Bolus chasing- perfusion MR imaging to evaluate cardiopulmonary circulation in congenital heart diseases using correlation analysis

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Introduction

Dynamic contrast-enhanced MR imaging has been used to access lung perfusion [3]. A direct differentiation of the bolus time sequence may improve our understanding the pathway of cardiopulmonary circulation, especially for those in complex congenital heart diseases. In this study, we proposed a correlation analysis method for bolus time sequence separation, such that the re-circulation effects and motion-induced SI fluctuations can be effectively eliminated. [4]

Material and Method

A total of 12 subjects (six healthy adults, 24~27 yr; six pediatric patients with congenital heart diseases, 8 months ~ 14 yr) underwent dynamic contrasted-enhanced (Gd-DTPA, 0.05~0.1 mM/Kg, rapid injection) MR imaging examinations. Multi-slice multi-frame images were acquired on a 1.5 system (GE Signa CVi, Milwaukee, Wisconsin) using an ECG-gated inversion-recovery-prepared segmented EPI technique (TR/TE/TI/ETL = 6.5/1.2/181/4, matrix 128x128, FOV = 280 - 480 mm, 3 – 6 slice per frame 30 – 60 frames, slice thickness 6~15 mm, temporal resolution 1 or 2 R-R interval). Patients under 8 y/o were heavy sedated and freely breathing during the exam. Series of correlation maps representing different bolus phases were computed using the method described below.

Generation of correlation maps was accomplished using a strategy similar to that for contrasted-enhanced MRA [1,2]. The SI-time curve of an ROI in the pulmonary artery was first obtained as the reference, following which the Pearson's correlation coefficients between this reference and the SI-time curve of each pixel were computed for all pixels in an image. In this manner, pixels showing similar temporal bolus phase to the pulmonary artery result in higher correlation coefficients. The derived correlation coefficients range from [-1 1]. A spatial c.c. map is derived by forcing negative coefficients to zero and normalized to 64 gray levels. The reference SI-time curve was further time-shifted successively to obtain series of correlation maps representing early and late bolus phases. Note that the only assumption of the above algorithm is that the SI-time curves are sufficiently similar to the upstream pulmonary artery.

Result

With the facilitation of smoothing and depression of the signal intensity after first pass, respiratory related inter-frame fluctuations and re-circulation could also be eliminated. SI-time curves deviating substantially from the shape of gamma variate do not cause problems in the analysis. The improvement of image quality and clear bolus chasing after correlation analysis were found in all normal volunteers and patients.

Two representative cases were illustrated. Figure 1 shows the result from an 8-month-old patient with residue stenosis of left pulmonary artery after total correction for Tetralogy of Fallot. Sequential bolus phases of correlation maps and original images are shown in Fig.1A~1D. With effectively depressing the intensity of the right pulmonary artery, the right pulmonary veins can be unambiguously discriminated(Fig.1B) and clear separation of the aorta and left ventricle is seen in Fig.1C. SI curves of several areas representing different bolus phase are shown in Fig.1E, which confirms the correlation analysis result. Fig2 shows the result from a 1 yr patient of pulmonary atresia with major aortopulmonary collateral artery. Complex SI-time curves plus severe inter frame fluctuations shown in (Fig.2B) evidently differ from gamma-variate shape. Clear bolus maps of right upper lung (Fig.2C) and left apical lung (Fig.2D) demonstrate the ability of correlation analysis on processing SI complex curve with severe intensity fluctuation.

Conclusion

The results from this study show that factors that could hamper conventional perfusion analysis such as re-circulation, complex SI-time response, and respiratory motion-related inter-frame fluctuations can be successfully eliminated using the proposed algorithm. With successively correlating a SI curve to reference curves of different bolus phases, correlation coefficients vary as a gaussian shape, which smoothens out the fluctuations and depresses the re-circulation. Correlation analysis is an effective means to chase the contrast bolus in congenital heart diseases to facilitate the visualization of the cardiopulmonary perfusion pathway.

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Reference

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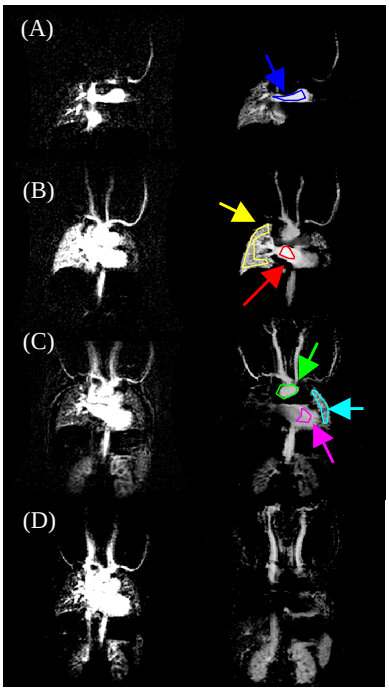

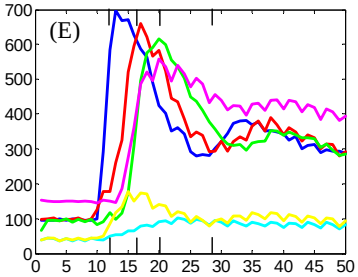

Figure1. (A)~(D) sequential bolus phases of original images(left column) and correlation maps (right column), (E) SI time curve of ROI defined on (A)~(D). (A) pulmonary arterial phase (right pulmonary artery and branchs,12th frame), (B) pulmonary venous phase (right pulmonary vein and lung parenchyma,16th frame), (C) systemic arterial phase (left ventricle, aorta, carotid arteries, 20th frame) and (D) systemic venous phase (jugular veins, 28th frame), . Note that the left pulmonary artery was not shown at pulmonary arterial phase (A) and left lung was delay perfused at systemic arterial phase (C), indicated severe stenosis of left pulmonary artery.

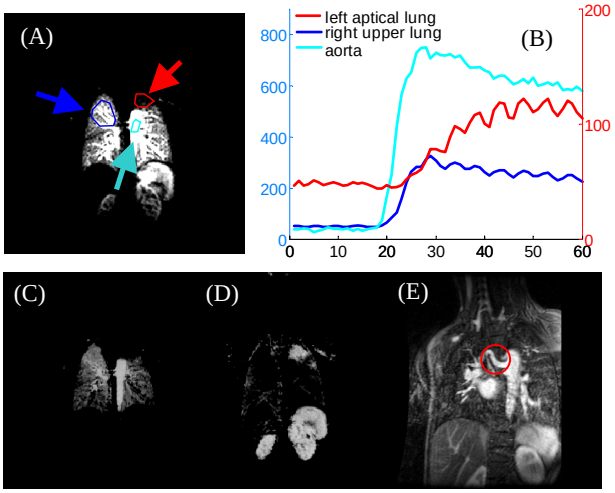

Figure2. (A) Original image. (B) The SI time curves of ROIs defined on (a). (C), Correlation maps showed synchronization of descending aorta and right upper lung, indicating right upper lung was supplied by collateral artery from descending aorta as shown by 3D MRA(E). (D). correlation map showed the severe delayed perfusion in the left apical lung even when the curve exhibits complex shape (B).