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# Echocardiography in the Assessment of Left Atrial Pressure After Pediatric Heart Surgery: A Comparison Study With Measurements Obtained From Left Atrial Catheter

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## Abstract

**Background:** Correlation between ventricular end-diastolic pressure and pulsed Doppler and tissue Doppler–derived E/e' ratio has been widely reported in adults but scarcely studied in children with congenital heart diseases. This ratio is defined as the relationship between diastolic transmitral flow velocity (cm/s; E) and myocardial diastolic relaxation velocity (cm/s; e') in the lateral aspect of the mitral annulus. Our main objective was to ascertain whether a correlation existed between direct measurement of left atrial pressure and echocardiographic E/e' ratio in children after heart surgery. **Methods:** Prospective study including 27 consecutive children after pediatric heart surgery. Data were analyzed according to whether they were obtained within the first 72 hours following surgery or later on. Sensitivity, specificity, positive and negative predictive values, and areas under the receiver–operating characteristics curve of E/e' ratio in detection of left atrial pressure values $\geq$13 mm Hg were evaluated. **Results:** Forty-eight studies were conducted in 27 patients. Thirty-two studies were performed during the first 72 hours after heart surgery and 16 beyond the third day. Median patient age was 0.82 years (5 days-16 years). Median left atrial pressure values and E/e' measurements of the whole cohort (N = 48) were 12.0 and 10.2, respectively. Intraclass correlation index between left atrial pressure values and echocardiographic E/e' ratio was 0.35, 0.25 for studies performed within 72 hours, but 0.78 ($P < .01$) for those performed later. There was also a high positive predictive value, since in 13 (87%) of 15 studies with an E/e' ratio $\geq$13, the left atrial pressure was $\geq$13 mm Hg. **Conclusion:** While echocardiographic E/e' ratio did not show a good correlation with left atrial pressure in the immediate postoperative period, the positive predictive value may suffice to aid clinicians in predicting elevated pressures.

## Keywords

echocardiography, atrium, congenital heart surgery, pediatric

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## Introduction

Left atrial pressure reflects left ventricle preload and, indirectly, diastolic function. In the immediate postoperative period following heart surgery, left atrial pressure measurement can provide important information on the dynamics of the left heart. Elevated left atrial pressure can be secondary to cardiac dysfunction (systolic and diastolic), volume overload, or surgical residual defects.[1] Direct measurement of left atrial pressure requires intrathoracic catheter placement and can be associated with greater morbidity, since it can be a source of sepsis, embolic events, or local hemorrhagic complication.[2,3] Noninvasive estimation of left atrial pressure could facilitate the management of these patients after heart surgery.

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Noninvasive estimation of left atrial pressure can be obtained by echocardiographic analysis of the E/e' ratio. The pulsed Doppler and tissue Doppler–derived E/e' ratio evaluates the relationship between diastolic transmitral flow velocity (cm/s; E) and myocardial diastolic relaxation velocity (cm/s; e') in the lateral aspect of the mitral annulus. In 1997, Nagueh et al showed pulmonary capillary wedge pressure measured with a Swanz-Ganz catheter to be correlated with the echocardiographic analysis of the E/e' ratio in adult patients.[4] These findings have been corroborated by several studies in adults,[5,6] however, data in children are scanty[7-9] and only few studies exist that correlate direct measurement of left atrial pressure with echocardiographic estimation.

The present study aimed to ascertain whether a correlation exists between left atrial pressure obtained invasively and the echocardiographic E/e' ratio in pediatric patients after heart surgery.

## Methods

After approval by the local institutional review board, we conducted a prospective study including all children (0-16 years of age) admitted to the pediatric intensive care unit (PICU) and the neonatal intensive care unit (NICU) between March 2010 and March 2012, who had undergone heart surgery and had a left atrial catheter in place. Patients in whom invasive pressure monitoring did not show a regular, reliable wave form were excluded from further analysis. Informed consent was obtained from the parents of the patients.

The data were divided into two groups according to whether the echocardiographic study had been obtained in the first 72 hours or later on. This time period was considered after preliminary observations had indicated that after 72 hours clinical findings of low cardíac output were generally recovering, and most of the patients attained a notable improvement in their hemodynamic condition.

Two different ultrasound machines were used for noninvasive left atrial pressure estimation: a Vivid 7 (GE healthcare, Horten, Norway) for patients admitted to the PICU and a Vivid *i* (GE healthcare, Horten, Norway) for those in the NICU.

### Study Variables

The following echocardiographic measurements were obtained: left ventricle ejection fraction, transmitral flow E wave (pulsed Doppler, four-chamber view), and e' wave in the lateral region of the mitral annulus (tissue Doppler, four-chamber view). E and e' waves were measured and averaged from three consecutive heart beats. Septal pulsed Doppler and septal tissue Doppler-derived E/e' ratio were not included to avoid variability due to anomalous septal movement secondary to surgery, which could hinder interpretation of the tissue Doppler measurements.[10,11]

The following clinical and demographic variables were collected: sex, age, body surface area, kind of underlying cardiac disease, univentricular or biventricular physiology, left atrial pressure value, and an inotropic score index proposed by Gaies et al as a marker of severity of illness after pediatric heart surgery based on quantitation of the amount of cardiovascular support received.[12] Left atrial pressure values were measured during the echocardiographic e' wave assessment in order to compare both results simultaneously.

### Statistical Analysis

A descriptive analysis of data was made. Data are expressed as median values and interquartile range (25th-75th percentile). Comparisons between studies performed before or after 72 hours were assessed with the nonparametric Mann-Whitney *U* test. Intraclass correlation index was used to analyze the correlation between echocardiographic E/e' ratio and left atrial pressure values. Sensitivity, specificity as well as positive and negative predictive values and areas under the receiver–operating characteristics curve of E/e' ratio in detection of left atrial pressure values $\geq$13 mm Hg were evaluated (we took this cutoff value since it is the first out of normal range [4-12 mm Hg]). Statistical significance level was considered as $P < .05$. Analyses were performed in SPSS v.15 (Chicago, Illinois).

## Results

Forty-eight studies were conducted in 27 (14 boys and 13 girls) patients with a median age of 0.82 years (5 days-16 years). Eleven patients had two or more studies, always on different days. The other 16 patients had only one study. Thirty-two (66.6%) studies were performed in the first 72 hours and 16 (33.3%) beyond the third day (>72 hours). Summary of cardiac diagnosis and clinical data are shown in Table 1. The median days of left atrial line placement for the whole cohort was 2.[2-6]

Left atrial pressure and E/e' ratio measurements and their intraclass correlation index, transmitral flow E wave, e' wave in the lateral region of the mitral annulus, left ventricle ejection fraction, and inotropic score for the two different study periods are shown in Table 2.

Median left atrial pressure values and E/e' measurements of the whole cohort (N = 48) were 12.0 (10-14) and 10.2 (8.8-12.2), respectively. Intraclass correlation index between left atrial pressure values and pulsed Doppler and tissue Doppler-derived E/e' ratio measurement of the whole cohort was 0.35 ($P < .05$), 0.25 for studies performed in the first 72 hours and 0.78 ($P < .01$) for those performed beyond 72 hours. A graphic correlation between left atrial pressure values and echocardiographic E/e' ratio is shown in Figure 1.

Sensitivity, specificity, predictive values, and receiver–operating characteristic curve areas of E/e' ratio to distinguish left atrial pressure values $\geq$13 mm Hg are presented in Table 3. Our results showed high specificity of the E/e' ratio with a positive predictive value of 87%, that is, in 13 of the 15 studies with an E/e' ratio $\geq$13, the left atrial pressure by direct measurement was high ($\geq$13 mm Hg). The negative predictive value was 73%. In 9 of the 33 studies with E/e' ratio <13, the left atrial pressure was $\geq$13 mm Hg.

**Table 1.** Summary of Clinical Data and Cardiac Diagnosis.

| | Sex | Age | BSA, $m^2$ | Cardiac Diagnosis | Cardiac Operation | Phisiology |
|---|---|---|---|---|---|---|
| 1 | M | 0.5 m | 0.24 | D-TGA | Arterial switch | Bi |
| 2 | M | 0.3 m | 0.23 | D-TGA | Arterial switch | Bi |
| 3 | F | 0.9 m | 0.23 | D-TGA | Arterial switch | Bi |
| 4 | F | 0.6 m | 0.23 | D-TGA | Arterial switch | Bi |
| 5 | F | 0.3 m | 0.19 | D-TGA | Arterial switch | Bi |
| 6 | M | 14 m | 0.47 | D-TGA + VSD + HRV + AoCoa | Glenn | Uni |
| 7 | F | 0.3 m | 0.22 | D-TGA | Arterial switch. | Bi |
| 8 | M | 0.3 m | 0.22 | D-TGA | Arterial switch | Bi |
| 9 | M | 7 m | 0.37 | ToF | Corrective surgery | Bi |
| 10 | M | 6 m | 0.37 | ToF | Corrective surgery | Bi |
| 11 | F | 6 m | 0.31 | ToF | Corrective surgery | Bi |
| 12 | M | 3 m | 0.28 | ToF | Corrective surgery | Bi |
| 13 | F | 10 m | 0.32 | ToF | Corrective surgery | Bi |
| 14 | M | 5 m | 0.31 | AVSD | Corrective surgery | Bi |
| 15 | M | 7 m | 0.33 | AVSD | Corrective surgery | Bi |
| 16 | F | 6 m | 0.27 | AVSD | Corrective surgery | Bi |
| 17 | F | 115 m | 1.05 | TA + D-TGA | Fontan | Uni |
| 18 | M | 172 m | 1.72 | TA + D-TGA | Fontan | Uni |
| 19 | M | 96 m | 0.87 | TA + D-TGA | Fontan | Uni |
| 20 | F | 18 m | 0.43 | PA + VSD | Corrective surgery | Bi |
| 21 | M | 36 m | 0.57 | PA + VSD | Corrective surgery | Bi |
| 22 | F | 38 m | 0.54 | DORV + D-TGA | Rastelli | Bi |
| 23 | M | 10 m | 0.46 | DORV + D-TGA | Rastelli | Bi |
| 24 | F | 0.1 m | 0.21 | Hypo arch + AoCoa | Corrective surgery | Bi |
| 25 | F | 197 m | 1.24 | Mitral prolaspe | Mitral prosthesis | Bi |
| 26 | F | 5 m | 0.31 | HCM | Heart TX | – |
| 27 | M | 127 m | 1.22 | ARVC | Heart TX | – |

Abbreviations: AoCoa, aortic coarctation; ARVC, arrhythmogenic right ventricular cardiomyopathy; AVSD, atrio-ventricular septal defect; BSA, body surface area; Bi, biventricular circulation; D-TGA, transposition of great arteries; DORV, double outlet right ventricle; F, female; HCM, hypertrophic cardiomyopathy; Hypo, hypoplastic; HRV, hypoplasic right ventricle; M, male; m, month; PA, pulmonary atresia; ToF, tetralogy of Fallot; TA, tricuspid atresia; TX, transplant; VSD, ventricular septal defect; Uni, univentricular circulation.

**Table 2.** Results of Correlation Between Left Atrial Pressure and E/e' Ratio.[a]

| Variables | Global (N = 48) | First 72 hours (n = 32) | After 72 hours (n = 16) | Significance (*P*) Comparing Pre and Post 72 h (*U* de Mann–Whitney) |
|---|---|---|---|---|
| LAP, mm Hg | 12.0 (10-14) | 12.5 (10.5-15) | 11.5 (10-14) | .9 |
| E/e' | 10.25 (8.8-12.6) | 10.0 (8.3-12.2) | 11.7 (9-13.2) | .17 |
| Intraclass correlation | 0.35 | 0.25 | 0.78 ($P < .01$) | – |
| E Wave, cm/s | 80 (55-96) | 76 (52-96) | 86 (66-102) | .56 |
| e' Wave, cm/s | 7.5 (5-9) | 7.5 (5-10.5) | 7 (5.25-9) | .79 |
| LVEF, % | 63 (54-70) | 60 (50-69.5) | 67 (64.5-71.5) | .02 |
| Inotropic score | 16 (10-25.5) | 20 (10-33) | 15 (13-20) | .86 |

Abbreviations: LAP, left atrial pressure; LVEF, left ventricular ejection fractionp; p25, percentile 25; p75, percentile 75.
[a]Values expressed with median and interquartile range –p25 and p75-.

## Comment

In our study, a good correlation was found between the E/e' ratio and direct left atrial pressure measurement beyond 72 hours following heart surgery ($r = .78$). However, this correlation was rather poor in the immediate postoperative period ($r = .25$).

Another relevant finding was high positive predictive value of E/e' ratio $\geq$13 (87%), as predictive of high left atrial pressure, regardless of whether the study was performed before or after 72 hours, with the negative predictive value somewhat lower (73%). Thus, when E/e' ratio was <13, the echocardiography was not so reliable to exclude patients with left atrial pressure $\geq$13 mm Hg.

Ommen et al,[5] after studying 100 consecutive adult patients simultaneously undergoing left heart catheterization and echocardiographic study, concluded that the E/e' ratio >15 was the best predictor of elevated filling pressures (mean left ventricle diastolic pressure >12 mm Hg) regardless of the systolic ventricular function of each patient. On the other hand, E/e' ratios <8

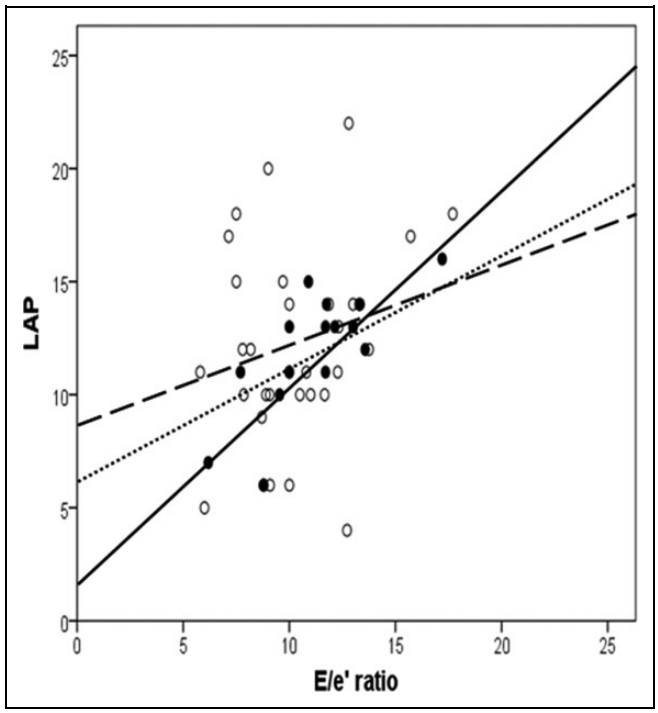


**Figure 1.** Correlation graphic of E/e' and left atrial pressure (LAP). Dotted line represents the correlation of all studies (N = 48). Dashed line represents the correlation of studies (unfilled circles) in the first 72 hours (n = 32), and black line represents the correlation of studies (black filled circles) after 72 hours (n = 16). Units: E/e' is an dimensionless ratio; left atrial pressure: mm Hg.

**Table 3.** Sensitivity, Specificity, Predictive Values, and Area Under ROC of E/e' ≥13 to Distinguish Left Atrial Pressure Values ≥13 mm Hg.

| | Global (N = 48) | Studies < 72 h (n = 32) | Studies > 72 h (n = 16) |
|---|---|---|---|
| Sensitivity, n (%) | 13/22 (59) | 7/14 (50) | 6/8 (75) |
| Specificity, n (%) | 24/26 (92) | 17/18 (94) | 7/8 (88) |
| PPV, n (%) | 13/15 (87) | 7/8 (88) | 6/7 (86) |
| NPV, n (%) | 24/33 (73) | 17/24 (71) | 7/9 (78) |
| Area under ROC curve ($P < .05$) | 0.75 | 0.72 | 0.82 |

Abbreviations: NPV, negative predictive value; PPV, positive predictive value; ROC, receiver–operating characteristics.

were correlated with low or normal filling pressures. Similarly, Lazarret et al[13] compared the E/e' ratio with direct left atrial pressure measurements in 37 children under one year of age in the first 24 hours postsurgery. They observed that E/e' ratios >15 correlated with left atrial pressure values >10 mm Hg, with high sensitivity and specificity. However, as occurred in our study, e' wave showed few changes in patients with left atrial pressure values <10 mm Hg.

In our study, left atrial pressure values in the first three days postsurgery were higher (median: 12.5 mmHg) than those of the E/e' ratio (median 10), which represented a poor correlation in the first 72 hours. These high left atrial pressure values may be related to the usual low cardiac output status in the immediate postoperative period[13] in which blood flow could be slower thereby generating E waves of lower velocity as shown in our work which could justify lower E/e' ratios. After 72 hours, the low cardiac output and systolic and diastolic functions are expected to recover with improvement in the left ventricular ejection fraction and a lower inotropic score as in our patients which probably contributed to the drop in left atrial pressure values observed after 72 hours (11.5 mm Hg [10-14]). Likewise, E/e' ratio values in this period rose slightly (11.7 [9-13.2]), thus showing a better correlation between the two variables. The improvement in cardiac output in this later period could have accounted for the increased E-wave and, consequently, for the increased E/e' ratio. E transmitral wave depends on the difference between the left atrial and the left ventricular pressures being preload sensitive and changing as diastolic dysfunction progresses.[6,9] On the contrary, the e'-wave value seems to be less preload dependent because early myocardial relaxation occurs earlier than ventricular filling.[6,9,14] In our study, the e'-wave value obtained by tissue Doppler varied little before and after 72 hours and thus appeared to play a less significant role in the overall E/e' ratio.

This study has several limitations. Indeed, the small sample size and heterogeneity of the congenital heart diseases in the selected patients could limit the value of the study. In addition, although all echocardiographic variables were measured always by the same investigator, not all the echocardiographic examinations were performed by the same physician. The e'-wave value was only taken in the lateral aspect of the mitral annulus. Echocardiographic E and e' waves were the unique variables taken into account to estimate the left atrial pressure in this study, whereas during the last decade other echo parameters have been described, like left atrial area or E wave deceleration time.[10]

Importantly, however, echocardiography continues to be the noninvasive technique of choice for assessing diastolic function and estimating left atrial pressure since it is rapid, innocuous, and can be performed at the patient's bedside.[2,5,15] We recognize, however, that no echocardiographic parameter alone is sufficiently robust to assess left ventricle filling pressures.[16,17] In keeping with this, in our study, the echocardiographic E/e' ratio did not show a good correlation with left atrial pressure in the immediate postoperative period. Nevertheless, although the E/e' ratio cannot replace direct left atrial pressure measurement, its positive predictive value may suffice to aid the bedside clinician in predicting elevated left atrial pressure in patients without left atrial catheters. We also suggest that further studies with larger numbers of patients are required to ascertain whether a better correlation exists between the E/e' ratio and the left atrial pressure values.

## Authors' Note

The authors had full control of the design of the study, methods used, outcome parameters, analysis of data, and production of the written support. The authors assert that all procedures contributing to this

work comply with the ethical standards and with the Helsinki Declaration of 1975, as revised in 2008, and has been approved by the institutional committee (Comité ètic d'investigació clínica, Hospital Vall d'Hebron).

## Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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