Accuracy of Phase-Contrast Velocity Mapping Proximal and Distal to Stent Artifact During Cardiac Magnetic Resonance Imaging

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Little data are available on the accuracy of phase-contrast magnetic resonance imaging (PC-MRI) velocity mapping in the vicinity of intravascular metal stents other than nitinol stents. Therefore, we sought to determine this accuracy using in vitro experiments. An in vitro flow phantom was used with 3 stent types: (1) 316L stainless steel, (2) nitinol self-expanding, and (3) platinum-iridium. Steady and pulsatile flow was delivered with a magnetic resonance imaging-compatible pump (CardioFlow 5000, Shelley Medical, London, Ontario, Canada). Flows were measured using a transit time flow meter (ME13PXN, Transonic, Inc, Ithaca, New York). Mean flows ranged from 0.5 to 7 L/min. For each condition, 5 PC-MRI acquisitions were made: within the stent, immediately adjacent to both edges of the stent artifact, and 1 cm upstream and downstream of the artifact. Mean PC-MRI flows were calculated by segmenting the tube lumen using clinical software (ARGUS, Siemens, Inc, Erlangen, Germany). PC-MRI and flow meter flows were compared by location and stent type using linear regression, Bland-Altman, and intraclass correlation (ICC). PC-MRI flows within the stent artifact were inaccurate for all stents studied, generally underestimating flow meter-measured flow. Agreement between PC-MRI and flow meter-measured flows was excellent for all stent types, both immediately adjacent to and 1 cm away from the edge of the stent artifact. Agreement was highest for the platinum-iridium stent (R = 0.999, ICC = 0.999) and lowest for the nitinol stent (R = 0.993, ICC = 0.987). In conclusion, PC-MRI flows are highly accurate just upstream and downstream of a variety of clinically used stents, supporting its use to directly measure flows in stented vessels. **(Am J Cardiol 2018;121:1634–1638)**

Phase-contrast magnetic resonance imaging (PC-MRI) accurately quantifies blood flow and velocity in a noninvasive manner in patients with congenital heart disease. In patients with repaired conotruncal anomalies, PC-MRI quantifies net fractional pulmonary blood flow[1–3] without the use of ionizing radiation needed for pulmonary scintography,[4] particularly important to women and children.[5–7] However, patients with congenital heart disease may require intravascular stenting of obstructed vessels. Paramagnetic intravascular stents often produce susceptibility artifacts, and PC-MRI flow measurements within or near the stent artifact could be inaccurate because of the resulting phase offset.[8–10] Yet, there are limited data regarding the accuracy of PC-MRI in the vicinity of stents. Previous flow phantom studies have demonstrated high accuracy and intraobserver agreement of PC-MRI in the vicinity of stents but have focused on single-stent types, particularly nitinol stents.[11–13] We previously reported our clinical experience with internally consistent PC-MRI flow measurements in patients with repaired conotruncal anomalies and stainless steel stents.[14] The objective of this in vitro study was to determine the accuracy of PC-MRI flow measurements in the vicinity of stents composed of a variety of clinically used materials. We hypothesized that PC-MRI is accurate outside of stent artifact but not within stent artifact.

Methods

An in vitro flow phantom (Figure 1) was used with 3 stent types: (1) 316L stainless steel (12 mm × 3.6 cm), (2) nitinol self-expanding (10 mm × 2 cm), and (3) platinum-iridium (19 mm × 2.9 cm). A cardiac magnetic resonance imaging (MRI)-compatible pump (CardioFlow 5000, Shelley Medical, London, Ontario, Canada) delivered steady and pulsatile flow through flexible polyvinyl chloride tubes. To accommodate the available stent sizes, tubes with a wall thickness of 3.1 mm and internal diameters of 6.3, 12.5, and 18.8 mm were used for stents 2, 1, and 3, respectively. The tubing was arranged in a U-configuration and surrounded by a gadolinium-doped water bath for adequate shim and calibration signal. Steady flow was delivered at 1, 3, 5, and 7 L/min, and

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pulsatile flow was delivered at 0.5 to 3.0 L/min (3 conditions per measurement location). Pulsatile flow waveforms were created by digitizing the waveform of a patient with pulmonary insufficiency and using the programmable pump to deliver this waveform (Figure 2). Mean flows ranged from 0.5 to 7 L/min. Both steady and pulsatile flows were gated to a heart rate of 75 beats/min. Flows were measured using a transit time ultrasound flow meter (ME13PXN, Transonic, Inc., Ithaca, New York) with an inline flow sensor calibrated to the blood mimicking fluid, which consisted of a mixture of 40% glycerin, 60% distilled water for a viscosity of 4.1 mPa-s at a temperature of 25°C.

Cardiac MRI was performed on a 1.5-T Avanto MRI scanner (Siemens Medical Solutions, Erlangen, Germany).

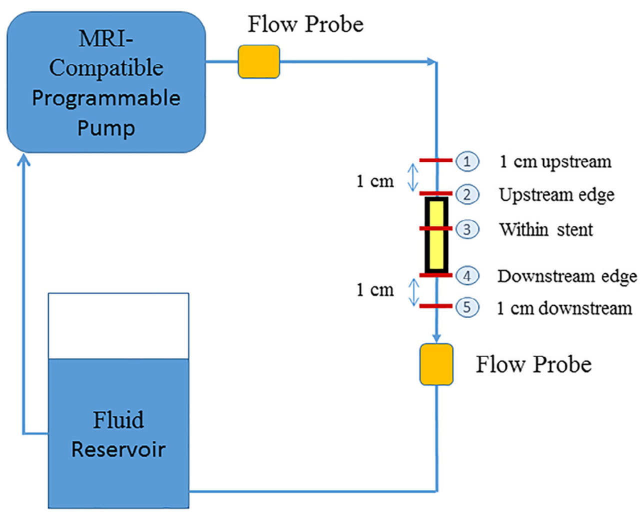

Figure 1. Schematic representation of the flow loop indicating locations of stented flow measurements.

Five PC-MRI acquisitions were made for each condition: within the stent, immediately adjacent to both edges of the stent artifact, and 1 cm upstream and downstream of the artifact. PC-MRI acquisition parameters were optimized to minimize echo time and signal loss. Parameters were as follows: matrix 192 × 192, field of view 200 to 240 mm, echo time 2.09 ms, repetition time 45 ms, flip angle 25°, averages 3, measured phases 17, calculated phases 30, bandwidth 500 Hz, and encoding velocity 100 to 350 m/s. The stent was aligned with the z axis (head foot direction) for the experiments. Mean PC-MRI flows were calculated by segmenting the tube lumen using clinical software (ARGUS, Siemens, Inc., Erlangen, Germany). To test the effect of bandwidth on stent flow measurement, 3 bandwidths (300, 500, and 789 Hz) were used for the stainless steel stent. To test the effects of stent orientation, flow experiments were repeated for a left-right and vertical stent orientation for the stainless steel stent.

PC-MRI and flow meter flows were compared by location and stent type using linear regression, Bland-Altman, and intraclass correlation (ICC). Agreement between PC-MRI flow and flowmeter flow was compared at 3 bandwidths for the stainless steel stent using ICC.

Results

Figure 2 depicts sample flow meter and PC-MRI waveforms. PC-MRI flows within the stent artifact were inaccurate for all stents studied, significantly underestimating flow meter-measured flow (Tables 1 and 2). Agreement between PC-MRI and flow meter-measured "near-stent" flow (includes flow both immediately adjacent to and 1 cm away from the edge of the stent artifact, both proximally and distally) was excellent for all stent types (Table 3). Near-stent flow agreement was highest for the platinum-iridium stent (Figure 3) and lowest for the nitinol stent (Figure 4). Near-stent flow for the stainless steel stent is shown in Figure 5.

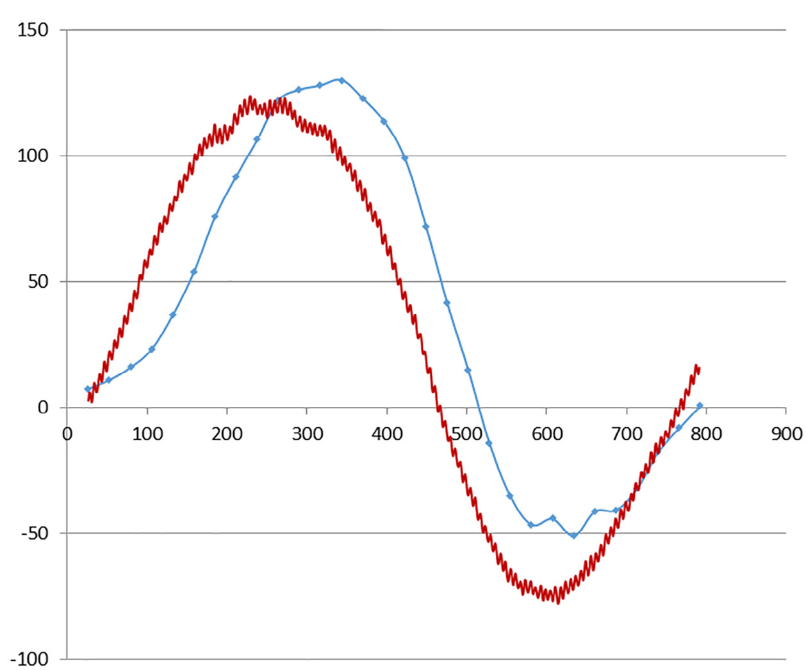

Figure 2. Sample flow meter (orange) and PC-MRI (blue) waveforms are shown. (Color version available online.)