Effects of very low spatial resolution on quantitative phase-contrast flow MRI measurements

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SYNOPSIS

Quantitative flow measurements using phase-contrast MR imaging suffers from the effect of limited sampling. Computer simulations are presented that show the effect on the estimates of velocity and flow rate at different contrasts. Results show that the estimated velocity decreases and the estimated flow rate increases as the spatial resolution decreases. When a background signal is present, the estimated flow rate reaches a maximum before it decreases and approaches zero. For full background suppression, however, the flow rate estimate at zero spatial resolution is a measure of the mean velocity in the vessel. Thus, in principle, accurate flow quantification is possible even at zero spatial resolution.

INTRODUCTION

Any object shape can be represented as an infinite sum of spatial harmonics. Only a few of these are sampled through the MR imaging process. As a result, the accuracy of the flow quantification is affected. Previous work has shown that some of these errors can be corrected [1,2]. The present work addresses the effect of limited sampling on flow quantification at different background-to-vessel-signal amplitude ratios. We especially investigated the effect on flow rate and velocity estimates at very low spatial resolution.

MATERIAL AND METHODS

The simulated object was represented by stationary background tissue and a vessel (d=4.8 mm) with laminar flow (v_{max}=40 cm/s) perpendicular to the x-direction. The background-to-vessel-signal amplitude ratio, SR, varied from 0 (full background suppression) to 1 (background signal). Numerical 1D phase-contrast simulations were performed with Mathcad7® (MathSoft Inc.,Cambridge, USA). Two flow-encoded representations of the object with opposite gradient first moment were implemented using a large number of discrete points. The k-space representations were calculated as the FFT of these points. The phase-encoded scanning process was simulated by sampling a limited number of equidistant data points symmetrically over the k-space center. The sampled k-space data was zero-padded to the full simulation space before reconstruction. The spatial resolution varied from 0.1 to 65.5 pix/diam. The flow rate was estimated as the sum of the velocities (venc/π x the phase difference between the reconstructions of the two oppositely flow-encoded objects) between the first zero crossings of the reconstructed velocity profile.

RESULTS

At the lower limit of the spatial resolution (0.1 pix/diam), the estimated v_{max} was 0.8, 0.9, 1.3, 2.9, 30.9 cm/s for SR=1, 0.73, 0.5, 0.25, 0 respectively (Fig. 1a). As the spatial resolution increased, the estimated v_{max} started to increase, oscillate and converge to the true v_{max}. In general, the error in the estimated flow rate was smallest for the highest spatial resolution (Fig. 1b). The estimated flow rate decreased with increased spatial resolution. For SR>0, the estimated flow rate reached a maximum where the value of the estimate and the spatial resolution at the maximum depended on SR. At the lower limit of the spatial resolution, the estimated flow rate was 47.7, 52.6, 78.5, 167.9, 3088.2 ml/s for SR=1, 0.73, 0.5, 0.25, 0 respectively.

DISCUSSION

The effect of limited sampling on flow quantification can be modeled by convolving the flow profile with the point-spread function (PSF) of the MR acquisition, i.e. a *sinc* function. The response is a smoothed flow profile that oscillates along the profile. The overestimation and underestimation of v_{max} at high spatial resolution (Fig. 1a) is due to these oscillations. At zero spatial resolution, the PSF is infinitely wide and the value of the only pixel represents the mean velocity in the object. In cases with full background suppression, e.g. hyperpolarized ^{13}C MRA [3], the estimated flow rate grows with the pixel size and the estimated v_{max} is a measure of the mean velocity in the vessel.

REFERENCES

[1] Lagerstrand *et al.* MRM 2002;48(5):883-889
[2] Hoogeveen *et al.* MRM 1999;41(3):520-528
[3] Svensson *et al.* MRM 2003 Aug;50(2):256-62

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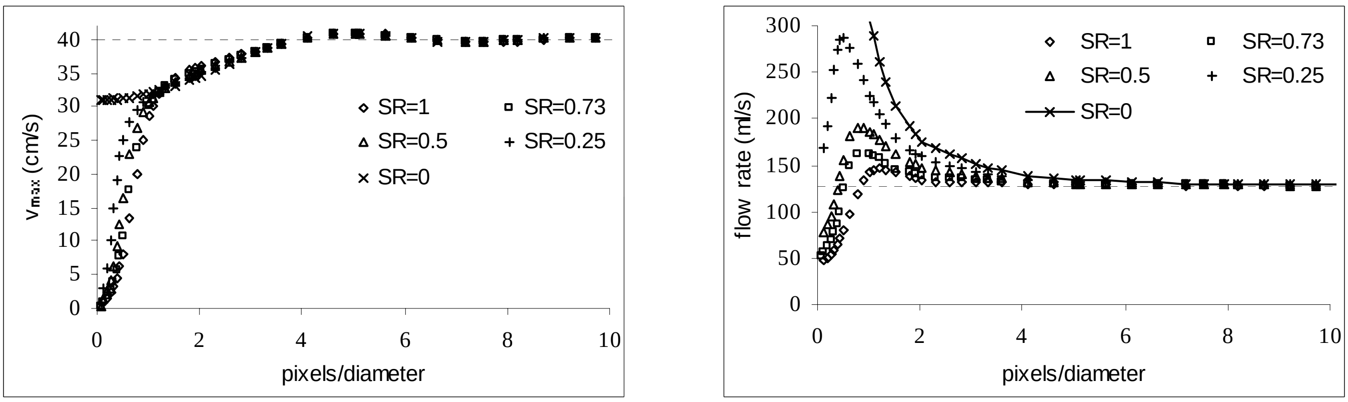

a) b)

Fig 1 a) The estimated v_{max} and b) flow rate as a function of the spatial resolution for different SR. The true v_{max} and flow rate (dotted lines) was 40 cm/s and 128 ml/s respectively.