# Evaluation of Real-Time Flow Measurements with Catheter Coils by simulations.

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## Introduction

Functional measurements such as phase contrast blood flow quantification provide important information especially for minimal invasive intravascular interventions. Recently, a real-time pulse sequence for flow velocity measurements with active catheter coils based on a fast projection technique was developed [1]. In these projection measurements the complex MR signal is a weighted sum over the catheter coil sensitivity profile. The resulting measured velocities are therefore expected to be strongly dependent on the coil position within the blood vessel, the coil sensitivity profile and the details of the applied pulse sequence. To evaluate these effects numerical simulations have been performed and compared with catheter flow measurements in a porcine aorta.

## Materials and Methods

The flow measurement sequence was implemented on a clinical 1.5 Tesla whole body MR-scanner (Siemens Magnetom Symphony, Erlangen). Small solenoid coils (6-8 turns, length: 1.5-2 mm, diameter: 2.1-2.4 mm) were attached to the tip of an intravascular catheter and used for both tip tracking [2] and flow measurement. The flow sequence used a slice selective rf-excitation (5 mm slice thickness, $\alpha = 70°$) orientated orthogonal to the vessel direction in order to suppress signal from stationary spins. Two consecutive velocity-encoded projections with no further spatial encoding were measured with alternate polarities of the flow encoding gradients resulting in a temporal resolution of 10.4 ms. The measurement slice was positioned automatically at the coil position and the measurement could be started interactively at any time during the intervention from a dedicated user interface. With this pulse sequence real-time flow measurements were performed in 8 pigs. Velocity time curves of these measurements were compared to a reference 2D PC flow measurement at the location of the catheter coil.

To assess the systematic errors caused by the non-selective nature of the data acquisition process, simulations were carried out using the software package IDL Version 5.4 (Research Systems, Boulder, CO). The three-dimensional sensitivity profile of the solenoid coil was calculated using the Biot-Savart law and numerical integration over the current path. A parabolic velocity field in a simulated blood vessel of 10 mm diameter was assumed with a maximum velocity of 100 cm/s in the vessel center. These parameters were chosen from the experimental data in the pig aorta. The magnetization in each cell of the simulated volume was calculated from the well-known FLASH signal equation. Finally, the complex sum of the magnetization weighted by the coil sensitivity was computed yielding a phase value, which was converted into a velocity using the VENC value of the gradient setting. A correction factor $\lambda$ was determined describing the ratio of simulated velocity over the true velocity averaged over the vessel cross section. Averaging over the vessel was performed to compare simulation results with in the animal model.

### Results

The simulations showed that velocity values are dependent on the position of the catheter within the blood flow profile. The correction factor $\lambda = v_{cat}/v_{PC}$ ranged from 1.6/1.8 for a vessel with radius 5mm/10mm in the center to 1.0/0.8 at the vessel circumference (Fig. 2, center). A linear velocity dependency was found in the simulations (Fig. 2, right) which could be reproduced by phantom experiments with static flow. The shape of the velocity time curve compared well with ECG-triggered 2D PC flow measurements at the same position (cf. Fig.1). Absolute velocity values deviated from the PC flow measurements by between 29% and –31%. After correction for the catheter position using the correction factor from the simulation results the deviation was reduced to –2% and –13% in 7 cases, however, in one case it was increased to –33 %.

## Discussion

Catheter flow measurements allow automated real-time velocity quantification of the blood flow at the catheter tip. The current simulations indicate, that the averaging process over the sensitivity profile of the coil can be summarized in a position-dependent scaling factor, which is practically independent on the velocity itself. This is consistent with measurement data in the porcine aortas. Among the limitations of the current model are the assumption of laminar flow and the parallel orientation of the coil with the static magnetic field, which might explain, why in one case the correction of the absolute flow value failed.

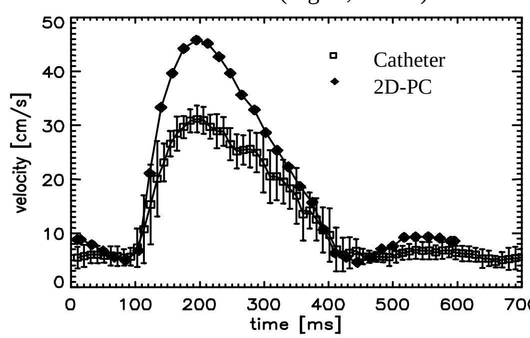


*Fig. 1: Comparison between ECG-triggered 2D PC flow measurement and retrospectivly averaged catheter flow measurement.*

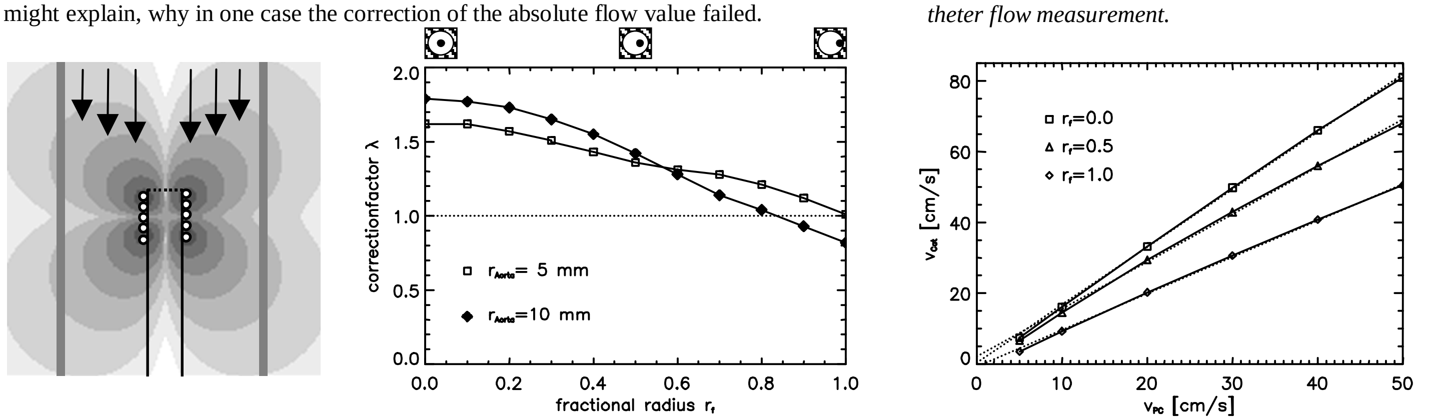


*Fig. 2: Left: Schematic diagram showing the catheter together with the logarithmically scaled numerical coil sensitivity in the blood vessel. Center: The correction factor $\lambda$ as a function of the fractional position of the catheter in the vessel ($r_f = 0$: center, $r_f = 1$: circumference) for two different vessel radii. Right: Velocity sensitivity for three different fractional positions.*

## References

[1] Volz S, Zühlsdorff S, Bock M, Semmler W, Proc ISMRM 2003, **11**:1195
[2] Dumoulin C, Souza SP, Darrow RD, Magn Reson Med 1993, **29:** 411-415