Investigation of spatial flow profile pattern in branch pulmonary arteries after repaired Tetralogy of Fallot

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Introduction

Phase-contrast cine magnetic resonance imaging (PC-MRI), which provides benefit of noninvasive evaluation of cardiopulmonary function, has been proven as a reliable quantification approach for long-term follow-up after surgical repair of Tetralogy of Fallot (ToF).[1] In general, forward flow appears during systolic period while regurgitant flow is expected to occur during diastole. Nevertheless, qualitative analysis has also shown inhomogeneous flow profile, with forward and backward flow existing simultaneously in the same cross-sectional area. It, therefore, suggests that the conventional estimates derived from the time-averaged curve are insufficient for describing flow profile pattern as well as severity of pulmonary regurgitation.[2] In this study, we propose the use of pixelwise flow parameters for each cardiac phase to investigate the flow symmetry and the degree of the flow homogeneity, by using indices including eccentricity and onset of the regurgitant flow, respectively. Our preliminary results indicate that the quantitative analysis shows consistency with the qualitative flow profile pattern for both branch pulmonary arteries.

Methods

Imaging was performed on a 1.5T General Electric Signa CV/i system. PC-MR images of right (RPA) and left (LPA) pulmonary arteries were obtained with retrospective ECG gating for a total of twenty-six patients (age: 4.68±3.32 y/o, 18 males and 8 females) after repaired ToF, by double-oblique technique to acquire true perpendicular plane of long axis of the pulmonary artery. Flow velocity of 20 time phases per cardiac cycle was measured for each direction with upper velocity limit (VENC) set as 200 cm/sec. The obtained data were postprocessed using built-in software in a commercial workstation (GE Medical System), and subsequently, quantitative flow parameters including pixelwise regurgitant fraction (RF_{px}, in %), eccentricity at systolic peak (Ecc_{sys}), onset of the regurgitant flow (T_{onset}), and the corresponding duration between onset and maximal backward flow (T_{dur}, in %) were calculated with in-house software, where region of interest (ROI) was manually delineated for each phase based on corresponding anatomic MR images of thorax. Specifically, eccentricity was treated as a normalized flow asymmetry index by calculating the distance between the center of velocity at Γ of the forward flow C_{vel} at systole, defined as

$$C_{vel,j} = \frac{\int_{\Gamma} j\,\mathbf{v}^{+}(t_{sys})\cdot\mathbf{n}\,d\sigma}{\int_{\Gamma} \mathbf{v}^{+}(t_{sys})\cdot\mathbf{n}\,d\sigma} \qquad j = x, y, z \qquad (1)$$

and the center of Γ normalized to the lumen radius, with value equivalent to 0 meaning symmetric flow and equal of 1 representing totally asymmetric flow.[3] The onset of regurgitant flow was identified by regurgitant flow reaching 5% of its maximum.

Descriptive data were presented as mean±SD. Paired t test was used to analyze significance of flow parameters in branch pulmonary arteries and Wilcoxon rank sum test was applied to group analysis, where the probability value < 0.05 was considered to be statistically significant.

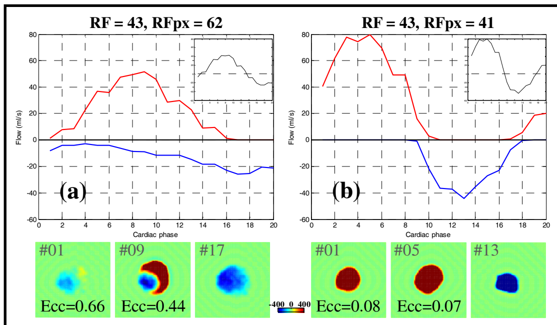

Fig. 1 Forward (red) and regurgitant (blue) flow curves within one cardiac cycle. Each time averaged curve is displayed in right up corner.

Table 1 Comparison of flow-related parameters in LPA and RPA.

	LPA (n=26)	RPA (n=26)
RF_{px}	50.74 ± 31.15**	33.93 ± 21.16**
Ecc_{sys}	0.24 ± 0.17*	0.13 ± 0.13*
T_{onset}	3.58 ± 3.36**	6.81 ± 4.29**
T_{dur}	43.85 ± 22.46*	31.15 ± 23.12*

* $p \leq 0.05$, ** $p \leq 0.01$

Results

Figure 1 illustrates the forward and backward flow curves in the RPA during one cardiac cycle from two individual patients, with the corresponding time averaged curves (right up coner). While identical regurgitant fractions (RF) of 43% are found for these two patients if defined conventionally, the selected flow velocity maps show distinct flow profile patterns with Ecc_{sys} of 0.44 and 0.07, seperately. The proposed spatial flow-related parameters are listed in Table 1. In the RPA, the RF_{px} (P=0.007), the Ecc_{sys} (P=0.011), and the T_{dur} (P=0.015) are significantly smaller than those in LPA. In contrast, T_{onset} is significantly later in RPA (P=0.004). Figure 2 are the boxplots for both branch pulmonary arteries. It exhibits significant difference of RF_{px} between groups of mild eccentric (Ecc_{sys}<0.3, with estimates of 45.1±35.2 for LPA and 30.3±16.9 for RPA) and marked eccentric (Ecc_{sys}>0.3, with estimates of 63.5±13.4 for LPA and 77.8±22.3 for RPA), indicating that a higher occurrence rate of backward flow is associated with a more asymmetric spatial flow profile.

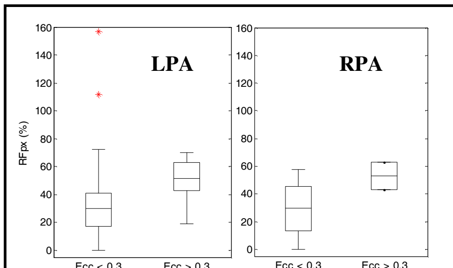

Fig. 2 Boxplots of grouped RFpx for LPA and RPA, where asterisks are outlier.

Discussion and Conclusion

The results from our study demonstrate that spatial heterogeneity in flow profile could be quantified by index of eccentricity, where flow symmetry in RPA is found with a smaller Ecc compared with that in LPA. The exploration of flow parameters of RF_{px}, backward flow starting and the duration also exhibits a more homogeneous flow profile within one cardiac cycle in RPA. On the other hand, the early onset of regurgitant flow and the longer time reaching the maximal regurgitation reflect higher RF_{px} in LPA, which may be an explanation for the under-estimation of conventional regurgitant fraction (RF) from time-averaged calculation nature. In addition, the increase eccentricity may imply the increase of vascular impedance, which may induce the severity of regurgitant flow in both branch pulmonary arteries.[1] In conclusion, these newly defined indices better reflect the degree of homogeneity for spatial flow profile, especially for ToF patients exhibiting largely atypical pulmonary flow. Thus the proposed indices may find applications in post-surgical evaluation of blood flow heterogeneity.

References

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