Evaluate Radial and Longitudinal Myocardial Motion Velocity in Left and Right Ventricles for Repaired Tetralogy of Fallot Patients by Phase-Contrast MRI

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Introduction: After two or three decades of the repaired surgery for tetralogy of Fallot (rTOF) in infancy, the cardiac function of patients will gradually deteriorated due to pulmonary regurgitation (PR) (1). Though PR can be tolerated well for many years, it has been confirmed that it leads to irreversible myocardial injury over time (2). Therefore, it is important to decide an appropriate timing for pulmonary valve replacement (PVR) surgery to prevent serious PR and thus the late cardiac failure. By evaluating the global ventricular function and degree of PR, the suitable timing of PR has been reported (2, 3). Nevertheless, regional analysis of both LV and RV function is still deficient because of the irregular geometry and thin wall thickness of RV and thus the difficulty of quantification on RV wall. This study aims to characterize regional cardiac function by evaluating radial (Vr) and longitudinal (Vz) motion velocities and time-to-peak (TTP) in basal, mid, and apical slices for rTOF patients in LV and RV. The curvature of septum is also assessed to distinguish the deformation of the interventricular septum in rTOF.

Methods: The study population consisted of 16 rTOF patients (24.2 ± 4.4 y/o; male/female: 9/7) and 15 normal controls (23.3±2.4 y/o; male/female: 8/7). All subjects underwent 2D dark-blood fast low angle shot (FLASH) sequence on a 3.0-Tesla MR scanner (Trio with Tim or Skyra, Siemens, Erlangen, Germany). Images were oriented in three short-axis slices (base, mid, apex). Prospective ECG-triggering (acquiring 85-90% of the R-R interval) and navigator-echo were performed to synchronize with cardiac and respiratory motion, respectively. The scanning parameters were TR/TE = 26/4.2 ms, pixel size = 1.17 x 1.17 mm^2, slice thickness = 6mm, flip angle = 7°, and Venc = 15 cm/s in-plane and 25 cm/s through-plane. Post-processing was performed on a self-developed program. LV and RV were divided into 16 and 10 segments, respectively(Fig. 1a). After manually determining the region-of-interests (ROIs) on each cardiac phase and each slice, peak Vr and Vz as well as the TTPr and TTPz of each segment can be assessed. The time frames were interpolated with a spline function and normalized to subject-specific systolic duration to be showed as percentage of the end-systole (%ES). The septal curvature was assessed on magnitude images of the basal slice at end-diastole. As shown in Fig. 2, r1 and r2 were radiuses fitted from arc AB (endocardial border) and arc CD (epicardial border), respectively. The fitting radius (R_f) is the mean of r1 and r2. A calculated radius (R_c) was defined as $R_c = \sqrt{\text{epicardial area}/\pi}$. A radius ratio was defined by R_f / R_c so that to normalized the subject-specific LV size.

Table 1. Basic characteristics of the study cohort.

	Normal (n=15)	rTOF (n=16)
Age (yrs)	23.3 ± 2.4	24.2 ± 4.4
Sex (male/female)	8/7	9/7
BSA (m^2)	1.6 ± 0.1	1.5 ± 0.2
LVESV (cm^3)	24.1 ± 6.2	26.2 ± 7.9
LVESVI (cm^3/m^2)	14.4 ± 5.0	17.3 ± 6.0*
LVEDV (cm^3)	87.4 ± 13.5	97.8 ± 19.2*
LVEDVI (cm^3/m^2)	54.2 ± 8.3	64.4 ± 11.1*
LVEF (%)	75.2 ± 5.1	73.6 ± 6.2

BSA= body surface area; LVESVI/LVEDVI = left ventricular end-systole/end-diastolic volume index; LVEF= left ventricular ejection fraction. Data are presented as mean ± SD. *p < 0.05

Fig. 1. (a) LV and RV were divided into 16 and 10 segments, respectively. (b) The localization of base, mid, apex slices.

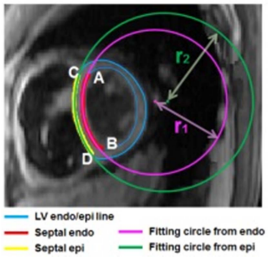

Fig. 2. The plot showed septal border and fitting circles.

Results: Table 1 summarizes the clinical parameters of cardiac function of the study population. Compared with normal, rTOF patients showed significant higher LVESVI (14.4 ± 5.0 vs. 17.3 ± 6.0 cm^3/m^2, $p < 0.05$) and LVEDVI (54.2 ± 8.3 vs. 64.4 ± 11.1 cm^3/m^2, $p < 0.05$), saying the patients presenting dilated LV. However, the LV ejection fraction (LVEF) in rTOF patients was comparable with normals (73.6 ± 6.2 % vs. 75.2 ± 5.1 %), indicating the preserved EF in the recruited patients. In Fig. 3, patients showed significantly decreased systolic Vr on RV free wall and exhibited higher diastolic Vr (expansion velocity) on RV anterolateral wall and LV septum. Further, rTOF patients demonstrated noticeable shorter systolic TTPz, particularly on RV anterolateral wall (Figs. 4(a,b)). In addition, patients also exhibited significantly reduced systolic Vz either in LV or RV (Figs. 4(c,d)). Figures 5(a,b) displayed the morphologically flatter septum in rTOF patients in comparison with normals. As shown in Fig. 5c, the fitting radius of rTOF is higher than normals (35.6 ± 7.1 mm vs. 29.6 ± 3.8 mm, $p < 0.01$). After with normalization to subject-specific LV size, patients with rTOF still showed obviously larger radius ratio compared with normals (1.6 ± 0.3 vs. 1.2 ± 0.1, $p < 0.001$).

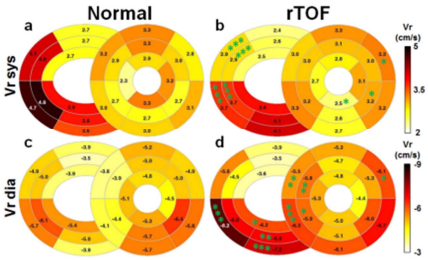

Fig. 3. The peak systolic Vr (a,b) and diastolic Vr (c,d) in normals and rTOF.

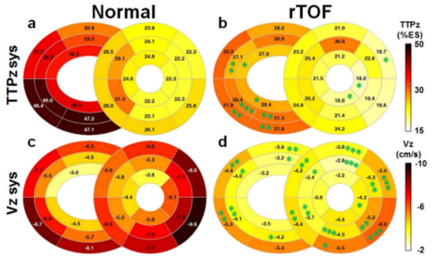

Fig. 4. Systolic TTPz (a,b) and Vz (c,d) in normals and rTOF. *p<0.05, **p<0.01, **p<0.001

Discussion & Conclusions: In this study, the septal curvature and myocardial motion velocities as well as the TTP in radial and longitudinal directions were quantified for rTOF patients and age-matched normals. The bullseye plots generally depicted lower peak systolic Vr, higher peak diastolic Vr, shorter systolic TTPz, and lower peak systolic Vz in rTOF patients. Stuber et al used MR tissue tagging and proposed that either the contractive or expansive myocardial motion can become significantly different to modulate the myocardial function in a compensatory mechanism in aortic stenosis patient (4). Tverskaya et al have reported that severe chronic volume overload caused stereotypical structural unusual to both LV and RV and markedly damaged contraction function (5). In our work, rTOF patients revealed abnormal enlarged LV volume (higher LVESVI and LVEDVI). Accordingly, it is expectable for rTOF patients to exhibit weaker systolic contraction, reflected by lower systolic Vr and lower systolic Vz as well as shorter systolic TTPz. In addition, higher diastolic Vr in RV anterolateral wall and LV septum may be a compensatory mechanism to overcome impaired RV function. Roeleveld et al have proposed that larger septal bowing of rTOF, revealing flattened interventricular septal curvature, is likely associated with RV pressure overload (6). Geva et al. demonstrated that impaired myocardium fiber with the symptoms of RV overload lead to progressive increase in the degree of PR over time (1). In this study, radius ratio quantified the flat septum in rTOF patients and the elevated ratio may suggest deteriorated RV compensatory mechanism due to sustained PR effect. In conclusion, prior to significant impaired LVEF, myocardial motion velocity-derived indices and radius ratio can provide satisfied information to evaluate regional myocardial function of rTOF patients. The establishments of those indices in this study might be helpful for patient managements regarding the timing of undergoing PVR surgery.

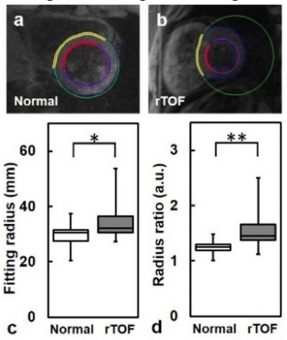

Fig. 5. The fitted circles in one normal (a) and one rTOF (b). The box plots showed group analysis of the fitting radius (c) and radius ratio (d). *p<0.05, **p<0.01.

References: **1.** T. Geva, *Semin Thorac Cardiovasc Surg Pediatr.* 2006;9:11. **2.** W.A. Helbing, et al. *J Am Coll Cardiol.* 1996; 28: 1827. **3.** A. Kempny, et al. *Int J Cardiol.* 2012; 154: 259. **4.** M. Stuber, et al. *Circulation.* 1999; 100(4). **5.** M. Tverskaya, et al. *Bull Exp Biol Med.* 2004; 138(6). **6.** R.J. Roeleveld, et al. *Radiology.* 2005. 234(3): 710.