Acceleration techniques for phase contrast flow quantification: a deal with the Devil?

Francesco Santini[1]

[1]*Division of Radiological Physics - Institute of Radiology and Nuclear Medicine, University of Basel Hospital, Basel, Switzerland*

Purpose. Flow quantification with MRI is a valuable tool for the assessment of pathologies of the cardiovascular (blood flow) or nervous (cerebrospinal fluid flow) systems. In the recent years, time-resolved volumetric acquisitions of velocity vectors have become popular. Due to the high dimensionality of the acquired data, long scan times are often required. Thus much research effort has been dedicated to applying acceleration techniques for maintaining a high temporal resolution while reducing the total scan time. Spatiotemporal techniques, while allowing high acceleration factors, increase the temporal footprint of each image, because every reconstructed frame also contains information from neighboring images. In particular, higher framerates can give the illusion of increased accuracy, while in fact leaving the actual information content unchanged. This work is to recall the basic concepts of signal sampling and MRI acceleration techniques applied to flow imaging, and to propose a general guideline to compare different acquisition/reconstruction methods in order to obtain the most efficient acquisition.

Outline of content.

Encoding and filtering. Even without acceleration techniques, most common flow acquisition strategies introduce a low-pass filtering of the velocity waveform during the encoding [1-3]. This low-pass filtering effect even increases for 3-directional encoding, but it can be mitigated by implementing view sharing and inverse filtering [4-5]. In the case of conventional encoding, it has been shown [5] that all the frequency components up to 1/4TR (where TR is the duration of a single encoding step) can be correctly depicted.

Acceleration and filtering. Conventional parallel imaging has been shown to be beneficial for the reduction of scan time, without negative effects on the accuracy of the flow quantification [6-8], except of the inevitable reduction in signal-to-noise. In fact, parallel imaging does not introduce any additional temporal correlation in the image series, and does not need any special investigation in terms of frequency response. Spatiotemporal (k-t) acceleration methods, on the other hand, by definition, rely on an autocorrelation of the detected signal in time. This quantity is tied by a Fourier-pair relation to the spectrum of the signal to be measured, in this case the velocity waveform. Thus, at larger acceleration factors the higher frequency components of the velocity waveform will be discarded, and in fact when k-t acceleration is used, a reduction in the signal dynamics can be observed [9].

Optimal encoding. Before choosing an encoding technique and an encoding framerate, two aspects should be taken into account: the frequency content of the velocity waveform and the low-pass filtering effect that is introduced by the encoding method. As an example, it has been shown that in the carotid artery the spectral components of the velocity waveform are mostly below 12Hz [10]. This means that, in case of optimal, non-accelerated three-directional encoding [5], the duration of a single encoding step needs to be approximately 20ms. Any higher framerate would only contain redundant information that could be easily obtained by simple interpolation. For the latter aspect, an analytical description of the frequency response of the acquisition strategy is not always feasible; therefore its estimation by means of simulations or flow phantoms is advisable. This can be obtained by feeding the acquisition/reconstruction system with sinusoidal flow waveforms at increasing frequencies and plotting the relative amplitudes of the measured signals (fig. 1). The conventional approach of using in vivo validations might be misleading because it doesn't allow a quantitative comparison among different methods and can lead to artifacts in pathological cases.

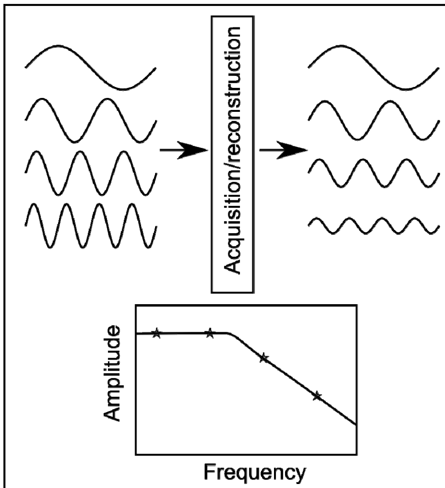

Fig. 1: scheme for the estimation of the frequency response of an acquisition/ reconstruction method.

Summary. Spatiotemporal acceleration is potentially beneficial in time-resolved imaging since higher frame rates can be achieved in shorter acquisition times compared to non-accelerated techniques. However this comes at the cost of larger temporal footprint and therefore stronger low-pass filtering in the temporal domain. There is a risk that an increased framerate, at the cost of complex reconstruction procedures and potential artifacts, yields no actual benefit in terms of accurate quantification of velocity waveforms. In order to optimize the scan efficiency and to correctly compare acceleration methods, it is crucial to have a quantitative evaluation of the amount of low pass filtering and a reasonable estimate of the true frequency content of the measured velocity waveform. By this, it is possible to choose an acquisition strategy and a framerate that minimize the acquisition time while maximizing the information content of the resulting dataset.

References. [1] Frayne R and Rutt BK JMRI 3:6 (1993): 907-917. [2] Frayne R and Rutt BK. JMRI 5:1 (1995): 65-73. [3] Polzin, JA *et al.* MRM 35:5 (1996): 755-762. [4] Santini F *et al,* Proc. ISMRM 2009 [5] Santini F *et al,* Proc. ISMRM 2011 [6] Beerbaum P *et al,* JCMR 7:2 (2005): 361-369. [7] Lew C *et al*, JMRI 31: 4 (2010): 1004-1014. [8] Lew C *et al,* Academic Radiology 14:3 (2007): 258-269. [9] Stadlbauer A *et al*, EJR 75:1 (2010): e15-21. [10] Holdsworth DW *et al,* Physiological Measurement 20:3 (1999): 219-240.