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ORIGINAL ARTICLE

Prediction of the development of pulmonary arterial hypertension with Tei Index in congenital heart diseases with left-to-right shunt

Soldan sağa şantlı doğumsal kalp hastalıklarında pulmoner arteriyel hipertansiyon gelişiminin Tei indeksi ile öngörülmesi

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ABSTRACT

Objective: The aim of this study was to determine the usefulness of the Tei Index, an echocardiographic parameter, in the early determination of pulmonary artery pressure (PAP) in congenital heart disease (CHD) with a left-to-right shunt.

Methods: Right and left ventricular functions were evaluated using Tei Index values determined with tissue Doppler echocardiography. Cardiac catheterization was performed in all cases. The presence of pulmonary arterial hypertension (PAH) was defined as a mean PAP of ≥25 mm Hg and a pulmonary vascular resistance index of >3 WU/m^2. Patients with a pulmonary/systemic blood flow ratio of ≥2 were considered candidates for surgery.

Results: The Tei Index values measured from the left ventricular posterior wall and the right ventricular anterior wall were found to be significantly higher in the patients with PAH (0.68±0.18, 0.67±0.16, respectively) compared with the patients without PAH (0.56±0.16, p=0.027; 0.51±0.12 p=0.001). A significant correlation was detected between the Tei Index value measured from the left ventricular posterior wall and the mean PAP (correlation coefficient: 0.491).

Conclusion: The right ventricular Tei Index values in children with CHD and a left-to-right shunt can be used as a parameter to follow up on the potential development of PAH, to make a diagnosis in the early period, and to make a timely decision about surgery.

ÖZET

Amaç: Çalışmamızın amacı, soldan sağa şantlı doğumsal kalp hastalıklarında pulmoner arter basıncını belirlemede bir ekokardiyografik parametre olan Tei İndeksi'nin kullanılabilirliğinin belirlenmesidir.

Yöntemler: İzole soldan sağa şantlı doğumsal kalp hastalığı olan ve cerrahi öncesi tanı amaçlı kalp kateterizasyonu yapılan 30 olgu ile 30 sağlıklı çocuk çalışmaya alındı. Grupların sağ ve sol ventrikül fonksiyonları Tei İndeksi belirlemek amacıyla doku Doppler ekokardiyografi ile değerlendirildi. Pulmoner ve sistemik kan akımları hesaplandı. Ortalama pulmoner arter basıncı ≥25 mm Hg ve pulmoner vasküler rezistans indeksi >3 WU/m^2 olan olgular pulmoner arteriyel hipertansiyon olarak kabul edildi. Pulmoner/sistemik kan akımı oranı ≥2 olanlar cerrahiye uygun olgular olarak değerlendirildi.

Bulgular: Sol ventrikül arka duvar ve sağ ventrikül ön duvardan ölçülen Tei İndeksi değerleri pulmoner arteriyel hipertansiyonu olan olgularda (0.68±0.18, 0.67±0.16) pulmoner arteriyel hipertansiyonu olmayan olgulara (0.56±0.16, 0.51±0.12) göre belirgin olarak yüksek tespit edildi (p=0.027, p=0.001). Ayrıca, sol ventrikül arka duvardan elde edilen Tei İndeksi ile ortalama pulmoner arter basıncı arasında belirgin korelasyon olduğu görüldü (korelasyon katsayısı: 0.491).

Sonuç: Soldan sağa şantlı doğumsal kalp hastalığı bulunan çocuklarda özellikle sağ ventrikülün çeşitli bölgelerinden ölçülen Tei İndeksi değerleri, pulmoner arteriyel hipertansiyon gelişiminin takibinde, bunun erken tanısında ve uygun zamanda cerrahiye karar vermede kullanılabilir.

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Pulmonary arterial hypertension (PAH) is a pathological condition that occurs as a result of structural and functional impairment of the pulmonary vascular bed, and often develops secondary to heart and lung disease. PAH in childhood is associated with congenital heart disease (CHD), particularly in patients with a left-to-right shunt. Eisenmenger syndrome may occur as a complication of a congenital heart defect that allows intracardiac communication, and subsequent closure of the hole is usually contraindicated.[1,2]

Cardiac catheterization is the gold standard to determine the pulmonary artery pressure (PAP). The Doppler method, which measures the tricuspid regurgitation to determine the pressure difference between the 2 spaces and the tricuspid annular plane systolic excursion is another widely used non-invasive method.[1] However, there are various difficulties in determining the PAP using these non-invasive methods. Studies have shown that right ventricular functions are important variables and indicators of a natural process in patients with pulmonary hypertension.[2,3]

Tei et al.[4,5] calculated the Tei Index (Myocardial Performance Index) using Doppler parameters that can be easily determined in clinical practice and the results are not affected by changes in pre-afterload, heart rate and blood pressure.[6]

The aim of this study was to examine whether the Tei Index can be used to predict the development of PAP in children with CHD and a left-to-right shunt.

METHODS

This study included 30 children with CHD and an isolated left-to-right shunt who underwent cardiac catheterization for diagnosis before surgery and 30 healthy children of the same age range. Cardiac catheterization was performed due to a suspicion of the development of PAH based on echocardiography results, inadequate weight gain, frequent pulmonary infections or other lower respiratory tract infections, progressive left ventricular dilatation, or suspicion of possible other cardiac lesions observed on echocardiography. Patients who were using PAH-specific therapy, had chronic pulmonary disease, or had a left or right ventricular outflow tract obstruction were excluded. Local hospital ethics committee approval and written informed consent was obtained from the patients.

Echocardiographic evaluation

Echocardiographic examinations were performed using a Sonos 5500 (Phillips Healthcare, Andover, MA, USA) with a 5.0 MHz transducer in the pediatric cardiology echocardiography laboratory. Echocardiograms were recorded on video tape and were analyzed by a second, blinded pediatric cardiologist directly from the stored images. The average result of 3 cycles was used for each parameter. All of the measurements were performed according to the guidelines of the American Society of Echocardiography.[7,8]

A routine echocardiographic examination was performed on all of the patients and control subjects. Measurements were obtained from 4 locations with the sample volume positioned on the lateral aspect of each atrioventricular valve annulus and the basal portion of the interventricular septal region of each ventricle. Tissue Doppler velocity measurements of peak early diastolic myocardial (Em), peak atrial systolic (Am), and peak systolic myocardial (Sm) velocity were performed using the standard technique. Em/Am ratios were also calculated. Time intervals of isovolumetric contraction time (IVCTm), myocardial ejection contraction time (CTm), and isovolumetric relaxation time (IVRTm) were measured in order to calculate the Tei Index values using the formula of the sum of isovolumetric contraction and relaxation times divided by the ejection time.[4,5] A Tei index value of >0.5 was considered high.

Hemodynamic evaluation

Midazolam and/or chloral hydrate was administered to the patients to induce sedation during catheterization. Ketamine was not used since it can affect pressure measurements. Pressure and oxygen measurements were performed in room air using an appropriate-size catheter (fluid-filled). Pulmonary and systemic blood flows and resistance were calculated. A mean PAP of ≥25 mm Hg and a pulmonary vascular resistance in-

Abbreviations:

Am	*Peak atrial systolic velocity*
ASD	*Atrial septal defect*
AVSD	*Atrioventricular septal defect*
CHD	*Congenital heart disease*
CTm	*Myocardial ejection contraction time*
Em	*Peak early diastolic myocardial velocity*
IVCTm	*Isovolumetric contraction time*
IVRTm	*Isovolumetric relaxation time*
PAH	*Pulmonary arterial hypertension*
PAP	*Pulmonary artery pressure*
PDA	*Patent ductus arteriosus*
Sm	*Peak systolic myocardial velocity*
VSD	*Ventricular septal defect*

dex of >3 WU/m^2 were considered to indicate PAH.[9] Patients with a mean pulmonary artery pressure of <25 mm Hg were classified as the group without PAH. Patients with a pulmonary/systemic blood flow ratio of ≥2 were considered candidates for surgery.

Statistical analysis

SPSS for Windows, Version 13.0 (SPSS Inc., Chicago, IL, USA) software was used to analyze the findings. The descriptive findings were presented as a mean±SD. The conformity to normal distribution was examined and variance analysis was used to compare the groups. The Student's t-test was applied for binary comparisons and Pearson's correlation analysis was used to examine the relationship between parameters. The significance level applied was p<0.05. Intraobserver and interobserver variability were assessed using Pearson's correlation analysis, coefficient of variance, and Bland-Altman analysis.

RESULTS

Patient characteristics

A total of 30 patients who were diagnosed with CHD using echocardiography and who underwent cardiac catheterization for consideration of surgical closure of the defect were included in the study. The diagnosis and the echocardiographic, clinical, and hemodynamic characteristics of the patients are provided in Table 1. Of our patients, 14 had a ventricular septal defect (VSD), 8 had an atrial septal defect (ASD), and 4 had both defects. Two had an atrioventricular septal defect (AVSD), 1 had a patent ductus arteriosus (PDA), and 1 had a single (common) atrium. The gender distribution of patients was 19 females and 11 males, and the mean age was 56 months. In all, 11 patients had PAH. There was no significant difference between the patient and control groups in terms of gender and age (p>0.05 for all).

The patients were divided into groups of those with PAH and those without PAH based on the PAP and blood flow ratio measured during cardiac catheterization. The congenital heart defects present in each group are shown in Table 2. In the patients with PAH, 7 (64%) had a VSD, 2 (18%) had an ASD, 1 (9%) had both atrial and ventricular septal defects, and 1 (9%) had an AVSD. In the patients without PAH, 7 (36%) had a VSD, 6 (31%) had an ASD, 3 (17%) had both atrial and ventricular septal defects, 1 (8%) had a single (common) atrium, and 1 (8%) had PDA.

Tissue Doppler echocardiographic measurements

The Em velocity, Sm velocity, CTm, and Em/Am ratio measured at 4 four levels were all significantly lower in patients with PAH (Table 3). The IVCTm and IVRTm intervals measured at 4 levels were significantly higher in the PAH group.

Tei Index measurement with tissue Doppler echocardiography

Table 4 provides the mean Tei Index values measured from the left ventricular posterior wall, the right ventricular anterior wall, and the edges of the septum with tissue Doppler in the patients with PAH, the patients without PAH, and the controls. The Tei Index values measured at these sites were significantly higher in the patient group compared with those of the control group. The left ventricular posterior wall Tei Index measurement of the patients with PAH (0.68±0.18) was statistically higher than that of the patients without PAH (0.56±0.16) (p=0.027). There was no statistically significant difference between the patients with PAH (0.57±0.12) and the patients without PAH (0.52±0.09) in the Tei Index value measured from the edges of the septum (p=0.389). The right ventricular anterior wall Tei Index value was significantly higher in the patients with PAH (0.67±0.16) than in the patients without PAH (0.51±0.12) (p=0.001). However, there was no statistically significant difference between the groups in the Tei Index value for the right ventricular edge of the septum (p=0.884).

The Tei Index measurement from the left ventricular posterior wall was >0.5 in 9 (82%) of 11 patients with PAH and 14 (74%) of 19 patients without PAH. The distribution of the pathological values of the left ventricular Tei Index measured with tissue Doppler echocardiography according to PAH status and pulmonary/systemic blood flow ratio is presented in Table 5. The right ventricular anterior wall Tei Index measurement was >0.5 in 10 (91%) of 11 patients with PAH and 9 (48%) of 19 patients without PAH. A Tei Index value >0.5 for the right ventricular anterior wall demonstrated a sensitivity and specificity for determining patients with PAH of 91% and 93.3%, respectively. The sensitivity and specificity of left ventricular posterior wall Tei Index results of >0.5 in patients with PAH was 81.8% and 96.6%, respectively.

Table 1. **Demographic features of the study population, echocardiographic diagnoses, tricuspid regurgitation gradient on echocardiography, and Qp/Qs ratio determined with cardiac angiography**

No	Sex	Age (months)	Weight (kg)	Congenital heart disease	TR gradient (mm Hg)	mPAP	Qp/Qs ratio
1	Female	72	21.3	ASD-VSD	25	15	2.896
2	Male	36	10.2	VSD	23	14	1.05
3	Male	132	41	ASD	21	15	2.56
4	Male	5	5.8	VSD	52	40	3.04
5	Female	24	8.5	VSD	41	30	1.802
6	Female	120	28	ASD	24	15	1.77
7	Male	36	12	VSD	70	55	2.22
8	Female	132	28	VSD	24	15	3.23
9	Female	5	4	VSD	46	35	1.83
10	Female	7	5.15	VSD	29	20	2.42
11	Female	192	55	ASD	25	15	2.95
12	Male	6	5.5	ASD-VSD	27	22	4.28
13	Male	8	6.3	ASD	23	20	2.32
14	Male	78	22	VSD	21	10	1.81
15	Female	168	35	VSD	89	75	5.73
16	Female	19	10	ASD	21	15	3.1
17	Male	6	5.7	VSD	57	40	16.7
18	Female	9	5.7	VSD-ASD	44	35	3.08
19	Male	6	6	AVSD	69	60	0.705
20	Female	26	9.5	Common atrium	32	20	2.89
21	Female	84	16	AVSD	30	20	1.64
22	Female	7	7.3	VSD	21	15	2.1
23	Female	156	40	VSD	47	35	1.41
24	Female	64	13	PDA	40	22	1.31
25	Female	76	15	ASD-VSD	23	17	1.79
26	Female	33	13	ASD	22	15	2.02
27	Female	9	5	ASD	63	50	1.15
28	Male	34	15	VSD	19	15	2.56
29	Male	126	32	VSD	21	15	1.43
30	Female	12	5.5	ASD	42	30	2.16

ASD: Atrial septal defect; VSD: Ventricular septal defect; AVSD: Atrioventricular septal defect; PDA: Patent ductus arteriosus; TR: Tricuspid regurgitation; mPAP: Mean pulmonary artery pressure; Qp/Qs: Pulmonary/systemic blood flow ratio.

The Tei Index value measured from the left ventricular edge of the septum was >0.5 in 7 (64%) patients with PAH and 13 (68%) patients without PAH. The sensitivity and specificity in identifying patients with PAH was 70% and 96.6%, respectively. The Tei Index measured from the right ventricular edge of the septum was >0.5 in 5 (45%) patients with PAH and 7 (36%) patients without PAH, which demonstrated a sensitivity and specificity in distinguishing patients with PAH of 50% and 93.3%, respectively.

The left ventricular posterior wall Tei Index value was >0.5 in 14 (77.8%) of 18 patients with a pulmonary/systemic blood flow ratio ≥2. The sensitivity and specificity of the Tei Index result in determining a pulmonary/systemic blood flow ratio of ≥2 was 77.7% and 96.6%, respectively. The Tei Index measurement from the right ventricle anterior wall was >0.5 in 11 (61.1%) of 18 patients with a pulmonary/systemic blood flow ratio of ≥2. The sensitivity and specificity of a Tei Index value of >0.5 for the right

Table 2. Congenital heart diseases in groups with and without pulmonary arterial hypertension

Congenital heart disease	Pulmonary arterial hypertension (mPAP ≥25 mm Hg)	Without pulmonary arterial hypertension (mPAP <25 mm Hg)	n
VSD	7	7	14
ASD	2	6	8
ASD+VSD	1	3	4
AVSD	1	1	2
Common atrium	–	1	1
PDA	–	1	1
Total	11	19	30

ASD: Atrial septal defect; VSD: Ventricular septal defect; AVSD: Atrioventricular septal defect; PDA: Patent ductus arteriosus.

ventricle anterior wall in isolating patients with a pulmonary/systemic blood flow ratio of ≥2 was 61% and 93.3%, respectively.

The left ventricular edge of the septum Tei Index value was >0.5 in 13 (72.2%) of 18 patients with a pulmonary/systemic blood flow ratio of ≥2, indicating a sensitivity and specificity of 72% and 96.6%, respectively. The Tei Index measurement performed from the right ventricular edge of the septum was >0.5 in 6 (33.3%) of 18 patients with a pulmonary/systemic blood flow ratio ≥2, which demonstrated a sensitivity and specificity in detecting patients with a pulmonary/systemic blood flow ratio ≥2 of 33.3% and 93.3%, respectively.

A significant correlation was detected between the Tei Index value measured from the left ventricular posterior wall and the mean PAP (correlation coefficient: 0.491). Similarly, a significant correlation was detected between the Tei Index result measured from the left ventricular edge of the septum and the pulmonary/systemic blood flow ratio (correlation coefficient: 0.431). While there was a significant correlation between Tei Index measurement from the right ventricular anterior wall and the pulmonary/systemic blood flow ratio (correlation coefficient: 0.495), no correlation was detected between the Tei Index value measured from the right ventricular anterior wall and the mean PAP.

The interobserver variability of the left ventricle Em and Am velocities, right ventricular IVCTm and CTm measurements was less than 5.1% (0.2%–7.3%). The intraobserver variability of right ventricular Em, Am, and Sm velocities was also low (coefficient of variation: 4%–8%).

DISCUSSION

The Tei Index is a non-invasive tool used to measure the right and left ventricular systolic and diastolic functions.[3,10–17] The index is equivalent to the sum of isovolumetric contraction time and isovolumetric relaxation time divided by ejection time.[5] These time intervals can be measured easily during routine Doppler echocardiographic examination.[1,18] This index is unaffected by the geometric shape of the ventricles and heart rate.[5,19] The PAP value and the pulmonary/systemic blood flow ratio are important in planning the treatment of CHD patients with a left-to-right shunt. On Doppler echocardiography, after systolic and diastolic gradients are determined from the tricuspid valve and pulmonary valve, respectively, the systolic and mean PAP can be measured using a simplified Bernoulli equation.[20] Pulmonary artery systolic pressure=4x(tricuspid regurgitation peak velocity)2+right atrial pressure[21–26] and mean PAP=4(pulmonary regurgitation peak velocity)2.[27] However, the lack of adequate regurgitation to measure peak velocity makes these methods impossible to apply in some PAH cases.

Eidem et al.[16] reported that the Tei Index quantitatively demonstrated right ventricular performance and is relatively independent of changes in preload and afterload. It has also been demonstrated that right ventricular Tei Index results were not different in pediatric patients with ASD compared with normal children while values were significantly higher in adult patients with ASD in contrast to healthy adults.[1] On the other hand, Baysal et al.[17] found increased Tei Index values in both the left and right ventricles in

Table 3. **Tissue Doppler echocardiographic measurements of the patients and controls**

Measurement	Pulmonary hypertension	Without pulmonary hypertension	Controls	*p*
Left ventricular posterior wall				
Em (cm/s)	13.89±3.66	15.65±4.08	17.36±4.08	0.013*, †, ‡
Am (cm/s)	8.87±2.29	8.85±2.19	8.15±2.89	0.715
Sm (cm/s)	7.26±1.85	8.69±2.92	10.63±2.92	0.032*, †, ‡
IVCTm (ms)	50.40±21.11	41.47±8.56	28.43±20.56	0.001*, †, ‡
IVRTm (ms)	60.29±7.84	50.08±9.31	50.68±17.31	0.017*, †
CTm (ms)	123.35±29.78	155.65±27.61	161.65±21.61	0.001*, †, ‡
Em/Am ratio	1.41±0.55	1.75±0.51	1.95±0.41	0.021*, †, ‡
Left ventricular septum				
Em (cm/s)	12.19±2.59	14.26±2.95	16.16±2.95	0.013*, †, ‡
Am (cm/s)	10.79±3.39	10.30±2.70	9.33±2.70	0.827
Sm (cm/s)	8.57±2.12	10.35±2.74	11.35±2.17	0.033*, †
IVCTm (ms)	52.50±9.16	40.43±3.11	27.74±12.11	0.001*, †, ‡
IVRTm (ms)	54.07±9.14	51.81±10.18	51.08±14.48	0.041*, †
CTm (ms)	131.88±27.18	158.24±24.60	162.24±24.60	0.023*, †, ‡
Em/Am ratio	1.26±0.36	1.68±0.22	1.78±0.31	0.001*, †, ‡
Right ventricular anterior wall				
Em (cm/s)	9.13±2.19	13.87±2.73	15.07±2.73	0.035*, †, ‡
Am (cm/s)	8.04±2.02	7.94±1.30	8.74±1.23	0.621
Sm (cm/s)	9.29±1.56	10.20±1.01	11.25±1.61	0.763
IVCTm (ms)	51.05±8.40	35.88±3.47	13.88±8.47	0.001*, †, ‡
IVRTm (ms)	50.67±10.54	42.69±8.34	40.69±9.34	0.034*, †
CTm (ms)	102.11±20.37	116.22±15.32	119.62±20.59	0.016*, †
Em/Am ratio	1.11±0.21	1.29±0.27	1.36±0.44	0.001*, †, ‡
Right ventricular septum				
Em (cm/s)	9.13±2.92	13.13±2.92	14.12±1.56	0.037*, †
Am (cm/s)	9.04±2.02	8.64±2.02	9.14±2.47	0.617
Sm (cm/s)	10.29±1.56	11.89±1.56	12.13±2.56	0.823
IVCTm (ms)	51.65±8.40	39.65±8.40	14.78±8.10	0.001*, †, ‡
IVRTm (ms)	50.60±8.54	43.60±8.54	42.79±7.51	0.011*, †
CTm (ms)	106.11±21.37	116.11±25.87	121.42±30.74	0.016*, †, ‡
Em/Am ratio	1.03±0.41	1.30±0.39	1.40±0.57	0.001*, †, ‡

Em: Peak early diastolic myocardial velocity; Am: Peak atrial systolic velocity; Sm: Peak systolic myocardial velocity; CTm: Contraction time; IVCTm: Izovolumetric contraction time; IVRTm: Izovolumetric relaxation time. *Pulmonary hypertension group vs. control subjects; †Non-pulmonary hypertension group vs. control subjects; ‡Pulmonary hypertension group vs. non-pulmonary hypertension group.

patients with left-to-right cardiac shunt lesions. Additionally, in a study performed on animals by Grignola et al.,[28] it was reported that the Tei index was a sensitive indicator to identify right ventricular dysfunction occurring in acute PAH. Dujardin et al.[29] found that the right ventricular IVCTm and IVRTm were significantly prolonged, the ejection time was significantly shortened, and that the Tei Index results were significantly greater in patients with primary pulmonary hypertension compared with controls. In a recent study performed in 12 children with idiopathic pulmonary hypertension using pulsed-wave Doppler, the mean

Table 4. Right and left ventricular Tei Index values of the study population measured using tissue Doppler echocardiography

	Pulmonary arterial hypertension (n=11)	Without pulmonary arterial hypertension (n=19)	Control group (n=30)	*p* (<0.05)
LVPW Tei Index	0.68±0.18	0.56±0.16	0.41±0.05	0.001* 0.001† 0.027‡
LVS Tei Index	0.57±0.12	0.52±0.09	0.39±0.05	0.001* 0.001† 0.389‡
RVAW Tei Index	0.67±0.16	0.51±0.12	0.41±0.057	0.001* 0.006† 0.001‡
RVS Tei Index	0.5±0.08	0.48±0.12	0.4±0.07	0.022* 0.02† 0.884‡

*Pulmonary hypertension group vs. control subjects; †Non-pulmonary hypertension group vs. control subjects; ‡Pulmonary hypertension group vs. non-pulmonary hypertension group. LVPW: Left ventricular posterior wall; LWS: Left ventricular septum; RVAW: Right ventricular anterior wall; RVS: Right ventricular septum.

Table 5. Comparison of right and left ventricular Tei Index values according to pulmonary arterial hypertension and pulmonary to systemic flow rate ratio

	LVPW Tei Index (n/%)		LVS Tei Index (n/%)		RVAW Tei Index (n/%)		RVS Tei Index (n/%)	
	>0.5	≤0.5	>0.5	≤0.5	>0.5	≤0.5	>0.5	≤0.5
Pulmonary arterial hypertension	9/(82)	2/(18)	10/(91)	1/(9)	10/(91)	1/(9)	5*/(45)	5*/(45)
Without pulmonary arterial hypertension	14/(74)	5/(26)	9/(48)	10/(52)	9/(48)	10/(52)	7/(36)	12/(64)
Qp/Qs≥2	14/(77.8)	4/(22.2)	11/(61.1)	7/(38.9)	11/(61.1)	7/(38.9)	6/(33.3)	12/(66.7)
Qp/Qs<2	9/(75)	3/(25)	8/(66.7)	4/(33.3)	8/(66.7)	4/(33.3)	6/(50)	5/(41.6)

LVPW: Left ventricular posterior wall; LWS: Left ventricular septum; RVAW: Right ventricular anterior wall; RVS: Right ventricular septum; Qp/Qs: Pulmonary/systemic blood flow ratio. *Tei Index value could not be measured in 1 patient with an atrioventricular septal defect.

Tei Index value was 0.64±0.30 in the right ventricle of the patients with PAH and 0.28±0.03 in the controls ($p<0.01$). The left ventricular Tei Index result of patients with PAH and controls was 0.44±0.15 and 0.34±0.03, respectively ($p<0.05$).[30] In the same study, the authors reported that the Tei Index measurement from the right ventricle was associated with invasively measured PAP and that the Tei values were useful in the clinical follow-up of these patients.[30] The Tei Index and mean PAP have also been accepted as criteria for PAH and have been noted as more reliable than systolic PAP measured from tricuspid valve regurgitation.[27] Cheung et al.[31] reported that a sudden increase in ventricular volume caused a sudden increase in Tei Index values.

In our study, the Tei Index values were measured in 4 sites using tissue Doppler: the right ventricular anterior wall, the left ventricular posterior wall, and the right and left ventricular edges of the septum. A systolic PAP of >35 mm Hg or mean PAP of ≥25 mm Hg at rest and >30 mm Hg during exercise or pulmonary vascular resistance index of >3 WU/m^2 are the most commonly used criteria for the diagnosis of pulmonary hypertension.[9,32,33] The Tei Index measurements measured from the right ventricular anterior wall, the left ventricular posterior wall and the left and right ventricular edges of the septum with tissue Doppler were found to be significantly higher in the patient group than the control group. There was no significant difference in the Tei Index values measured from the left and right ventricular edges of the septum between the patients with and without PAH. Also, there was a significant correlation determined between the Tei Index value measured from the left ventricular posterior wall and the mean PAP (correlation coefficient: 0.491).

Roberson et al.[34] reported that the upper limit for right ventricular Tei Index measurement was 0.44 in infants and 0.54 in adolescents. The upper limit for the right ventricle has also been reported as0.44 for infants and 0.49 for 18-year-olds.[35] Our study yielded Tei Index values of the right ventricular anterior wall and left ventricular posterior wall that were >0.5 in 91% and 82%, respectively, of the patients with PAH. The sensitivity and specificity of a Tei index value >0.5 in detecting patients with pulmonary hypertension was 91% and 93.3%, respectively, for the right ventricular anterior wall, 81.8% and 96.6% for the left ventricular posterior wall, 50% and 93.3% for the right ventricular edge of the septum, and 70% and 96.6% for the left ventricular edge of the septum. In patients with PAH, the sensitivity was higher on the right ventricular anterior wall compared with the other sites.

In this study, the patients were divided into 2 groups using a cutoff of a pulmonary/systemic blood flow ratio <2. In the patients with a pulmonary/systemic blood flow ratio ≥2, the Tei Index values for the left ventricular posterior wall, right ventricular anterior wall, left ventricular edge of the septum, and right ventricular edge of the septum were >0.5 in 77.8%, 61.1%, 72.2%, and 33.3% of the patients, respectively. The sensitivity and specificity of a Tei Index value >0.5 in detecting patients with a pulmonary/systemic blood flow ratio ≥2 was 61% and 93.3% for the right ventricular anterior wall, 77.7% and 96.6% for the left ventricular posterior wall, 33.3% and 93.3% for the right ventricular edge of the septum, and 72% and 96.6% for the left ventricular edge of the septum,. There was a significant correlation between the Tei Index and the pulmonary/systemic blood flow ratio for the right ventricular anterior wall and the left ventricular edge of the septum (correlation coefficient: 0.495 and 0.431, respectively). Additionally, the Tei Index values obtained from the left ventricular posterior wall and the left ventricular edge of the septum were more often >0.5 compared with the right ventricular anterior wall and the right ventricular edge of the septum. Our results suggested that as the pulmonary/systemic blood flow ratio increased, the number of patients with a Tei Index value >0.5 in the left ventricular posterior wall increased.

Limitations of the study

Our patient group consisted of children with CHD, who may experience heart rate variability. The patient group was not homogenous in terms of the type of heart defect and some patients had both increased volume and pressure load. The various defects caused an increase in volume in different ventricles and it was not possible to determine the effects of volume and pressure overload on the Tei Index values.

Conclusion

Our study results indicated that the Tei Index values increased substantially in patients with very large defects, which can affect the ventricles hemodynamically. The Tei Index measurements from various regions of the right ventricle in children with CHD with a left-to-right shunt can be used as a parameter to follow up on the development of PAH, to diagnose it in the early period, and to make a timely decision about surgery. Finally, higher Tei Index values measured with tissue Doppler can be used as a criterion in directing the treatment of patients with a left-to-right shunt. Additional studies with larger groups are needed.

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