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Evaluation of Right Ventricle Diastolic and Systolic Function in Patients with Intracardiac Shunts by Strain Echocardiography and Tissue Doppler

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ABSTRACT

Background: The right ventricle performance is very important in the prognosis of the patients with intracardiac shunts. Development of RV failure is associated with higher mortality. It can be directly related to the shunt itself or indirectly associated with elevated pulmonary artery pressure.

Objective: The aim of this work was to assess the diastolic and the systolic performance of the right ventricle in patients with different types of intracardiac shunts by the Echocardiography in comparison with the normal population.

Patients and methods: Our study included 132 patients undergoing echocardiography in the Outpatient Clinic of Tanta University Hospital. The study was conducted starting from 1st of February 2018 to 28th of February 2019. The study included 63 female and 69 male patients. Their age ranged from 1 month to 49 years old. RV diastolic and systolic function were assessed in the four groups using MPI, Stroke work, longitudinal RV strain rate.

Results: Our results showed higher values of the parameters measured in the atrial septal defects (ASD) patients' group compared to the normal subjects and the other intracardiac shunt's patients. Also, ASD's patients were associated with higher pulmonary artery pressure values and worse RV function parameters in general.

Conclusion: We concluded that the new echocardiographic measures are good and reliable tool to assess the right ventricle function in the patients with intracardiac shunts. Additionally, ASD' patients are associated with worse outcome especially if they develop elevated pulmonary artery pressure.

Keywords: Right Ventricle Diastolic and Systolic, Echocardiography, Tissue Doppler.

INTRODUCTION

Intracardiac shunting means abnormal flow of the blood in the heart because of a defect in the structure of either the ventricles or the atria. These alternative pathways cause blood flow to bypass the normal circulation, resulting in the mixing of arterial and venous blood **(1)**.

Intracardiac shunts is classified into right-left, left-right or bidirectional. It also may be congenital or acquired (as VSD complicating acute myocardial infarction) **(2)**. The most common congenital intracardiac shunting are atrial septal defects (ASD), ventricular septal defects (VSD), and patent foramen ovale (PFO). These defects may be asymptomatic, or they may produce symptoms, which can range from mild to severe **(3)**. Each type of shunt carries different hemodynamic stress and physiologic demands. The long-term capacity of the right ventricle (RV) to withstand the stresses and meet those demands has become recognized as a key contributor to late clinical outcomes **(4)**.

Right ventricle (RV) function is one of the most important predictors of morbidity and mortality in congenital heart diseases. RV failure is a progressive process that begins with myocardial injury, stress, neurohumoral activation, cytokine activation, altered gene expression and ventricular remodeling **(1)**. RV failure may be due to pressure or volume overload. When the RV is exposed to pressure overload, it corresponds first with hypertrophy leading to dilatation and loss of contractile force that may be complicated with right ventricular ischemia worsening the ventricular dysfunction. RV can adapt to high volume overload for a long time without significant dysfunction and patients can remain asymptomatic until Eisenmenger syndrome and pulmonary vasculopathy develop **(5)**.

Transthoracic echocardiography (TTE) is a useful method for initial evaluation of RV structure and function in these type of patients. In our study, we discussed the measures of normal RV function and the impact of the most common intracardiac shunts in RV function **(6)**.

AIM OF THE STUDY

The aim of this work was to assess the diastolic and the systolic performance of the right ventricle in patients with different types of intracardiac shunts by the echocardiography in comparison to the normal population.

PATIENTS AND METHODS

Patients:

Study Population

Our study included 132 patients undergoing echocardiography in the Outpatient Clinic of Tanta University Hospital. The study was starting from 1st of February 2018 to 28th of February 2019.

Patients were divided into four groups as follows:

- The first group consisted of 27 healthy subjects with normal echocardiography and totally asymptomatic.
- The second group consisted of 51 patients diagnosed with atrial septal defect (ASD).
- The Third group included 21 patients diagnosed as patent foramen ovale (PFO).
- The Fourth group consisted of patients diagnosed with ventricular septal defect (VSD).

The study included 63 female and 69 male patients. Their ages ranged from 1 month to 49 years old.

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RV diastolic and systolic function were assessed in the four groups using MPI, Stroke work and longitudinal RV strain rate. Additionally, the patients could be divided into two groups according to tricuspid maximum velocity (TR Vmax) either ≤ 2.8 or > 2.8.

Inclusion Criteria

Patients having intracardiac shunts (whatever the degree) undergoing echocardiography evaluation of right ventricle. Intracardiac shunts will include atrial septal defect (ASD), ventricular septal defect (VSD) and patent foramen ovale (PFO).

Exclusion Criteria:

1) Patient's parents unwilling to participate in the study.
2) Children age less than 1 month
3) Complex congenital heart diseases such as TGA.
4) Obstructive heart lesions such as PS.
5) Arrhythmias such as AF.

Ethical Considerations

- No risks for the subjects who share in this study.
- An informed consent was obtained from all participants in this research and a sample of this form was attached.
- **The study was approved by the Ethics Committee of the Faculty of Medicine, Tanta University.**
- The participation was voluntary and the patient might discontinue participation at any time without penalty or loss of benefits.
- Results of our research were only for academic interest, to keep the confidentiality of the data and volunteers participating in the research.
- Any unexpected risk appearing during the course of the research was cleared to the participants and the ethical committee on time.
- There were adequate provisions to maintain privacy of participants and confidentiality of the data as follows:
  - We put code number to every participant with the name and address kept in special file.
  - We hided the patient name when we used the research.
- We were using the results of the study only in a scientific manner and not to use it in any other aims.

Methods

All the patients were subjected to the following:

• History: With a special emphasis on patient's age, gender, family history and history of chronic disease.

• Clinical examination: General and local examination including body mass index (BMI), blood pressure, pulse, temperature, respiratory rate and local examination of the heart and lung and other systems.

• **Echocardiography:** Echocardiography is by far the most common modality used to image the RV, locating any intracardiac shunt and assess the RV function appropriately. In our study, echocardiography was performed using a Vivid E9 (GE Healthcare, Milwaukee, WI) platform, with probe frequencies appropriate for body habitus and age. Gain and compression were optimized. Studies were performed with subject's breathing room air. The tricuspid inflow velocity was recorded from the apical-4-chamber view with the pulsed-wave Doppler. Sample volume positioned at the tips of the tricuspid leaflets during diastole. The peak early (E) and late (A) diastolic velocities, their ratio (E/A) and the tricuspid E-wave deceleration time were measured. The S: D ratio was calculated from the tricuspid regurgitation (TR) jet. Systolic duration was measured as the duration (onset to termination) of TR flow. Diastolic duration was measured from termination of TR to onset of the subsequent TR tracing. RV wall thickness was measured in the apical view by calculating the extension of the free RV wall during diastole. Its importance is derived especially with the presence of pulmonary hypertension.

Noninvasively derived RV Stroke work (RVSW) was determined by multiplying peak RV systolic pressure by RV stroke volume. Stroke volume was calculated from the pulmonary valve area multiplied by the velocity-time integral (VTI) of pulmonary flow at the same location. More specifically, the diameter of the pulmonary valve annulus was measured on a parasternal short axis image during systole, and the cross-sectional area of the pulmonary valve was calculated. After pulsed-wave Doppler interrogation at the level of the pulmonary valve, the VTI was determined by measuring the area under the curve of the spectral Doppler pattern [7].

RV systolic pressure was estimated by measuring the velocity of the tricuspid regurgitant jet and using the modified Bernoulli equation to arrive at peak RV pressure (P = 4V2).

Finally, echocardiographically derived RVSW was calculated as:

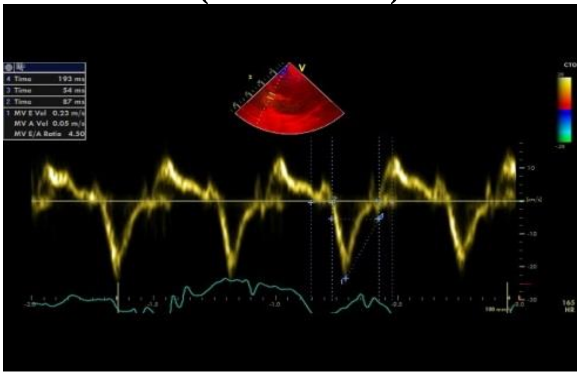
4 × (peak tricuspid regurgitant jet velocity) 2 × (pulmonary valve area × velocity-time integral).

• Tissue Doppler Echocardiography

TDI was recorded from the apical 4-chamber view with the pulse-wave Doppler sample-volume placed on the tricuspid lateral annulus. Peak early (E′) and late (A′) diastolic myocardial annular velocity, isovolumic relaxation time (IVRT), isovolumic contraction time (IVCT) and ejection time (ET) were measured. The ratio between tricuspid E and early diastolic myocardial velocity (E′) was calculated (E/E′).

The TDI-derived myocardial performance index was calculated. MPI was determined by obtaining the sum of the isovolumic periods and dividing by RV ejection time.

MPI = (IVCT+IVRT) ÷ ET



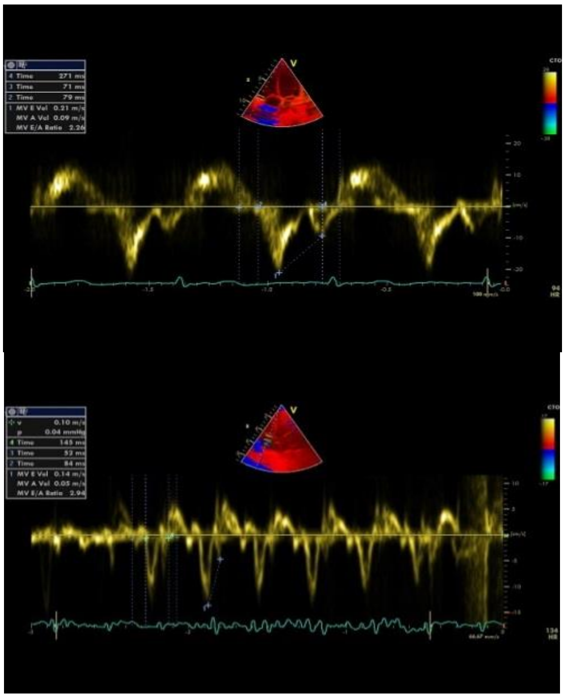
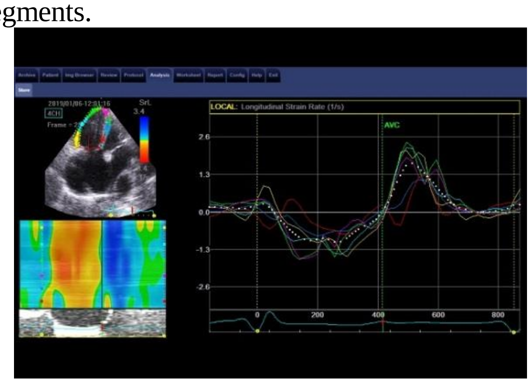


Figure (1): Tissue Doppler placed on the tricuspid lateral annulus measurement in selected normal cases and ASD patients.

• Strain Echocardiography

Speckle-tracking analysis of the RV was performed offline, Gray-scale 2D images were obtained from the apical 4-chamber view.

The RV endocardial border including septum was traced manually from an end-systolic frame to include the free wall and septum. The epicardial border was automatically detected by the software and the region of interest was manually adjusted to include the thickness of the RV myocardial wall. Adequate tracking was visually verified. A six-segment model was created according to the software: three at the RV free wall and three at the interventricular septum (IVS). Speckle-tracking RV longitudinal strain rate curves were automatically generated for every segment. Global longitudinal systolic strain rate (pGLSRs), early global longitudinal diastolic strain rate (pGLSRe) and late global longitudinal diastolic strain rate (pGLSRa) were calculated as the average of the six segments.



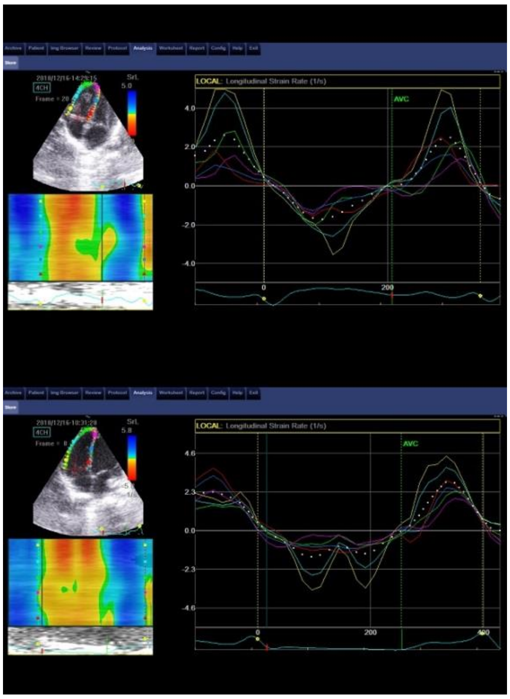


Figure (2): Measurement of different parameters of RV global longitudinal strain rate in selected ASD, normal and VSD cases respectively**.**

Statistical analysis of the data

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0**. (**Armonk, NY: IBM Corp**).** Qualitative data were described using number and percent. The Kolmogorov-Smirnov test was used to verify the normality of distribution. Quantitative data were described using range (minimum and maximum), mean, standard deviation and median. Significance of the obtained results was judged at the 5% level.

The used tests were

1- Chi-square test: For categorical variables to compare between different groups.

2- Monte Carlo correction: Correction for chi-square when more than 20% of the cells have expected count less than 5.

3- F-test (ANOVA): For normally distributed quantitative variables, to compare between more than two groups and Post Hoc test (Tukey) for pairwise comparisons.

4- Kruskal Wallis test: For abnormally distributed quantitative variables to compare between more than two studied groups and Post Hoc (Dunn's multiple comparisons test) for pairwise comparisons.

RESULTS

This study was done in Tanta University Hospital including 132 patients. The patients were divided into four groups: normal subjects, ASD patients, PFO patients, and VSD patients.

The results of our study were illustrated in tables (6 - 18) and figures (18 - 37).

Demographic data of our patient groups:

Regarding the patient's gender, table (1) illustrated that the normal echo group included 15 female (55.6%) and 12 males (44.4%), whereas the group of ASD patients included 24 female (47.1%) and 27 males (52.9%) and the group of PFO patients included 9 female (42.9%) and 12 males (57.1%) and the group of VSD patients included 15 female (45.5%) and 18 males (54.5%). There was no significant difference between the studied groups (p> 0.05).

As regards age, table (1) showed that the mean age of the normal echo group was 8.91 ± 12.39 (range 0.42 – 40.0) years old, whereas the mean age of the group of ASD patients was 10.42 ± 12.79 (range 0.17 – 49.0) years old, the mean age of the group of PFO patients was 2.27 ± 1.85 (range 0.42 – 6.0) years old and the mean age of the group of VSD patients was 3.68 ± 4.24 (range 0.25 – 16.0) years old. There was significant difference in comparing the normal subjects and PFO patients and in comparing the ASD and VSD patients (p1 & p3 ≤ 0.05).

Regarding Body mass index (BMI), table (1) revealed that the mean BMI of the normal echo group was 19.32 ± 5.83 (range 16.0 – 35.0) kg/m^2, whereas the mean BMI of the group of ASD patients was 19.31 ± 5.30 (range15.30 – 34.0) kg/m^2, the mean BMI of the group of PFO patients was 16.50 ± 0.65 (range15.70 – 17.30) kg/m^2 and the mean BMI of the group of VSD patients was 16.82 ± 2.36 (range15.40 – 24.0) kg/m^2. There was positive significant difference between the normal and PFO groups, the normal and VSD groups, the ASD and PFO groups, and the ASD and VSD groups (p1, p2 & p3 ≤0.05).

Table (1): Comparison between the different studied groups according to demographic data

	Diagnosis								**Test of Sig.**	**P**
	Normal (n= 27)		**ASD (n= 51)**		**PFO (n= 21)**		**VSD (n= 33)**			
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**		
Sex										
Male	12	44.4	27	52.9	12	57.1	18	54.5	χ^2= 0.940	0.816
Female	15	55.6	24	47.1	9	42.9	15	45.5		
Age (years)										
Min. – Max.	0.42 – 40.0		0.17 – 49.0		0.42 – 6.0		0.25 – 16.0		H= 10.087	0.018*
Mean ± SD.	8.91 ± 12.39		10.42 ± 12.79		2.27 ± 1.85		3.68 ± 4.24			
Median	4.0		5.0		2.0		2.08			
p_1			0.510		0.049*		0.202			
Sig.bet.Grps			p_2=0.385, p_3=0.005*, p_4=0.385							
BMI (kg/m^2)										
Min. – Max.	16.0 – 35.0		15.30 – 34.0		15.70 – 17.30		15.40 – 24.0		H= 23.258*	<0.001*
Mean ± SD.	19.32 ± 5.83		19.31 ± 5.30		16.50 ± 0.65		16.82 ± 2.36			
Median	17.0		17.10		16.50		16.10			
p_1			0.783		0.024*		<0.001*			
Sig.bet.Grps			p_2=0.023*, p_3<0.001*, p_4=0.215							

χ^2: **Chi square te**st

H: H for **Kruskal Wallis test,** pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Dunn's for multiple comparisons test)**

p: p value for comparing between the different studied groups

p_1: p value for normal and each other group

p_2: p value for comparing between ASD and PFO

p_3: p value for comparing between ASD and VSD

p_4: p value for comparing between PFO and VSD

*: Statistically significant at p ≤ 0.05

Table (2) showed that the mean RA volume of the normal echo group was 38.78 ± 16.37 (range 13.0 – 70.0) ml^3, whereas the mean RA volume of the group of ASD patients was 34.59 ± 17.79 (range14.0 – 87.0) ml^3, the mean RA volume of the group of PFO patients was 28.0 ± 7.59 (range13.0 – 40.0) ml^3 and the mean RA volume of the group of VSD patients was 23.45 ± 6.51 (range14.0 – 31.0) ml^3. There was positive significant difference in comparing the normal subjects and PFO patients and in comparing the ASD and VSD patients (p_1 & $p_3 \leq 0.05$).

Regarding the RV wall thickness, table (2) revealed that the mean RV wall thickness of the normal echo group was 0.58 ± 0.16 (range 0.30 – 0.80) cm, whereas the mean RV wall thickness of the group of ASD patients was 0.69 ± 0.22 (range0.31 – 1.10) cm, the mean RV wall thickness of the group of PFO patients was 0.45 ± 0.07 (range 0.36 – 0.55) cm and the mean RV wall thickness of the group of VSD patients was 0.55 ± 0.18 (range 0.36 – 1.0) cm. There was positive significant difference in comparing the ASD and PFO patients and in comparing the ASD and VSD patients (p_2 & $p_3 \leq 0.05$).

Table (2): Comparison between the different studied groups according to RA volume and RV wall thickness

	Diagnosis				Test of sig.	p
	Normal (n= 27)	**ASD (n= 51)**	**PFO (n= 21)**	**VSD (n= 33)**		
RA Volume (ml^3)						
Min. – Max.	13.0 – 70.0	14.0 – 87.0	13.0 – 40.0	14.0 – 31.0	H= 15.996*	0.001*
Mean ± SD.	38.78 ± 16.37	34.59 ± 17.79	28.0 ± 7.59	23.45 ± 6.51		
Median	40.0	30.0	28.0	26.0		
p_1		0.226	0.046*	<0.001*		
Sig.bet.Grps		p_2=0.260, p_3=0.002*, p_4=0.166				
RV Wall thickness (cm)						
Min. – Max.	0.30 – 0.80	0.31 – 1.10	0.36 – 0.55	0.36 – 1.0	F= 9.640*	<0.001*
Mean ± SD.	0.58 ± 0.16	0.69 ± 0.22	0.45 ± 0.07	0.55 ± 0.18		
Median	0.60	0.63	0.49	0.51		
p_1		0.056	0.089	0.914		
Sig.bet.Grps		p_2<0.001*, p_3=0.004*, p_4=0.252				

F: **F for ANOVA test**, pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Tukey)**
H: H for **Kruskal Wallis test,** pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Dunn's for multiple comparisons test)**
p: p value for comparing between the different studied groups, p_1: p value for normal and each other group, p_2: p value for comparing between ASD and PFO , p_3: p value for comparing between ASD and VSD, p_4: p value for comparing between PFO and VSD, *: Statistically significant at $p \leq 0.05$

Table (3) showed that the mean pulmonary valve area of the normal echo group was 2.71 ± 0.71 (range 2.0 – 3.90) cm whereas the mean pulmonary valve area of the group of ASD patients was 2.65 ± 0.81 (range1.19 – 4.10) cm, the mean pulmonary valve area of the group of PFO patients was 2.30 ± 0.37 (range1.90 – 3.0) cm and the mean pulmonary valve area of the group of VSD patients was 2.49 ± 0.33 (range2.10 – 3.40) cm.

Regarding the pulmonary valve VTI, table (3) showed that the mean pulmonary valve VTI of the normal echo study was 23.46 ± 10.89 (range 14.0 – 50.90) whereas the mean pulmonary valve VTI of the group of ASD patients was 24.23 ± 5.18 (range15.10 – 32.50), the mean pulmonary valve VTI of the group of PFO patients was 21.71 ± 4.94 (range16.60 – 29.50) and the mean pulmonary valve VTI of the group of VSD patients was 19.81 ± 4.51 (range14.40 – 32.40).

Table (3): Comparison between the different studied groups according to pulmonary valve area and pulmonary valve VTI

RV	Diagnosis				Test of sig.	P
	Normal (n= 27)	**ASD (n= 51)**	**PFO (n= 21)**	**VSD (n= 33)**		
Pulmonary valve area						
Min. – Max.	2.0 – 3.90	1.19 – 4.10	1.90 – 3.0	2.10 – 3.40	F= 2.138	0.099
Mean ± SD.	2.71 ± 0.71	2.65 ± 0.81	2.30 ± 0.37	2.49 ± 0.33		
Median	2.50	2.60	2.20	2.50		
Pulm valve VTI						
Min. – Max.	14.0 – 50.90	15.10 – 32.50	16.60 – 29.50	14.40 – 32.40	H=5.225	0.156
Mean ± SD.	23.46 ± 10.89	24.23 ± 5.18	21.71 ± 4.94	19.81 ± 4.51		
Median	18.90	26.10	20.20	19.20		

F: **ANOVA test** H: **Kruskal Wallis test,** p: p value for comparing between the different studied groups.

Table (4) showed that the mean (IVCT) value of the normal echo study was 71.11 ± 37.12 (range 32.0 – 140.0) m/s whereas the mean (IVCT) value of the group of ASD patients was 79.82 ± 23.99 (range 24.0 – 110.0) m/s, the mean (IVCT) value of the group of PFO patients was 50.0 ± 17.18 (range 32.0 – 79.0) and the mean (IVCT) value of the group of VSD patients was 59.36 ± 20.91 (range 28.0 – 89.0). There was positive significant difference in comparing the normal subjects and PFO patients, comparing the ASD and PFO patients and in comparing the ASD and VSD patients (p_1, p_2 & $p_3 \leq 0.05$).

Regarding (IVRT) value, table (4) showed that the mean (IVRT) value of the normal echo study was 77.11 ± 51.48 (range30.0 – 211.0) m/s whereas the mean (IVRT) value of the group of ASD patients was 80.76 ± 36.74 (range28.0 – 166.0) m/s and the mean (IVRT) value of the group of PFO patients was 61.86 ± 26.63 (range30.0 – 101.0) m/s, the mean (IVRT) value of the group of VSD patients was 55.91 ± 13.43 (range39.0 – 89.0)m/s. There was positive significant difference between the ASD and VSD groups ($p_3 \leq 0.05$).

Table (4): Comparison between the different studied groups according to IVCT and IVRT

	Diagnosis				F	p
	Normal (n= 27)	**ASD (n= 51)**	**PFO (n= 21)**	**VSD (n= 33)**		
IVCT (m/s)						
Min. – Max.	32.0 – 140.0	24.0 – 110.0	32.0 – 79.0	28.0 – 89.0		
Mean ± SD.	71.11 ± 37.12	79.82 ± 23.99	50.0 ± 17.18	59.36 ± 20.91	8.409*	<0.001*
Median	55.0	84.0	40.0	60.0		
p_1		0.486	0.028*	0.296		
Sig.bet.Grps		p_2<0.001*, p_3=0.003*, p_4=0.561				
IVRT (m/s)						
Min. – Max.	30.0 – 211.0	28.0 – 166.0	30.0 – 101.0	39.0 – 89.0		
Mean ± SD.	77.11 ± 51.48	80.76 ± 36.74	61.86 ± 26.63	55.91 ± 13.43	4.131*	0.008*
Median	65.0	75.0	50.0	53.0		
p_1		0.972	0.440	0.095		
Sig.bet.Grps		p_2=0.163, p_3=0.010*, p_4=0.929				

F: **F for ANOVA test**, pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Tukey)**
p: p value for comparing between the different studied groups
p_1: p value for normal and each other group, p_2: p value for comparing between ASD and PFO
p_3: p value for comparing between ASD and VSD, p_4: p value for comparing between PFO and VSD
*: Statistically significant at $p \le 0.05$.

Table (5) showed that the mean ejection time of the normal echo study was 215.0 ± 38.77 (range139.0 – 260.0) whereas the mean ejection time of the group of ASD patients was 220.9 ± 80.86 (range 106.0 – 415.0), the mean ejection time of the group of PFO patients was 190.7 ± 23.54 (range 139.0 – 219.0) and the mean ejection time of the group of VSD patients was 237.7 ± 84.43 (range 142.0 – 427.0).

Regarding E/E' time, table (5) showed that the mean E/E' time of the normal echo study was 3.64 ± 1.39 (range2.0 – 6.0) whereas the mean E/E' time of the group of ASD patients was 4.98 ± 1.46 (range2.93 – 8.0), the mean E/E' time of the group of PFO patients was 4.37 ± 1.38 (range2.0 – 6.0) and the mean E/E' time of the group of VSD patients was 5.52 ± 1.47 (range3.35 – 8.54). There was positive significant difference between the normal subjects and ASD group, between the normal subjects and VSD groups, and between the PFO and VSD groups (p_1, $p_4 \le 0.05$).

Table (5): Comparison between the different studied groups according to Ejection time and E/E' time

	Diagnosis				Test of Sig.	p
	Normal (n= 27)	**ASD (n= 51)**	**PFO (n= 21)**	**VSD (n= 33)**		
Ejection time						
Min. – Max.	139.0 – 260.0	106.0 – 415.0	139.0 – 219.0	142.0 – 427.0	H= 3.640	0.303
Mean ± SD.	215.0 ± 38.77	220.9 ± 80.86	190.7 ± 23.54	237.7 ± 84.43		
Median	213.0	192.0	197.0	194.0		
E/E' time						
Min. – Max.	2.0 – 6.0	2.93 – 8.0	2.0 – 6.0	3.35 – 8.54	F= 9.429^*	$<0.001^*$
Mean ± SD.	3.64 ± 1.39	4.98 ± 1.46	4.37 ± 1.38	5.52 ± 1.47		
Median	3.11	5.0	4.54	5.43		
p_1		0.001^*	0.297	$<0.001^*$		
Sig.bet.Grps		p_2=0.372, p_3=0.337, p_4=0.026^*				

H: H for **Kruskal Wallis test**
F: **F for ANOVA test**, pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Tukey)**
p: p value for comparing between the different studied groups, p_1: p value for normal and each other group
p_2: p value for comparing between ASD and PFO, p_3: p value for comparing between ASD and VSD
p_4: p value for comparing between PFO and VSD, *: Statistically significant at $p \leq 0.05$

Table (6) showed that the mean early diastolic RV global strain rate of the normal echo study was 2.13 ± 0.94 (range0.65 – 3.72) whereas the mean early diastolic RV global strain rate of the group of ASD patients was 1.76 ± 0.59 (range 0.93 – 2.85), the mean early diastolic RV global strain rate of the group of PFO patients was 2.39 ± 0.52 (range1.38 – 3.02) and the mean early diastolic RV global strain rate of the group of VSD patients was 2.37 ± 0.94 (range 1.25 – 4.88). There was positive significant difference in comparing the ASD and PFO patients and in comparing the ASD and VSD patients (p_2, $p_3 \leq 0.05$).

Regarding the late diastolic RV global strain rate, the mean late diastolic RV global strain rate of the normal echo study was 1.31 ± 0.85 (range 0.22 – 2.80) whereas the mean late diastolic RV global strain rate of the group of ASD patients was 0.89 ± 0.50 (range 0.29 – 2.27), the mean late diastolic RV global strain rate of the group of PFO patients was 1.48 ± 0.83 (range 0.58 – 2.80) and the mean late diastolic RV global strain rate of the group of VSD patients was 1.49 ± 0.60 (range 1.01 – 3.09). There was a positive significant difference in comparing the normal subjects and ASD patients, in comparing ASD and PFO patients, and in comparing ASD and VSD patients (p_1, p_2 & $p_3 \leq 0.05$).

As regards the RV systolic global strain rate, the mean RV systolic global strain rate of the normal echo study was 1.31 ± 0.49 (range 0.59 – 2.15) whereas the mean RV systolic global strain rate of the group of ASD patients was 1.34 ± 0.45 (range 0.82 – 2.20), the mean RV systolic global strain rate of the group of PFO patients was 1.64 ± 0.34 (range1.07 – 2.15) and the mean RV systolic global strain rate of the group of VSD patients was 1.70 ± 0.21 (range1.35 – 2.10). There was positive significant difference in comparing the normal subjects and PFO patients, in comparing normal subjects and VSD patients, in comparing ASD and PFO patients, and in comparing the ASD and VSD patients (p_1, p_2 & $p_3 \leq 0.05$).

Table (6): Comparison between the different studied groups according to different parameters of RV global longitudinal strain rat

	Diagnosis				F	p
	Normal (n= 27)	**ASD (n= 51)**	**PFO (n= 21)**	**VSD (n= 33)**		
Early diastolic RV global strain rate						
Min. – Max.	0.65 – 3.72	0.93 – 2.85	1.38 – 3.02	1.25 – 4.88		
Mean ± SD.	2.13 ± 0.94	1.76 ± 0.59	2.39 ± 0.52	2.37 ± 0.94	5.895*	0.001*
Median	2.36	1.67	2.44	2.30		
p_1		0.172	0.632	0.615		
Sig.bet.Grps		p_2=0.008*, p_3=0.002*, p_4=1.000				
Late diastolic RV glob strain rate						
Min. – Max.	0.22 – 2.80	0.29 – 2.27	0.58 – 2.80	1.01 – 3.09		
Mean ± SD.	1.31 ± 0.85	0.89 ± 0.50	1.48 ± 0.83	1.49 ± 0.60	7.217*	<0.001*
Median	1.23	0.70	1.23	1.21		
p_1		0.048*	0.816	0.697		
Sig.bet.Grps		p_2=0.005*, p_3<0.001*, p_4=1.000				
Negative global RV systolic longitudinal stain rate						
Min. – Max.	0.59 – 2.15	0.82 – 2.20	1.07 – 2.15	1.35 – 2.10		
Mean ± SD.	1.31 ± 0.49	1.34 ± 0.45	1.64 ± 0.34	1.70 ± 0.21	8.278*	<0.001*
Median	1.30	1.22	1.70	1.70		
p_1		0.989	0.024*	0.001*		
Sig.bet.Grps		p_2=0.021*, p_3<0.001*, p_4=0.953				

F: **F for ANOVA test**, pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Tukey)**
p: p value for comparing between the different studied groups
p_1: p value for normal and each other group
p_2: p value for comparing between ASD and PFO
p_3: p value for comparing between ASD and VSD
p_4: p value for comparing between PFO and VSD
*: Statistically significant at $p \leq 0.05$.

Table (7) showed that the mean RV MPI of the normal echo study was 0.63 ± 0.30 (range 0.31 – 1.35) whereas the mean RV MPI of the group of ASD patients was 0.82 ± 0.34 (range 0.17 – 1.31), the mean RV MPI of the group of PFO patients was 0.61 ± 0.28 (range0.31 – 1.04) and the mean RV MPI of the group of VSD patients was 0.54 ± 0.21 (range 0.28 – 0.88). There was positive significant difference in comparing the normal patients and ASD patients, in comparing ASD and PFO patients and in comparing the ASD and VSD patients (p_1, p_2 & $p_3 \leq 0.05$).

Regarding the RV stroke work, table (7) showed that the mean RV stroke work of the normal echo study was 1900.56 ± 276.26 (range 1480.0 – 2300.0) whereas the mean RV stroke work of the group of ASD patients was 2327.65 ± 634.68 (range1420.0 – 3700.0), the mean RV stroke work of the group of PFO patients was 1809.29 ± 539.28 (range 1320.0 – 2900.0) and the mean RV stroke work of the group of VSD patients was 1711.82 ± 457.86 (range 1320.0 – 3000.0). There was positive significant difference in comparing the normal patients and ASD patients, in comparing normal subjects and VSD patients, in comparing ASD and PFO patients, and in comparing the ASD and VSD patients (p_1, p_2 & $p_3 \leq 0.05$).

Table (7): Comparison between the different studied groups according to RV MPI and RV stroke work

RV	Diagnosis				Test of Sig.	p
	Normal (n= 27)	ASD (n= 51)	PFO (n= 21)	VSD (n= 33)		
MPI						
Min. – Max.	0.31 – 1.35	0.17 – 1.31	0.31 – 1.04	0.28 – 0.88	F= 6.242*	0.001*
Mean ± SD.	0.63 ± 0.30	0.82 ± 0.34	0.61 ± 0.28	0.54 ± 0.21		
Median	0.53	0.88	0.53	0.49		
p_1		0.042*	0.994	0.581		
Sig.bet.Grps		p_2=0.035*, p_3<0.001*, p_3=0.798				
Stroke work						
Min. – Max.	1480.0 – 2300.0	1420.0 – 3700.0	1320.0 – 2900.0	1320.0 – 3000.0	H= 31.833*	<0.001*
Mean ± SD.	1900.56 ± 276.26	2327.65 ± 634.68	1809.29 ± 539.28	1711.82 ± 457.86		
Median	1950.0	2350.0	1500.0	1600.0		
p_1		0.017*	0.122	0.026*		
Sig.bet.Grps		p_2<0.001*, p_3<0.001*, p_4=0.648				

F: **F for ANOVA test**, pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Tukey)**
H: H for **Kruskal Wallis test,** pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Dunn's for multiple comparisons test)**
p: p value for comparing between the different studied groups
p_1: p value for normal and each other group
p_2: p value for comparing between ASD and PFO
p_3: p value for comparing between ASD and VSD
p_4: p value for comparing between PFO and VSD
*: Statistically significant at $p \leq 0.05$

Table (8) showed that the mean TR Vmax value of the normal echo study was 1.48 ± 0.61 (range 0.62 – 2.53) whereas the mean TR Vmax value of the group of ASD patients was 2.74 ± 0.65 (range 1.73 – 3.94), the mean TR Vmax value of the group of PFO patients was 1.48 ± 0.32 (range 1.17 – 2.0) and the mean TR Vmax value of the group of VSD patients was 1.98 ± 0.60 (range 1.40 – 3.20). There was positive significant difference in comparing the normal subjects and ASD patients, in comparing normal subjects and VSD patients, in comparing ASD and PFO patients, in comparing the ASD and VSD patients, and in comparing VSD and PFO patients (p_1, p_2, p_3 & $p_4 \leq 0.05$).

Table (8): Comparison between the different studied groups according to TR Vmax

TR Vmax	Diagnosis								Test of Sig.	p
	Normal (n= 27)		ASD (n= 51)		PFO (n= 21)		VSD (n= 33)			
	No.	%	No.	%	No.	%	No.	%		
Normal (≤2.8)	27	100.0	27	52.9	21	100.0	25	75.8	χ^2= 29.816	^{MC}p= <0.001*
Elevated (>2.8)	0	0.0	24	47.1	0	0.0	8	24.2		
Min. – Max.	0.62 – 2.53		1.73 – 3.94		1.17 – 2.0		1.40 – 3.20		H= 66.775	<0.001*
Mean ± SD.	1.48 ± 0.61		2.74 ± 0.65		1.48 ± 0.32		1.98 ± 0.60			
Median	1.25		2.80		1.40		1.70			
p_1			<0.001*		0.938		0.010*			
Sig.bet.Grps			p_2<0.001*, p_3<0.001*, p_4=0.013*							

χ^2: **Chi square test** MC: **Monte Carlo**
H: H for **Kruskal Wallis test,** pairwise comparison bet. each 2 groups was done using **Post Hoc Test (Dunn's for multiple comparisons test)**
p: p value for comparing between the studied groups
p_1: p value for normal and each other group
p_2: p value for comparing between ASD and PFO
p_3: p value for comparing between ASD and VSD
p_4: p value for comparing between PFO and VSD
*: Statistically significant at $p \leq 0.05$.

DISCUSSION

In our study, we noticed a statistically significant difference in TR Vmax between the normal group and the patients with intracardiac shunts. There was significant difference in TR Vmax between the ASD patients and normal group, ASD and PFO patients, and ASD and VSD patients. **Nashat *et al.*** **[8]** studied the atrial septal defects and its relation to pulmonary arterial hypertension. She found that adverse prognosis and outcome with pre-tricuspid lesions as ASD over post-tricuspid lesions VSD. Our results are in agreement with **Nashat *et al.*** **[8]** regarding effect of ASD on pulmonary arterial hypertension and RV dysfunction.

PW Doppler and PW tissue Doppler imaging measurements correlate with invasive cardiac catheterization measurements in children with PAH due to intracardiac shunts **[3]**.

TDI is used in echocardiography to measure the motion (velocity) of the myocardial tissue. Moreover, TDI may be superior to blood flow Doppler, as it reflects the functional status of the myocardium directly, is less subject to background noise and also provides information about systolic and diastolic time intervals in the same cardiac cycle **[9]**.

In our study using the Doppler imaging to assess the RV function, there was a statistically significant difference in (E), (A), (E/A), (S:D) between the normal group and the patients of intracardiac shunts. We noticed statistically significant difference between the normal subjects and ASD patients through measuring E, E/A, S:D and statistically significant difference between the ASD and PFO patients through measuring A, E/A, S:D. There was statistically significant difference in E between the normal subjects and VSD patients, while there was statistically significant difference in S:D between the ASD and VSD patients.

Regarding the tissue Doppler measurements, there was statistically significant difference in (E'), (A'), (IVCT), (IVRT), (E/E') between the normal group and the patients with the intracardiac shunts.

We noticed a statistically significant difference in (E'), (E/E') in comparing the normal group and ASD patients and statistically significant difference in (E'), (A'), (IVCT) in comparing the ASD and PFO patients, while there was a statistically significant difference in (A'), (IVCT) in comparing the normal group and PFO patients.

Cevik *et al.* **[3]** investigated the value of the Doppler tissue imaging as an estimate of pulmonary arterial pressure in children with pulmonary hypertension due to congenital intracardiac shunts, including 40 healthy children and 29 children with CHD and using both invasive and non-invasive methods proving their great importance in evaluating the pulmonary artery pressure in the patients with intracardiac shunts. Our results are in agreement with **Cevik *et al.*** **[3]** regarding the doppler and the tissue Doppler measurements significance between the patients with intracardiac shunts and the normal population.

The novel recommended methods to quantitatively assess RV function include RV myocardial performance index (RV MPI) and strain imaging **[10]**. Strain imaging is the only echocardiographic parameter that evaluates both RV systolic and diastolic function at the global and segmental level of the myocardial tissue at the same time **[11]**. In the present study, there was statistically significant difference in systolic and diastolic (both early and late) RV global longitudinal strain rate between the normal group and intracardiac patients. There was significant difference in systolic and diastolic RV global longitudinal strain rate values in the comparison between the ASD and PFO patients and between the ASD and VSD patients.

Kenichi *et al.* **[5]** assessed the right ventricular diastolic performance in children aged 0 to 18 years with pulmonary arterial hypertension associated with congenital heart disease compared to invasive cardiac catheterization. Besides, **Koestenberger *et al.*** **[1]** studied the transthoracic echocardiography use in the evaluation of pediatric pulmonary hypertension and ventricular dysfunction using strain rate, tissue Doppler, MPI, TAPSE variables compared to invasive cardiac catheterization. Our results are in agreement with the above-mentioned studies on the importance and validity of the use of strain imaging for RV evaluation in patients with intracardiac shunts.

Eidem *et al.* **[12]** stated that the MPI is a simple, quantitative, non-geometric index of ventricular function that is readily applicable to the study of RV function as well as the assessment of distorted ventricular morphologies present in congenital heart disease. It is especially appealing because it is a Doppler-derived index that is easily reproducible in children and adults because it measures relatively large time intervals.

Ding *et al.* **[13]** concluded that MPI is free from the effect of age, heart rate and blood pressure. **Ishii *et al.*** **[14]** also concluded that by combining systolic and diastolic time intervals, MPI is a feasible approach to assess global RV function in children with abnormal RV shape due to CHD. **Eidem *et al.*** **[12]** reviewed the usefulness of the myocardial performance index for assessing right ventricular function in congenital heart disease and concluded that preload elevation increases IVCT and ejection time but reduces IVRT leading to higher MPI values in patients with CHD. In our study, MPI is noticed to be a statistically significant different between the normal group and the patients with the intracardiac shunts. There was significant difference between the ASD patients and the normal group, ASD and PFO patients, and ASD and VSD patients. Our results are in agreement with the study done by **Koestenberger *et al.*** [1] and **Eidem *et al.*** [12] on the affection of MPI by RV dysfunction.

RV stroke work (RVSW), which incorporates stroke volume and systolic pressure, may be more representative of both static and dynamic workload and therefore may be a determinant of RV failure. **DiMaria *et al.*** [7] published a study on the validity of echocardiographic estimation of right ventricular stroke work in children with pulmonary arterial hypertension proving that RV stroke work is a potential novel index of RV function, can be estimated noninvasively and is related to pulmonary hemodynamics and other indices of RV performance. Based on our results, stroke work showed statistically significant difference between the normal group and the patients with intracardiac shunts. There was significant difference between the normal group and ASD patients, normal group and VSD patients, ASD and PFO patients and ASD and VSD patients. This also is an agreement with the study done by **DiMaria *et al.*** [7] proving that there is significant difference in RV stroke work in patients with RV dysfunction and pulmonary hypertension.

CONCLUSION

The echocardiographic parameters used in our study such as MPI, Stroke work, TDI, and Strain rate give simultaneous and accurate measurements of systolic and diastolic function of the right ventricle in patients with intracardiac shunts.

All these echocardiographic parameters were affected with the development of pulmonary hypertension and right-side heart failure in the patients with intracardiac shunts. However, it was found that they are significantly elevated in patients with ASD compared to other intracardiac shunts patients and normal population.

Elevated pulmonary artery pressure is also associated with higher values of these parameters affecting the RV function and it was noticed especially in the ASD patients.

RECOMMENDATIONS

Based on our results, it is very important to precisely evaluate the right ventricle in patients with intracardiac shunts using the new echocardiographic parameters as they are considered as good indicators for determining the RV systolic and diastolic function and for assessing the probability of development of pulmonary hypertension. They are also characterized by being noninvasive, precise, easy to obtain and accurate.

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