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ORIGINAL ARTICLE

Right Ventricle Segmental Strain Trends in Patients undergoing Tetralogy of Fallot Repair: An Observational Study

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ABSTRACT

Introduction: Incidence of right ventricular (RV) dysfunction in early postoperative period after Tetralogy of Fallot (TOF) repair ranges from 28 to 63%. Echocardiography is the first-line tool for the assessment of RV function in early postoperative period. As speckle tracking echocardiography (STE) has emerged as a new promising tool for assessing myocardial performance and is independent of geometric assumptions and angle dependence, it is more sensitive for detecting changes in myocardial performance than conventional echocardiographic parameters of RV function. The current study demonstrates echocardiographic parameters assessed by conventional two-dimensional (2D) echocardiography and STE in patients before and after TOF repair.

Materials and methods: Fifty-nine consecutive patients planned for complete intracardiac repair for TOF were enrolled in this prospective cohort study. The 2D echocardiography and STE were performed a day prior to TOF repair, in the early postoperative period between days 3 and 7 and after discharge at 3 months.

Results: The median age of patients was 6 years, with 57.6% males (34/59). Baseline hemoglobin and room air oxygen saturation were 17.7 ± 3.7 gm% and 79.4% ± 8% respectively. Two patients did not survive the procedure (3.4%). Right ventricular longitudinal peak systolic strain (RV LPSS) in early postoperative period was significantly decreased in all segments of both septal and lateral wall. However, RV LPSS assessed at midterm follow-up at 3 months postoperatively significantly improved in all segments of RV compared with assessment done in the early postoperative period, and was significantly better than preoperative values in all three segments of the septal wall.

Conclusion: Our study shows that the use of 2D strain or speckle tracking is a feasible and easy-to-implement technique for the evaluation of RV function after TOF repair.

Keywords: Echocardiography, Right ventricle, Right ventricular longitudinal segmental strain, Tetralogy of Fallot.

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INTRODUCTION

Right ventricular (RV) function evaluation is always a challenging task in congenital heart diseases. It is especially relevant in Tetralogy of Fallot (TOF), which involves significant surgical intervention and hemodynamic stress on the RV in the perioperative period. The RV function in the postoperative period is also an important determinant of long-term survival and an independent predictor of future New York Heart Association class status and heart failure.[1] Right ventricular hypertrophy, higher RV pressures, and RV systolic dysfunction have also been shown to predict long-term mortality as well as occurrence of future ventricular tachycardia.

The RV has complex morphological and functional properties. Most of the imaging modalities are optimized and focused on assessment of left ventricle, as it was thought to be the ventricle of importance in the past. However, as the importance of RV is increasingly being recognized,[2,3] a variety of techniques and different modalities have been devised for the estimation of its structure and function. The cardiac magnetic resonance imaging (MRI) is considered to be the gold standard investigation; however, it has its own limitations of availability, time consumption, cost involved, and feasibility in the early postoperative settings. Echocardiography, when utilized in a technically and clinically appropriate setting, has been found to correlate well with cardiac MRI. Due to the unique geometry of RV, which is crescentic in transverse section and triangular in the coronal plane, the conventional two-dimensional (2D) quantification of RV performance is considered less accurate and reproducible. Further, the myocardium of the RV contracts longitudinally as well as radially, and also exhibits torsion in the infundibular region. The longitudinal contraction contributes maximum to its function, and is assessed by the measures of tricuspid annulus plane systolic excursion (TAPSE) as well as the longitudinal strain by tissue Doppler imaging (TDI). Though TAPSE has been a well-recognized measure of global RV function, it appears more simplistic and lacks segmental analytical properties to assess RV function. Moreover, TDI has an intrinsic limitation of being angle dependent and is subjected to significant interobserver and intraobserver variations.[4] Thus, the speckle tracking echocardiography (STE) has emerged as a novel method to assess myocardial performance, especially in RV. This technique does not depend on ventricular geometry and angle. The STE-derived strain is a more sensitive marker for detecting changes in myocardial performance than conventional echocardiographic parameters of RV function.[5,6] In the current study, we plan to assess RV function in a series of patients who underwent intracardiac repair (ICR) for TOF at a tertiary-level cardiac center in India by 2D echocardiography, TDI, and STE serially in the early postoperative period and till 3 months postoperatively.

MATERIALS AND METHODS

In this study, we enrolled 59 consecutive patients of TOF who underwent complete ICR at the Advanced Cardiac Center of the Postgraduate Institute of Medical Education and Research. The study was approved by the Institutional Ethical Committee, and written informed consent was obtained from the legal guardians.

ANESTHESIA TECHNIQUE

Premedication was given with 0.5 mg/kg of midazolam orally half an hour before surgery. Inside the operating room, electrocardiography, pulse oximetry, and noninvasive blood pressure were applied. Anesthesia was induced with sevoflurane in oxygen, followed by fentanyl 5 µg/kg administered through peripheral intravenous access, and endotracheal intubation facilitated by vecuronium 0.1 mg/kg. Arterial catheter was inserted in femoral or radial artery, and right internal jugular vein was cannulated with triple lumen catheter for central venous access. A baseline transthoracic echocardiogram (TTE) was performed after induction of general anesthesia. After endotracheal intubation, a pediatric transesophageal echocardiography probe was introduced. Anesthesia was maintained by isoflurane, fentanyl infusion 1 to 2 µg/kg/hour, and vecuronium boluses. A standard anticoagulation technique was used for all the patients before cannulation. Heparin 4 mg/kg was given for achieving activated clotting time (ACT) more than 480 seconds. During bypass, ACT was checked every hour, to monitor adequacy of anticoagulation.

INTERVENTION AND PERIOPERATIVE MANAGEMENT

All patients underwent ICR via median sternotomy under cardiopulmonary bypass (CPB) support. Surgical procedure was categorized for the purpose of analysis as type I: Only RV outflow tract obstruction (RVOTO) resection and ventricular septal defect (VSD) closure; type II: RVOTO resection, pericardial patch augmentation of the RV outflow tract (RVOT), and VSD closure; and type III: RVOTO resection, patch augmentation of RVOT, and branch pulmonary artery and VSD closure. Cardioplegia used during the procedure was either intermittent cold blood cardioplegia as per institutional protocol or del Nido cardioplegia (as part of another randomized trial to compare the two cardioplegia types). Postoperatively, patients were initially monitored in the cardiac intensive care unit as per protocol, prior to transfer to the step-down cardiac observational unit. Inotrope scores were monitored at 24 and 48 hours postoperatively, and creatine kinase-MB levels were trended at baseline, 24 hours postoperatively, and at day 7 and 3 months postoperatively.

ECHOCARDIOGRAPHY PROTOCOL AND DATA COLLECTION

Serial TTEs were performed, at baseline (preoperatively), in the early postoperative period (between days 3 and 7) and at 3 months postoperatively.

For each of the echocardiograms, a comprehensive TTE was performed using M5S transducer (Vivid 7; GE Medical Systems, Horten, Norway). The RV fractional area change (FAC) (%) was assessed by measuring the area at end diastole and systole in apical four-chamber view; TAPSE (mm) was assessed by M-mode echocardiography from the apical four-chamber view. A 5 mm sample volume was placed at the lateral corner of tricuspid annulus for measuring tissue Doppler velocities. The resulting velocities, tricuspid annulus peak systolic velocity (Ss), and early diastole (E)) were recorded at a sweep speed of 100 mm/s. The myocardial performance index (MPI) was calculated according to the following equation:

$$\text{RV MPI} = \frac{\text{Isovolumic contraction time (ICT)} + \text{Isovolumic relaxation time (IRT)}}{\text{RV ejection time (ET)}}$$

Speckle tracking-derived RV wall longitudinal peak systolic strain (RV LPSS) was measured on the apical four-chamber images. Strain of the basal, mid, and apical segments of the RV septal and lateral wall values was averaged to calculate RV global longitudinal strain (GLS) (%). All data were digitally stored.

For analysis, an average of three consecutive readings of above-mentioned parameters was used.

Statistics

Descriptive statistics are presented as frequencies and proportions, mean ± standard deviation (SD) or median and interquartile range (IQR) where appropriate. Categorical variables are presented as percentages. Categorical variables were assessed using chi-square test, and continuous variables were assessed using t-test, analysis of variance (ANOVA), or Kruskal–Wallis where appropriate. All p-values ≤ 0.05 are considered significant. All data were analyzed using Statistical Package for the Social Sciences, version 21.

RESULTS

The median age was 6 years (IQR 3–13 years), with 34 (57.6%) being males. Baseline hemoglobin value and room air oxygen saturation were 17.7 ± 3.7 gm% and 79% ± 8% respectively (Table 1).

Table 1: Demographic data (n = 59)

Variable	*n = 59 (Mean ± SD)*
Age (years)	6.62 ± 2.62
Gender (M/F)	34/25
BSA (m^2)	0.797 ± 0.28
Baseline Hb (gm%)	17.7 ± 3.48
Room air SaO_2 (%)	79 ± 8

Values are reported as mean ± SD or numbers; Hb: Hemoglobin

Twenty-six (44.1%) patients received standard cold blood cardioplegia, while 55.9% (33/59) received the del Nido cardioplegia; 14 (23.7%) patients had only RVOTO resection, while 43 (72.9%) had RVOT resection with patch augmentation; and 2 patients underwent branch pulmonary arteries augmented as well.

Mean CPB time was 142.1 minutes (SD 43.4 minutes) and the mean aortic cross clamp (AXC) time was 94.3 minutes (SD 34.1 minutes). All patients regained spontaneous sinus rhythm at the end of procedure. Fourteen (23.7%) had junctional ectopic tachycardia (JET) in the postoperative period and was managed accordingly.

When assessing RV function using TAPSE, FAC, and MPI compared with the preoperative values, there was a significant initial decrease in the RV function early postoperatively (days 3 to 7) (Table 2). All these measures then significantly improved over baseline values at 3 months follow-up.

When compared with preoperative state at 3 months, there was no significant association of amount of improvement in TAPSE, MPI, or FAC with patient sex, type of procedure, or presence of MAPCAs. There was a significantly greater improvement in TAPSE in patients who stayed free of arrhythmias postoperatively as compared with patients who had JET (1.40 ± 0.688 *vs* 0.934 ± 0.577, p = 0.044).

Type of cardioplegia used had a mixed effects on measures of RV function. There was a significantly greater improvement in the FAC in patients receiving the del Nido cardioplegic as compared with the standard preparation (FAC 0.32 ± 0.13 *vs* 0.28 ± 0.15, p = 0.015). The improvement in TAPSE was also greater in the del Nido group, although the values are statistically not significant (TAPSE 1.48 ± 0.60 *vs* 1.19 ± 0.58, p = 0.094).

There was no significant correlation of amount of improvement in TAPSE, MPI, or FAC with age, baseline hemoglobin, duration of CPB or AXC, residual RVOTO, inotropic score at 24 hours or 48 hours postoperative, or CVP postoperatively. There was no significant difference in CPK-MB levels between the two groups (p > 0.05).

Table 2: The RV systolic function parameters by 2D echocardiography at serial measurements

RV function parameter		*Preoperative*		*Postoperative (between days 3 and 7)*	*p-value*[1]		*3 months*	*p-value*[2]
TAPSE (mm)	n = 58	15.38 ± 2.73	n = 58	6.22 ± 1.31	<0.001*	n = 51	13.78 ± 2.25	<0.001*
MPI	n = 57	0.46 ± 0.09	n = 57	0.58 ± 0.17	<0.001*	n = 51	0.41 ± 0.07	<0.001*
FAC (%)	n = 57	39.75 ± 5.75	n = 57	37.00 ± 5.05	<0.001*	n = 50	47.56 ± 4.39	<0.001*
Global strain	n = 56	−19.35 ± 3.30	n = 56	−14.59 ± 3.23	<0.001*	n = 48	−22.90 ± 2.26	<0.001*

*p-value significant at <0.05; 1: Comparing preoperative and postoperative values; 2: Comparing 3 months value and postoperative value

Table 3: The RV longitudinal segmental strain values at serial measurements

RV LPSS segmental (%)	Preoperative	Postoperative	p-value[1]	Postdischarge 3 months	p-value[2]	p-value[3]
Basal septum	−14.98 ± 6.49	−12.45 ± 5.57*	0.026*	−20.55 ± 3.53#	<0.001*	<0.001*
Mid septum	−16.02 ± 6.87	−11.86 ± 5.80*	<0.001*	−21.41 ± 4.31#	<0.001*	<0.001*
Apical septum	−16.38 ± 6.79	−13.70 ± 5.25*	0.014*	−22.27 ± 4.15#	<0.001*	<0.001*
Basal lateral	−17.83 ± 6.84	−13.91 ± 5.63*	0.002*	−20.60 ± 35.02#	<0.001*	0.054
Mid lateral	−20.83 ± 7.42	−13.96 ± 6.04*	<0.001	−21.34 ± 4.30#	<0.001*	0.592
Apical lateral	−21.12 ± 9.26	−14.44 ± 6.19*	<0.001	−20.90 ± 5.56#	<0.001*	0.932

*p-value <0.05; 1: Comparing preoperative and postoperative values; 2: Comparing 3 months value and postoperative value; 3: Comparing 3 months value and preoperative value; Values reported as mean ± standard deviation

Table 4: Comparison of echocardiographic parameter of RV function between different types of surgery performed

Variable		Type I (n = 14)	Type II (n = 43)	Type III (n = 2)	ANOVA p-value
TAPSE	Preoperative	15.14 ± 3.0	14.9 ± 3.31	17.0 ± 1.4	0.64
	Early postoperative	6.14 ± 0.77	5.95 ± 1.28	6.5 ± 2.12	0.49
	At 3 months	13.42 ± 2.02	13.76 ± 2.31	15.50 ± 2.12	0.48
MPI	Preoperative	0.45 ± 0.08	0.48 ± 0.12	0.43 ± 0.13	0.21
	Early postoperative	0.57 ± 0.13	0.56 ± 0.15	0.52 ± 0.9	0.35
	At 3 months	0.38 ± 0.06	0.40 ± 0.06	0.42 ± 0.12	0.58
FAC	Preoperative	39.71 ± 6.74	39.44 ± 5.85	43.50 ± 4.94	0.65
	Early postoperative	40.35 ± 5.31	37.85 ± 5.11	44.50 ± 7.76	0.09
	At 3 months	48.00 ± 4.40	47.44 ± 4.50	46.00 ± 1.41	0.83
S’	Preoperative	9.23 ± 1.21	10.32 ±0.90	10.28 ± 1.43	0.53
	Early postoperative	5.28 ± 0.72	5.68 ± 1.19	5.50 ± 0.70	0.92
	At 3 months	11.00 ± 1.20	11.53 ± 1.35	11.43 ± 1.30	0.58
GLS	Preoperative	−19.96 ± 3.19	−19.13 ± 3.29	−18.50 ± 3.53	0.67
	Early postoperative	−15.12 ± 3.58	−13.31 ± 5.32	−14.00 ± 1.41	0.51
	At 3 months	−23.06 ± 1.64	−22.81 ± 2.45	−23.80 ± 2.26	0.80

Compared with the preoperative values, the RV LPSS in the early postoperative period was significantly decreased in all segments of both septal and lateral wall after the TOF repair. However, RV LPSS at the midterm follow-up at 3 months postoperatively was significantly improved in all segments of RV compared with early postoperatively, and was significantly better than preoperative values in all three segments of the septal wall (Table 3).

When the values of all parameters of RV function were compared between the groups of type of surgery performed, it was found to have a nonsignificant difference (Table 4), thus interpreting that the type of surgery performed did not have any significant effect on RV function.

Two patients did not survive the procedure (3.4%). Baseline hemoglobin level was significantly higher (17.52 ± 3.70 *vs* 22.0, $p < 0.001$) in patients who have perioperative mortality. Higher inotrope score at 48 hours also tended toward significant association with mortality ($p = 0.088$). None of the other baseline parameters (age, sex, type of procedure, presence of MAPCAs, type of cardioplegic agent, or duration of CPB or AXC) had any significant association with poor periprocedural outcome.

DISCUSSION

We report the trend of RV strain measures in patients with TOF operated at a tertiary level referral center in India, with a significant drop after complete ICR, but significant improvement above preoperative values at 3 months.

In the current era, ICR of TOF is the preferred surgical intervention in this lesion.[7] The outcomes are good for the smaller babies as well, with evidence of longer postoperative stay but overall fewer surgical procedures and subsequent hospitalizations.[8] We had two patients die in the immediate postoperative period; however, the sample size was low and the study was not powered enough to determine any significance of association with the baseline or outcome variables.

The RV dysfunction in TOF patients after repair has been found to be associated with adverse events and outcomes. This is an association that persists into adulthood after repair as a toddler. Lu et al[9] showed patients with RV LPSS fraction less than the median had increased odds of decreased physical functioning, including in patients with normal RV ejection fractions. Moon et al[10] reported lower RV strain values in TOF patients with ventricular tachycardia or death as compared with control TOF group. The RV dysfunction is systolic as well as diastolic, and also impacts the LV function through abnormal ventriculo-ventricular interactions. In their study comparing TOF patients postoperatively with controls, Friedberg et al[11] found that TOF patients had significant depression of the RV ejection fraction, as well as RV diastolic dysfunction. Further, higher RV volumes were associated with lower LV early diastolic radial and circumferential strain rate as well.

In this setting of relatively later repairs, where the RV has been experiencing outflow tract obstruction for a longer duration, the studies of RV function gain more significance. We found that RV LPSS is significantly reduced in septal and lateral wall in the early postoperative period. However, over the mid-term follow-up (3 months), RV LPSS was significantly increased in septal wall and improved in lateral wall in TOF repair patients compared with preoperative values. The strain assessment by ultrasound speckle tracking is a promising tool, which directly measures myocardial shortening free of geometric assumptions and insonation angle. The results of this study are in tune with the study of Xie et al[12] who found that RV GLS measured by 2D STE was increased in patients at 6 months after ICR of TOF as compared with the preoperative values. Early postoperative RV dysfunction may be due to inadequate myocardial preservation and reperfusion injury. The improvement in the postoperative RV function might be due to the fact that surgical correction closes the ventricular septal defect and reduces the RV pressure overload, in which myocardium takes 3 months for recovery.

Our study was limited by the relatively smaller number of patients, and the short follow-up duration of 3 months. We are continuing to study patients undergoing TOF repair at our center, and continuing their long-term follow-up at 6 months and 1 year to assess trends in the RV function, and their association with medium and longer term outcomes.

CONCLUSION

Our study shows that the use of 2D strain or speckle tracking is a feasible and easy-to-implement technique for the evaluation of RV function in TOF repair patients in follow-up. The improvement in RV systolic function is not impacted significantly by duration of CPB; however, occurrence of postoperative JET in this population is associated with lesser improvement in TAPSE at 3 months postoperatively. Hence, patients that experience JET merit closer monitoring during postoperative follow-up. Further, patients receiving del Nido cardioplegic have better FAC at 3 months postoperatively. Overall, it is promising that there is sustained improvement in RV systolic function at 3 months postoperatively, regardless of preoperative severity of disease or duration or type of surgical intervention.

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