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Diagnostic Value of Echocardiographic Indices in Determining Right Atrial Pressure Compared to Catheterization in Pediatrics and Young Adults

Çocuk ve Genç Erişkinlerde Sağ Atriyal Basıncın Belirlenmesinde Kateterizasyona Kıyasla Ekokardiyografik İndekslerin Tanısal Değeri

ABSTRACT

Objective: Determining right atrial pressure (RAP) is an important hemodynamic parameter for calculating right ventricular pressure, commonly measured using right heart catheterization, an invasive procedure. However, non-invasive methods should be prioritized, particularly in pediatric patients. There is a lack of evidence regarding this issue in pediatric and young adult populations compared to adults.

Method: This diagnostic cross-sectional study was conducted to investigate echocardiographic criteria for estimating right atrial pressure in 350 pediatric patients from March 2020 to December 2021.

Results: The mean right atrial pressure was significantly higher in patients with a Caval index of less than 50% (7.89 ± 4.48 mmHg vs. 6.3 ± 3.18 mmHg, P = 0.002) and in those with cyanotic congenital heart disease (CHD) (P = 0.018). There was a significant correlation between a Caval index cut-off point of 50% and a mean RAP cut-off point of 10 mmHg (P = 0.024), with a specificity of 85.7% for a Caval index < 50% in estimating right atrial pressure > 10 mmHg. Additionally, a difference was observed between the tricuspid valve E/E´ ratio with a cut-off point of 7 and the mean right atrial pressure with a cut-off point of 5 mmHg (P = 0.043), with a sensitivity of 70.2% for a tricuspid valve E/E´ratio > 7 in estimating right atrial pressure > 5 mmHg.

Conclusion: This study demonstrated that echocardiographic indices, such as the Caval index and tricuspid valve E/E´ ratio, can be useful in non-invasive estimation of right atrial pressure. However, age-specific reference values and cut-off points for these indices should be considered to improve their accuracy.

Keywords: Right atrial pressure, pediatrics, echocardiography, inferior vena cava, Caval index

ÖZET

Amaç: Sağ atriyal basıncın belirlenmesi, sağ ventrikül basıncının hesaplanması için önemli bir hemodinamik kriterdir ve genellikle sağ kalp kateterizasyonu (invazif bir prosedür) kullanılarak ölçülür. Ancak, özellikle pediatride non-invaziv yöntemlere öncelik verilmelidir. Yetişkinlere kıyasla bu yaş gruplarında bu konuya ilişkin kanıt eksikliği bulunmaktadır.

Yöntem: Araştırma, Mart 2020 - Aralık 2021 tarihleri arasında 350 pediatrik hastada sağ atriyal basıncı tahmin etmek için ekokardiyografik kriterleri araştırmak için yapılan tanısal tipte kesitsel bir çalışmadır.

Bulgular: Ortalama sağ atriyal basınç, Caval indeksi %50'den az olan hastalarda (7,89 ± 4,48 mmHg'ye karşı 6,3 ± 3,18 mmHg, P = 0,002) ve siyanotik KKH olanlarda (P = 0,018) anlamlı olarak daha yüksekti. Kesim noktası %50 olan Caval indeksi ile kesim noktası 10 mmHg olan ortalama RAP arasında anlamlı bir korelasyon vardı (P-değeri = 0,024) ve sağ atriyal basıncın >10 mmHg olduğunu tahmin etmek için Caval indeksi<%50'nin özgüllüğü=%85,7 idi. Ek olarak, triküspit kapağın E/E´si 7 kesme noktası ile ortalama sağ atriyal basınç 5 mmHg kesme noktası arasında bir fark vardı (P-değeri =0,043) ve sağ atriyal basınç >5 mmHg tahmini için triküspit kapak E/E´>7 duyarlılığı=%70,2 idi.

Sonuç: Bu çalışma, Caval indeksi ve triküspit kapak E/E´ gibi ekokardiyografik indekslerin sağ atriyal basıncı non-invaziv olarak tahmin etmede yararlı olabileceğini göstermiştir. Bununla birlikte, bu indekslerin doğruluğunu artırmak için yaşa özgü referans değerlerini ve kesme noktalarını dikkate almak çok önemlidir.

Anahtar Kelimeler: Kaval indeks, ekokardiyografi, inferior vena kava, pediatri, sağ atriyal basınç

ORIGINAL ARTICLE
KLİNİK ÇALIŞMA

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Congenital heart diseases (CHDs) are the most prevalent congenital malformations, affecting approximately 1% of all live births worldwide. If left untreated, CHDs can lead to significant morbidity and mortality.

In addition to clinical features, data from echocardiography, catheterization, and other modalities are essential for appropriate management.

Right atrial pressure (RAP) is a crucial hemodynamic parameter that not only reflects the filling pressure of the right heart but also aids in estimating right ventricular systolic pressure non-invasively using echocardiography. The signal of tricuspid regurgitation, observed in spectral continuous-wave Doppler imaging, reflects the pressure gradient between the right ventricle (RV) and the right atrium (RA). Additionally, assessing RAP is important when evaluating restructured connections between the atria.[1-5] RAP is commonly measured using right heart catheterization, an invasive procedure associated with various complications, including arrhythmia, pericardial effusion, cardiac perforation, emergency cardiac surgery, local vascular complications requiring surgical intervention, and mortality.[6] Fortunately, echocardiography has emerged as a non-invasive alternative. Several echocardiographic indices have been proposed for pressure estimation, eliminating the need for catheterization, improving patient comfort, and reducing the risk of complications associated with invasive procedures.[7-10]

Objectives

Although several studies have investigated and established echocardiographic indices, such as inferior vena cava (IVC) diameter, IVC collapsibility, and the ratio of tricuspid E-wave velocity to E'-wave velocity (E/E') for estimating RAP in adult patients,[11,12] evidence in the pediatric population with CHD is sparse and limited.[13] Therefore, this study aimed to assess echocardiographic indices for estimating RAP in pediatric patients with CHD.

Materials and Methods

This cross-sectional study was conducted on patients with CHD who underwent cardiac catheterization and were admitted to the pediatric cardiology ward at Shahid Beheshti University Hospital from March 2020 to December 2021. Patients were included consecutively, while those with interrupted inferior vena cava, tricuspid atresia, severe tricuspid regurgitation, or pure left catheterization were excluded.

Demographic and clinical data were obtained from medical records. A senior pediatric cardiology fellow, under the supervision of an attending pediatric cardiologist, performed all echocardiographic studies in the catheterization laboratory one to two hours before cardiac catheterization using an EKO 7 machine (Samsung, Republic of Korea). The studies were conducted in 2D, color Doppler, and tissue Doppler modes using two probes (2-4 HZ and 3-8 HZ).

The IVC diameter was measured in the "biocidal view" at a point 1 cm from the IVC-right atrial junction. The M-mode modality was used to measure the maximum IVC diameter (IVC_{max}) and the minimum IVC diameter (IVC_{min}) during quiet respiration at end-expiration and during an inspiratory sniff, respectively. The

ABBREVIATIONS

CHD	Congenital heart disease
E/E'	E-wave velocity to E'-wave velocity
IV	Intravenous
IVC	Inferior vena cava
PPV	Positive pressure ventilation
RA	Right atrium
RAP	Right atrial pressure
RV	Right ventricle

IVC collapsibility (Caval index) was calculated using the formula: $(IVC_{max} - IVC_{min}) / IVC_{max} \times 100$. The E-wave velocity of the tricuspid valve was measured using pulsed Doppler, with the cursor positioned at the tip of the valve. Additionally, the E' velocity was measured using tissue Doppler at the lateral tricuspid annulus.

Cardiac catheterization was performed after a fasting period of 4 to 6 hours, depending on the patient's age, under different anesthesia modes, including conscious sedation with spontaneous breathing, conscious sedation requiring positive pressure ventilation (PPV), or general anesthesia with PPV. During the fasting period, an intravenous (IV) line was placed, preferably in an upper extremity, before the patient arrived in the catheterization laboratory. This facilitated the administration of IV 10% dextrose water at a rate of 4 cc/kg/hr to ensure adequate hydration. The pressures of the right atrium, right ventricle, and pulmonary artery were measured using a multi-purpose (A2) catheter while the patients were sedated. Three measurements were taken for all echocardiographic and catheterization parameters, and the mean value was recorded.

This study was approved by the Ethical Committee of the Shahid Beheshti University of Medical Sciences (Approval Number: IR.SBMU.MSP.REC.1396.276, Date: 25.07.2018). Patients were included after providing written informed consent. The study was conducted in accordance with the Declaration of Helsinki.

The collected data were analyzed using appropriate descriptive tools and statistical tests in SPSS 22 software (IBM, NY, USA). Pearson and Spearman correlation coefficient tests were used to evaluate the correlation between the quantitative and categorical values of RAP and E/E´ with echocardiographic indices. The t-test and Chi-square test were used to assess the significance of RAP differences across echocardiographic index groups. A p-value less than 0.05 was considered statistically significant.

Results

Among the 350 cases, 189 (54%) were male. The patients' ages ranged from 5 days to 22 years, with a mean age of 57.80 ± 63.01 months. Of these, four patients (1.1%) were neonates, 96 patients (38.4%) were under one year old, and 62 patients (24.8%) were older than 12 years (Figure 1).

Table 1 details the types of congenital heart disease included in the study. The most common CHDs were ventricular septal defect (17.7%) and tetralogy of Fallot (13.4%). Acyanotic CHD accounted for 68% of cases (238 patients). Among the 271 cases that underwent pulmonary artery pressure measurement, 105 patients (38.7%) exhibited pulmonary hypertension, defined as

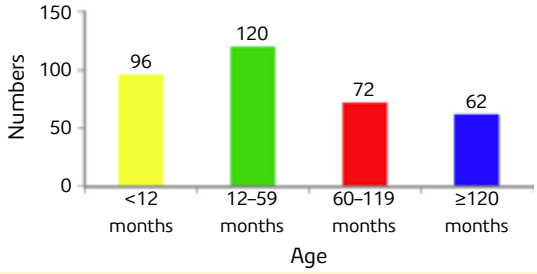

Figure 1. Age distribution of studied patients.

a mean pulmonary arterial pressure > 20 mmHg at rest. Table 2 provides additional echocardiographic and catheterization data, including results from the correlation analysis between mean right atrial pressure and echocardiographic indices.

As illustrated in Table 3, a significant correlation was observed between mean RA pressure and the maximum and minimum diameters of the inferior vena cava, as well as the Caval index. Table 4 further demonstrates that mean RA pressure was significantly higher in patients with a Caval index < 50% (7.89 ± 4.48 mmHg vs. 6.3 ± 3.18 mmHg, P = 0.002) and in those with cyanotic CHD.

Tables 5 and 6 explore the relationship between echocardiographic parameters, catheterization findings, and mean RAP categorized by cut-off values of 5 and 10 mmHg. Notably, a significant correlation was found between the Caval index with a cut-off point of 50% and categorized mean RAP with a cut-off of 10 mmHg (P = 0.024). However, no significant correlation was observed between categorized tricuspid valve E/E' ratios and classified mean RAP.

Based on the data, the sensitivity, specificity, positive predictive value, and negative predictive value (NPV) of a Caval index < 50% for predicting RAP > 10 mmHg were 25.3%, 85.7%, 33.3%, and 80.2%, respectively. Additionally, a significant correlation was identified between categorized tricuspid valve E/E' ratios (cut-off points of 5 and 10) and classified mean RAP in patients aged 1–5 years (P = 0.020 and P = 0.021, respectively) (Table 7).

Table 1. Types of Congenital Heart Disease in Studied Patients

Disease Type	Number (%)	Disease Type	Number (%)
VSD	62 (17.7)	Co-A	13 (3.7)
TOF	47 (13.4)	AS	12 (3.4)
PDA	39 (11.1)	ASD (S.V.)	9 (2.6)
ASD II	26 (7.4)	VSD + AI	8 (2.2)
PS	26 (7.4)	PPHN	6 (1.7)
AVSD	24 (6.8)	MS	4 (1.1)
VSD + PS	23 (6.5)	TAPVC	4 (1.1)
TGA	22 (6.2)	DCM	4 (1.1)
Pulmonary Atresia	19 (5.4)	Truncus Arteriosus	2 (0.6)

AI, Aortic Insufficiency; AS, Aortic Stenosis; ASD (S.V.), Atrial Septal Defect (Sinus Venosus); ASD II, Atrial Septal Defect Secundum; AVSD, Complete Atrioventricular Septal Defect; Co-A, Coarctation of the Aorta; DCM, Dilated Cardiomyopathy; MS, Mitral Stenosis; PDA, Patent Ductus Arteriosus; PPHN, Primary Pulmonary Hypertension; PS, Pulmonary Stenosis; TAPVC, Total Anomalous Pulmonary Venous Connection; TGA, Transposition of the Great Arteries; TOF, Tetralogy of Fallot; VSD, Ventricular Septal Defect.

Table 2. Demographic, Echocardiographic, and Catheterization Findings of Studied Patients

	Minimum	Maximum	Mean ± SD
Age (months)	0.16	348	57.80 ± 43.01
Weight (kg)	2.50	84	16.92 ± 14.99
Max. IVC Diameter (cm)	0.19	2.60	0.77 ± 0.41
Min. IVC Diameter (cm)	0.03	1.43	0.27 ± 0.24
TV. E (cm/s)	32	143	76.79 ± 21.85
TV. E´ (cm/s)	3	37	12.40 ± 4.16
Mean PAP (mmHg)	7	93	26.62 ± 16.47
RVSP (mmHg)	16	160	65.19 ± 30.37
Mean RAP (mmHg)	2	20	6.55 ± 3.45
Caval Index	25	95	66.88 ± 14.58
E/E´ Ratio	1.68	23.50	6.84 ± 3.07

IVC, Inferior Vena Cava; PAP, Pulmonary Artery Pressure; RAP, Right Atrial Pressure; RVSP, Right Ventricular Systolic Pressure; TV, Tricuspid Valve.

Discussion

This study evaluated the correlation between echocardiographic indices and catheterization-measured RAP in a cohort of pediatric and young adult patients with CHD. To our knowledge, this represents one of the largest studies addressing this topic in pediatric populations.

Our findings indicate a significant correlation between mean RAP and the maximum and minimum diameters of the IVC, as well as the IVC collapsibility index. Additionally, a significant correlation was observed between tricuspid valve E/E' velocity and RAP > 5 mmHg in the 1–5 years age group. Importantly, the IVC collapsibility index < 50% demonstrated high specificity for estimating RAP > 10 mmHg. However, tricuspid valve E/E' velocity > 7 did not show a significant correlation with RAP > 5 mmHg overall.

Previous studies have reported mixed findings regarding these associations. Yildirimturk et al.[14] investigated 39 patients with rheumatic mitral valve stenosis and found no significant association between the tricuspid valve E/E' ratio and RAP.

Table 3. Correlation Between Mean Right Atrial Pressure (RAP) and Echocardiographic and Catheterization Findings in Studied Patients

		Max. IVC Diameter	Min. IVC Diameter	Mean PAP	TV. E	TV. E´	RVSP	Caval Index	E/E´
Mean RAP	Correlation	0.220	0.214	0.096	0.084	-0.033	0.143	-0.127	0.081
	P Value	**0.006**	**0.003**	0.117	0.137	0.557	0.012	**0.019**	0.149

Table 4. Correlation of Echocardiographic Parameters and Catheterization Findings with Mean Right Atrial Pressure (RAP) in Studied Patients

		Number of Patients	Mean of Mean RAP ± SD	P
Gender	Male	189	6.58 ± 3.40	0.89
	Female	161	6.53 ± 3.53	
Cyanosis	No	238	6.25 ± 3.32	**0.018**
	Yes	112	7.20 ± 3.66	
P.HTN	No	166	6.55 ± 3.15	0.165
	Yes	105	7.16 ± 3.94	
Caval Index	< 50%	59	7.89 ± 4.48	**0.002**
	≤ 50%	287	6.30 ± 3.18	
E/E´ Ratio	< 7	201	6.10 ± 3.20	0.128
	≥ 7	83	6.79 ± 3.79	
E/E´ Ratio	< 10	264	6.32 ± 3.36	0.243
	≥ 10	41	7.00 ± 3.91	

P.HTN, Pulmonary Hypertension.

Table 5. Correlation of Echocardiographic Parameters and Catheterization Findings with Mean Right Atrial Pressure (RAP) at Cutoff Levels of 5 mmHg and 10 mmHg in Studied Patients

	Mean RAP ≥5 mmHg	Mean RAP < 5 mmHg	P	Mean RAP ≥10 mmHg	Mean RAP <10 mmHg	P
Max. IVC Diameter			**0.002**			**0.017**
Number	178	165		268	75	
Mean ± SD	0.70 ± 0.37	0.84 ± 0.44		0.74 ± 0.39	0.87 ± 0.47	
Min. IVC Diameter			**0.011**			**0.022**
Number	178	165		268	75	
Mean ± SD	0.24 ± 0.21	0.31 ± 0.26		0.26 ± 0.22	0.33 ± 0.29	
TV. E			0.416			0.438
Number	173	142		251	64	
Mean ± SD	76.19 ± 21.96	78.21 ± 21.73		76.62 ± 21.85	79.00 ± 21.85	
TV. E´			0.556			0.580
Number	173	142		251	64	
Mean ± SD	12.33 ± 3.95	12.61 ± 4.38		12.52 ± 4.19	12.20 ± 4.01	
Mean PAP			0.649			0.097
Number	127	140		205	62	
Mean ± SD	26.26 ± 16.55	27.19 ± 16.54		25.82 ± 15.72	29.80 ± 18.74	
RVSP			**0.004**			0.128
Number	152	155		236	71	
Mean ± SD	60.34 ± 29.10	70.12 ± 30.41		63.84 ± 30.21	70.05 ± 29.56	
Caval Index			0.266			0.166
Number	178	165		268	75	
Mean ± SD	67.77 ± 14.07	66.03 ± 14.94		67.51 ± 13.88	64.88 ± 16.46	
E/E´			0.888			0.558
Number	173	142		251	64	
Mean ± SD	6.82 ± 3.12	6.87 ± 3.06		6.79 ± 3.13	7.04 ± 2.91	

IVC, Inferior vena cava; TV, Tricuspid Valve; PAP, Pulmonary Artery Pressure; RVSP, Right Ventricular Systolic Pressure.

However, a positive correlation was identified between the Caval index and RAP in patients with atrial fibrillation ($r = 0.56$, $P < 0.05$) and between IVC diameter and RAP in patients with normal sinus rhythm ($r = 0.62$, $P < 0.005$).

Table 6. Correlation of Classified Echocardiographic Parameters and Catheterization Findings with Categorized Mean Right Atrial Pressure (RAP) at Cutoff Levels of 5 mmHg and 10 mm Hg in the Studied Patients

	Mean RAP ≥5 mmHg	Mean RAP <5 mmHg	P	Mean RAP ≥10 mmHg	Mean RAP <10 mmHg	P
E/E´ Ratio			0.053			0.807
>7	110 (55.8%)	87 (44.2%)		158 (80.2%)	39 (19.8%)	
≤7	44 (54.3%)	37 (45.7%)		66 (81.5%)	15 (18.5%)	
E/E´ Ratio			0.926			0.917
>10	141 (54.4%)	118 (45.6%)		204 (78.8%)	55 (21.2%)	
≤10	22 (53.7%)	19 (46.3%)		32 (78.0%)	9 (22.0%)	
Caval Index			0.099			**0.024**
> 50%	24 (42.1%)	33 (57.9%)		38 (66.7%)	19 (33.3%)	
≤ 50%	153 (54.1%)	130 (45.9%)		227 (80.2%)	56 (19.8%)	

Table 7. Correlation of Categorized Echocardiographic Parameters and Catheterization Findings with Classified Mean Right Atrial Pressure (RAP) at Cutoff Levels of 5 mmHg and 10 mmHg in Studied Patients

		Mean RAP ≥ 5	Mean RAP <5	P		Mean RAP ≥5	Mean RAP <5	P		Mean RAP ≥5	Mean RAP <5	P
< 12 months	E/E´ > 7	32	20	0.190	E/E´ > 10	40	24	0.156	Caval Index >50%	5	3	0.987
	E/E´ ≤ 7	22	7		E/E´ ≤ 10	13	3		Caval Index ≤50%	54	32	
12–59 months	E/E´ > 7	45	19	**0.020**	E/E´ > 10	56	31	**0.021**	Caval Index >50%	5	9	0.126
	E/E´ ≤ 7	12	15		E/E´ ≤ 10	4	9		Caval Index ≤50%	58	43	
60–119 months	E/E´ > 7	17	29	0.921	E/E´ > 10	25	34	0.669	Caval Index >50%	4	7	0.742
	E/E´ ≤ 7	5	8		E/E´ ≤ 10	2	4		Caval Index ≤50%	25	35	
≥ 120 months	E/E´ > 7	16	19	0.808	E/E´ > 10	20	29	0.667	Caval Index >50%	10	14	0.832
	E/E´ ≤ 7	5	7		E/E´ ≤ 10	3	3		Caval Index ≤50%	16	20	

Arya et al.[7] studied pediatric and young adult populations and found that long-axis IVCmax ($r = 0.30$, $P < 0.05$) and E-wave velocity ($r = 0.36$, $P < 0.01$) correlated significantly with mean RAP, though the IVC collapsibility index and tricuspid valve E/E' ratio did not.

A study conducted by Amoozgar et al.[15] found that estimated right atrial pressure greater than 8 mmHg moderately increased when the inferior vena cava diameter exceeded 6 mm, with a positive likelihood ratio of 4.67. Additionally, Pearson correlation analysis revealed a weak positive association ($r = 0.23$) between IVC collapse during the respiratory phase and mean RAP, though this relationship was not statistically significant ($P = 0.108$).

Kircher et al.'s study[16] identified a weak correlation between the end-expiratory IVC diameter and RA pressure, whereas a stronger correlation was observed with the end-inspiratory diameter and respiratory Caval indices. A 50% collapse in respiratory Caval indices emerged as the most reliable predictor of RA pressure above or below 10 mmHg, with an accuracy rate of 88% sensitivity and 81% specificity.

Mintz et al.[17] reported an association between right atrial pressure ≥ 10 mmHg and an end-diastolic IVC diameter ≥ 10 mm/m^2.

Lorsomradee et al.[18] demonstrated a significant correlation between IVC diameter and RAP less than or equal to 11 mmHg

(r = 0.801, P < 0.001). However, a weak correlation was noted between IVC diameter and RAP exceeding 11 mmHg (r = 0.272, P = 0.065) in patients who had undergone cardiac surgery.

Egbe et al.[19] found strong correlations between IVC_{max} and invasive RAP (r = 0.56, P < 0.001), IVC_{min} and RAP (r = 0.58, P < 0.001), and the IVC collapsibility index (IVCCI) and RAP (r = −0.72, P < 0.001) in their analysis of 918 subjects. Their findings indicated that an IVCCI less than 60% was more effective in diagnosing RAP > 10 mmHg compared to the criteria set by the American Society of Echocardiography.

Limitations

Several limitations warrant consideration. First, accurately measuring the IVC collapsibility index in infants is challenging due to respiratory artifacts, a recognized issue in pediatric populations. Second, the timing of echocardiographic examinations was not synchronized with cardiac catheterization, potentially introducing variability in RAP measurements, particularly in patients receiving positive pressure ventilation. Finally, while significant correlations were observed between IVC diameters and RAP, these measurements were not normalized for body surface area or expressed as z-scores, limiting their clinical applicability.

Conclusion

This study demonstrated that echocardiographic indices, such as the Caval index and tricuspid valve E/E' ratio, can be useful for non-invasive estimation of RAP. However, it is essential to consider age-specific reference values and cut-off points for these indices to enhance their accuracy. Additionally, these indices should be used cautiously in patients with comorbidities that may impact IVC diameter and collapsibility. Further research is required to validate these findings and establish standardized procedures for using echocardiographic indices in pediatric patients with CHD in clinical practice.

Ethics Committee Approval: This study was approved by the Ethical Committee of the Shahid Beheshti University of Medical Sciences (Approval Number: IR.SBMU.MSP.REC.1396.276, Date: 25.07.2018).

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