and their response to therapy.

Conclusion

The left ventricular end-systolic elastance can be estimated easily through noninvasive methods. This index correlates well with directly measured data. The baseline values presented here can be used to assess the response of patients with HF to therapy and for optimizing the therapeutic strategies. Furthermore, Ees can be used to clarify integrated cardiovascular response to altered vascular loading. The method is simple, cost effective, and fast. With a little practice, one can routinely use this important index at bedside.

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