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Baseline correction does not improve flow quantification in phase-contrast velocity measurement for routine clinical practice

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ABSTRACT

Introduction: Velocity offset errors may influence flow measurement in phase-contrast cardiovascular magnetic resonance (CMR). By using a stationary gel phantom, offset errors probably may be corrected. We tested its impact on flow measurement and, in particular, on shunt calculation in patients proven not to have any shunt.
Methods: Flow measurements were carried out in 24 patients with congenital heart disease. Baseline correction was performed by using a stationary gel phantom.
Results: Significantly more patients without shunts incorrectly showed a calculated shunt after baseline correction.
Conclusions: Baseline correction did not improve flow measurement and was clinically not relevant for routine CMR.

1. Introduction

Cardiovascular magnetic resonance (CMR) has become a standard tool for functional assessment of patients with congenital heart disease. Quantitative flow measurements using phase-contrast CMR have improved clinical decision making [1–3]. By using quantitative blood flow data based on phase-contrast CMR, it is possible to measure aortic or pulmonary regurgitation, to assess shunt flow and cardiac output, and to validate volume data of the ventricles [4–9].

The phase-contrast sequences have been improved over the past decades, but several problems still exist. It is known for example that vessel movement during phase-contrast CMR leads to under- or overestimation of flow measurements [10,11].

Moreover, velocity offset errors may influence image acquisitions which are caused by noncompensated eddy-current-induced magnetic fields [11].

It has been postulated that these velocity offset errors can be corrected by baseline correction of velocity by using a stationary gel phantom. By using identical acquisition parameters, a stationary gel phantom may provide a baseline reference for zero velocity [5,12] (Fig. 1).

In the last years, several attempts have been made to correlate these errors to clinical practice [12–15]. However, it is still unknown how important these offset errors are for routine clinical assessment of congenital heart disease by CMR. Furthermore, it seems that offset errors are very dependent on the specific settings of the equipment used in the specific center [13].

The aim of this study was to test the clinical impact of baseline velocity offset error correction in patients with congenital heart disease in clinical routine. Patients who do not show any shunt by clinical data, echocardiography, and cardiac catheterization should not show any shunt in CMR. Therefore, we evaluated its impact on shunt calculation in patients proven not to have a shunt.

2. Methods

2.1. Image acquisition

Twenty-four consecutive patients with congenital heart disease receiving routine clinical CMR were included into the study. The patients' heart defects were Marfan's syndrome, pulmonary atresia, coarctation of the aorta, Ebstein's anomaly, tetralogy of Fallot, bicuspid aortic valve, aortic stenosis and regurgitation, pulmonary stenosis, and aortic aneurysm. Patients with shunts were excluded from the study. All patients with a previous cyanotic heart defect have had corrective heart surgery and did not have a shunt.

Flow measurements were carried out in the vessel of interest according to the clinical question. Data sets of 16 patients with no shunts proven by clinical data, echocardiographic evaluation, and angiography were used for pulmonary blood flow (Qp)/systemic blood flow (Qs) calculations. A standard cardiac 1.5-T magnetic resonance imaging (MRI) scanner and a standard cardiac 12-channel coil

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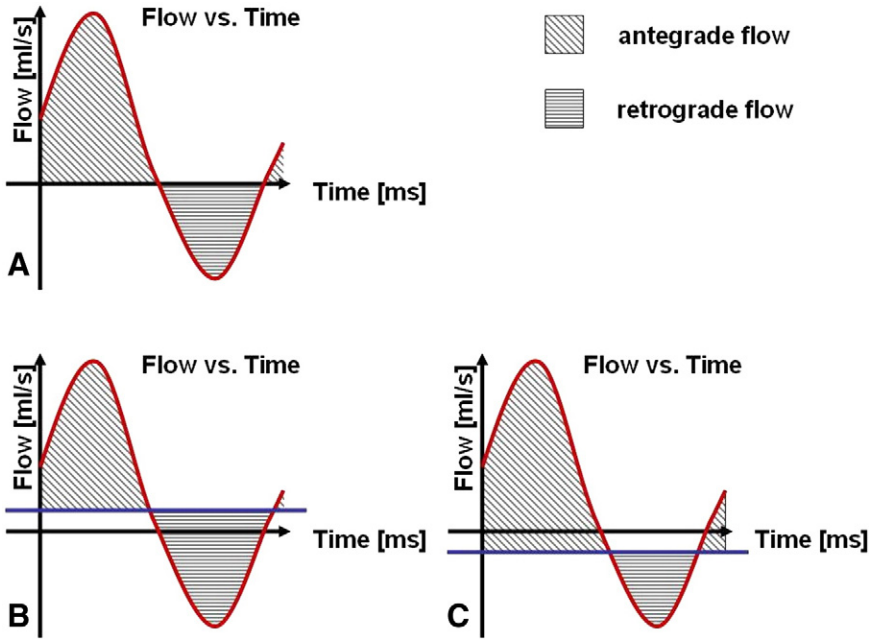

Fig. 1. Influence of baseline correction on flow measurement. (A) Example of a flow profile of the MPA with severe regurgitation. (B and C) Effect of baseline correction on antegrade and retrograde flow. The blue line indicates the baseline correction. A positive net flow of baseline error decreases the antegrade flow in the vessel and increases the retrograde flow; a negative net flow of baseline correction increases the antegrade flow and decreases the retrograde flow in the target vessel.

were used for all patients (MAGNETOM Avanto, version software VB15; Siemens Healthcare, Erlangen, Germany). Flow measurement was performed using a phase-sensitive gradient echo sequence in a double-oblique plane perpendicular to the proximal ascending aorta at the level of the sinutubular junction after the origin of the coronary arteries and the proximal pulmonary artery about 1 cm distal the semilunar valve [3,16]. The right and the left pulmonary arteries were measured between the pulmonary bifurcation and first artery branching [2]. Image data were collected during free breathing. The following acquisition parameters were used: retrospective electrocardiogram (ECG) gating, the velocity encoding 200–550 cm/s according to the assumed jet velocity, slice thickness 5 mm, repetition time 36.7 ms, echo time 3.09 ms, flip angle 30°, averages 3, segmentation 3, number of phase encoding steps 192, receiver bandwidth 31.25 kHz, rectangular field of view 260 to 330 mm, matrix 256×256, phase partial Fourier off, and acquisition time approximately 2.5 min depending on the heart rate of the patients. Data was reconstructed to provide 30 magnitude and phase images per cardiac cycle. All measurements were automatically compensated for the concomitant gradient effects.

Immediately after patient examination, the phase-contrast velocity was measured in the gel phantom by placing the phantom into the scanner and using identical examination parameters and position settings as in the patient examination before. If more than one vessel was measured in the patient, the measurements were repeated using the different slab orientations.

We used a gel phantom as described by the working group Cardiovascular Magnetic Resonance of the European Society of Cardiology [13]. The gel phantom was a large bottle of gelatine added with gadolinium–diethylenetriamine pentaacetic acid and propyl-4-hydroxybenzoat as an antifungal agent. The ECG simulator was set to the corresponding mean heart frequency recorded during phase-contrast measurements in the patient. The measurement in the gel phantom was immediately done subsequent to the patient's scan without starting a new examination file.

It is important to note that we always positioned the vessel of interest such that is was located in the axial plane at the isocenter to maximize gradient fidelity, even though the acquisition plane itself may be oblique. Therefore, we exactly followed the acquisition protocol for the image plane position in blood flow measurement as recommended by the Society of Cardiovascular Magnetic Resonance expert consensus group on congenital heart disease [17]. Additionally, we took meticulous care of placing the region of interest (ROI) into the center of the axial image plane because placing the ROI out of the center of the image plane can lead to larger errors (see "Discussion").

Furthermore, the ECG was monitored continuously during acquisition. The running acquisition in the patient was always aborted when three heart beats were not triggered correctly or extra systoles were additionally triggered. In case of recurrent arrhythmias during flow acquisition in the patient, phantom data only were used for velocity calculation in the phantom.

2.2. Image analysis

The phase-contrast images were processed using the postprocessing software ARGUS (Syngo MultiModality Workplace, version VE23B; Siemens Healthcare, Erlangen, Germany). For baseline correction, the measured velocities were subtracted from the specific vessel velocities in the patient on an image-by-image basis.

2.3. Qp/Qs analysis

Qp/Qs ratio was calculated by dividing the main pulmonary artery (MPA) flow by the aortic flow. We defined a Qp/Qs ratio of 0.9 to 1.2 as correctly calculated for patients without shunt lesions derived from our clinical experience in congenital heart disease, assuming coronary flow to be about 5% of Qs without any shunt lesion.

2.4. Statistical analysis

Statistical analysis was performed using the Wilcoxon signed rank test for matched-pair analysis and the Kruskal–Wallis test for unpaired group analysis. The standard statistic software GraphPad Prism (GraphPad Prism version 5.0; GraphPad Software Inc., La Jolla, CA, USA) was used for statistical analysis.