Investigation of flow instabilities in branch pulmonary arteries after repaired Tetralogy of Fallot

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Introduction

Phase-contrast cine magnetic resonance imaging (PC-MRI), which allows noninvasive evaluation of cardiopulmonary function, has been proven as an accurate method for long-term follow-up after surgical repair of Tetralogy of Fallot (TOF) [1]. With extensive exploration of repaired TOF, it has also been reported that the branch pulmonary arteries often have unequal regurgitation fraction (RF) and contribute to RPA/LPA flow asymmetry. It is well known that the development of flow turbulence partly responsible for thrombus formation depends on physiological conditions such as diameter variation or volumetric flow [2]. Accordingly, the blood flow stability may be disturbed due to either forward force or regurgitant occurrence. In this study, we use Reynolds number (Re), an index for transition from laminar to turbulent flow, to investigate the blood flow behavior for both branch pulmonary arteries. Our preliminary results indicate that the presence of flow instabilities in the repaired TOF patients shows a higher prevalence for RPA than LPA, with the significance test and correlation estimated to further discuss the flow inequality.

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-eight patients (age: 4.84±3.29 y/o, 19 males and 9 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 forward/backward/net flow volume (FFV/BFV/NFV, in ml/min), mean cross-sectional area (mean A, in mm^2), and Re index 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, the dimensionless parameter Re describing the ratio of inertial forces/viscous forces was calculated by equation 1, where $\bar{v}(t)$ is mean cross-sectional velocity, $D(t)$ is diameter, and $Q(t)$ is volumetric flow, with constant blood viscosity (μ = 4.5 cp) and density (ρ = 1060 kg/m^3) applied [2].

$$\mathrm{Re}(t) = \frac{\rho \bar{v} \left| D(t) \right|}{\mu} = \frac{4\rho \cdot \left| Q(t) \right|}{\pi\mu \cdot D(t)} \qquad (1)$$

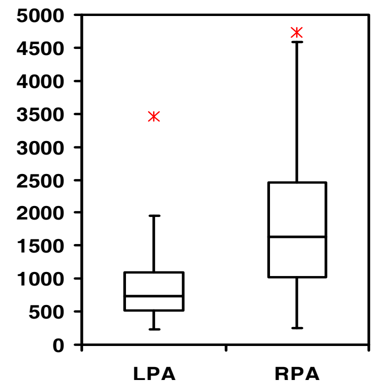

Fig. 1 Boxplot of peak Reynolds number for LPA and RPA, where asterisks are outlier.

Descriptive data are presented as mean±SD. Paired t test was used for comparison of flow parameters in branch pulmonary arteries, and linear regression analysis was performed to evaluate the association between Re index and NFV. The statistical analyses were programmed with the built-in function in MatLab (MathWorks, MA), and the probability value < 0.05 was considered to be statistically significant.

Results

Figure 1 is the boxplot of peak Reynolds number (Re_{peak}) for LPA and RPA, and the Re(t)-related parameters are listed in Table 1. In the RPA, both Re_{mean} (P=0.0012) and Re_{peak} (P=0.0032) are significantly greater than that in LPA. In contrast, the averaged cross-sectional areas are similar for pulmonary artery branches. Figure 2 demonstrates the scatter plot and linear regression for Re_{peak}/NFV of RPA. The linear regression analysis revealed a strong correlation between Re_{peak} and NFV for RPA (P<0.001) as well as for LPA (P<0.001, not shown). For supplementary, the estimated FFV was greater in the RPA (1519.2±1152.3 ml/min) than that in LPA (704.9±634.0 ml/min; P<0.001), whereas it showed no significant difference in BFV for RPA (510.9± 532.9 ml/sec) and LPA (327.3±354.4 ml/min; P=0.057).

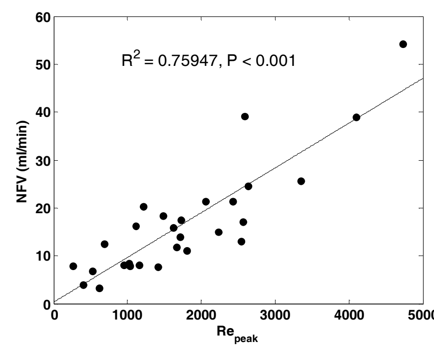

Fig. 2 Correlation of peak Reynolds number with net flow volume.

Discussion and Conclusion

The results from our study demonstrate that the flow instabilities in RPA are present due to a significant higher Re index compared with that in LPA. With equation 1, where Re(t) is determined by blood flow and diameter of vessels while constant values of μ and ρ are applied, it may also imply that the turbulence in RPA is dominated by the higher FFV instead of regurgitation, since the averaged cross-sectional areas and BFV show no significant difference between LPA and RPA. Possible relationship between the flow instabilities in RPA and patient prognosis remains to be explored. On the other hand, the linear regression analysis results of the strong positive correlation in NFV and Re_{peak} suggest that Re could be another predictive indicator about perfusion asymmetry. It should be noted that the stability assessment in vivo is limited by Re(t) itself defined originally for laminar flow in a rigid pipe, and precise model is needed to develop. In conclusion, the preliminary investigation with Reynolds number in this study shows that the RPA might be more prone to flow instability compared with LPA.

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

	LPA (n=28)	RPA (n=28)
Re_{mean}	474.8±304.3*	854.2±519.6*
Re_{peak}	1036.4±810.2*	1771.1±1078.4*
Mean area	88.3±65.9	129.1±135.6

* p < 0.01

References

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