Whole heart flow-sensitive 4D MRI in patients after repair of tetralogy of Fallot

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Introduction: Tetralogy of Fallot (TOF) is the most common cyanotic congenital heart defect and accounts for about 10% of all congenital heart diseases [1]. Pulmonary valve insufficiency with consecutive right ventricular volume overload is the most serious long-term postoperative problem [2]. MRI has become the method of choice for evaluating cardiovascular function after surgery for TOF [3]. Standard MRI protocols, however, provide neither a complete picture nor detailed information about 3D hemodynamics and flow alterations occurring in the right ventricular outflow tract and the entire pulmonary vascular system at different points in time. The purpose of this study was to employ flow-sensitive 4D MRI for the analysis of flow characteristics in patients after repair of TOF, particularly with respect to changes in the pulmonary system and their correlation with pulmonary vascular geometry.

Methods: Measurements were performed in ten patients (age 12.1±8.1 years, range 2–24 years) and four healthy controls (age 26±0.8 years, range 25–27 years) on a 1.5T and 3T MR system (Avanto & Trio, Siemens, Germany). The MRI protocol consisted of a time-resolved contrast-enhanced MR angiography (CE-MRA) (TE=1.0, TR=2.5, FA 25°, spatial resolution=1.3mm³, temporal resolution=2.2-4.9s) and k-space segmented flow-sensitive 4D-MRI acquisitions, subsequent visualization was analyzed using a 3-grade ranking (0-2) with regard to vortex severity, retrograde flow and flow acceleration. We detected a close relationship between TOF patients and controls.

TOF patients revealed a significantly smaller angle between the TP and lPA (angle β = 0.71–0.79) and between flow regurgitation in the rPA and the branching angles of the main pulmonary artery: angle γ = 1.8±0.4) (Fig.3). Flow acceleration, vortices and retrograde flow were not detected in the healthy volunteer group.

Discussion: 4D MR flow analysis revealed abnormal flow patterns in the entire group of TOF patients, which correlated significantly to vascular geometry. Compared to healthy controls, the different angles between the pulmonary arteries in TOF patients had a major impact on pulmonary retrograde flow and flow ratios. We detected a close correlation between the pulmonary arteries’ diameter and vortex appearance which may lead to ineffective antegrade flow and vascular dilatation. Beyond its unique potential to demonstrate the complexity of vascular morphology and function in TOF patients, 4D MR flow analysis may prove valuable in clinical routine by providing important data for therapy and for improving the monitoring of patients with TOF.

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Fig. 1: Top row: 3D particle trace visualization for 3 systolic time-frames (A-C) illustrates high systolic velocities (red color) and vortex formation (arrows) in the pulmonary trunk (TP) and left pulmonary artery (IPA). Coincidence of severe vortex flow (grading 2) and enlargement of the TP.

Fig. 2: A: Comparison of peak systolic blood flow velocities in ascending aorta (AAo) and pulmonary trunk (TP) and B: flow ratio to the left (IPA) and right pulmonary arteries (rPA) between TOF patients and controls.

Fig. 3: Evolution of blood flow in the TP and pulmonary arteries visualized by 3D particle trace originating from an emitter plane at the level of the pulmonary valve. Substantial flow acceleration (>1.5m/s) during systole is clearly evident (white arrow). Pulmonary valve insufficiency resulted in substantial diastolic retrograde flow (small black arrows). Marked asymmetry of flow to and fro the left (IPA) compared to the right (rPA) pulmonary artery was detected (highest rPA/IPA flow ratio = 8.2 in the study cohort).