Non-contrast virtual bolus angiography with sub-second temporal resolution

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Introduction: State-of-the-art vessel bolus imaging uses gadolinium (Gd) contrast-enhanced MR angiography (CEMRA), which provides high spatial resolution in 3D but typically at the expense of temporal resolution. Moreover, CEMRA is incapable of visualizing vascular pulsatility. Conventional phase-contrast (PC) MRI [1] yields velocity data, does not require administration of a contrast-agent, and has sub-decisecond (1/10 sec) effective temporal resolution when acquired in cine [2]. The described method creates a dynamic virtual-bolus (DVB) from cine PC-MRI, with goals to (i) enable post/non-contrast bolus visualization, and to (ii) observe dynamic vessel pulsatility to evaluate vessel distensibility.

Methods: The DVB method was initially developed for peripheral angiography of the femoral arteries, in which arterial flow is pulsatile (Fig. 1a) and is mainly in the superior-inferior (S/I) direction. The method initializes for each vessel voxel the distance reached X and the net distance traversed D. Starting with the first cardiac phase where Δt is the interval of each cardiac phase, D is incremented by $d = v \cdot \Delta t$ (Fig. 1b), similar to the work of Pelc [3]. The DVB signal s is determined by a piece-wise smooth bolus function that is high when $X < D$ and low when $X > D$ (Fig. 1c). The cardiac phase is incremented in modulo of the total number of cardiac phases. The velocity integration is repeated until there are no further changes to s.

Cine 2D-PC data were acquired *in vivo* with peripheral gating at 3T (GE MR750) with S/I VENC = 80 cm/sec, coronal FOV = 38 cm, matrix of 256 x 256, 8 x 12 mm slices, 4 acquisitions/frame, providing ~13frames that were interpolated to 20 cardiac phases for a typical scan time of 1 min/slice. A slice overlap of 2 mm was applied to reduce gaps from slice-selection.

Results: The *in vivo* results of Fig. 2 are frames from a DVB movie, showing both (a) long time-course and (b) high temporal resolution of 55 msec. Pulsatility of the bolus was observed (Fig. 2b), whereby the bolus advanced during systole and retreated during diastole. The polarity of the velocity images (Fig. 2c) show correspondence with the bolus signal (bright in systole, dark in diastole).

Discussion and Conclusion: The initial feasibility of non-contrast DVB with high temporal resolution was shown. Time trial simulations of cylindrical vessels indicated sub-second accuracies at the end of DVB. To negotiate complex vascular trees and small vessels, the algorithm incorporated region-based updates of both d and s. Unlike streamlines [4], DVB provides voxel-based visualization and utilizes a bolus function. While arteries were segmented from the PC data itself, arterial and venous images from a separate pulse sequence could improve vessel segmentation. This technique would also be well suited for use following Gd-chelate administration, especially after the safe cumulative Gd-chelate dose limits have been reached.

References: [1] Dumoulin *et al*, Radiol, 161:717-720, 1986; [2] Pelc *et al*. Magn Reson Quarterly 7:229–254, 1991. [3] Pelc, US Patent 5,195,525, 1993. [4] Napel *et al*, J Magn Reson Imaging 2: 143–153, 1992.

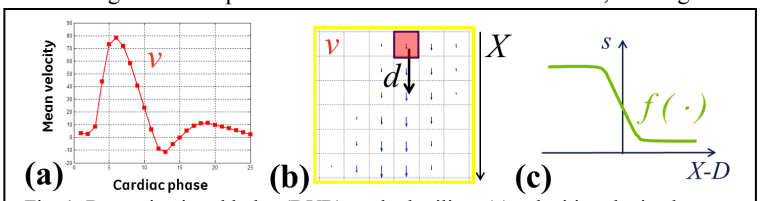

Fig. 1. Dynamic virtual bolus (DVB) method utilizes (a) velocities obtained across a cardiac cycle and (b) for each voxel and cardiac phase, increments the net distance traversed D by the projected distance d traversed. (c) A piece-wise smooth function f produces the DVB signal, which depends on D and distance reached X.

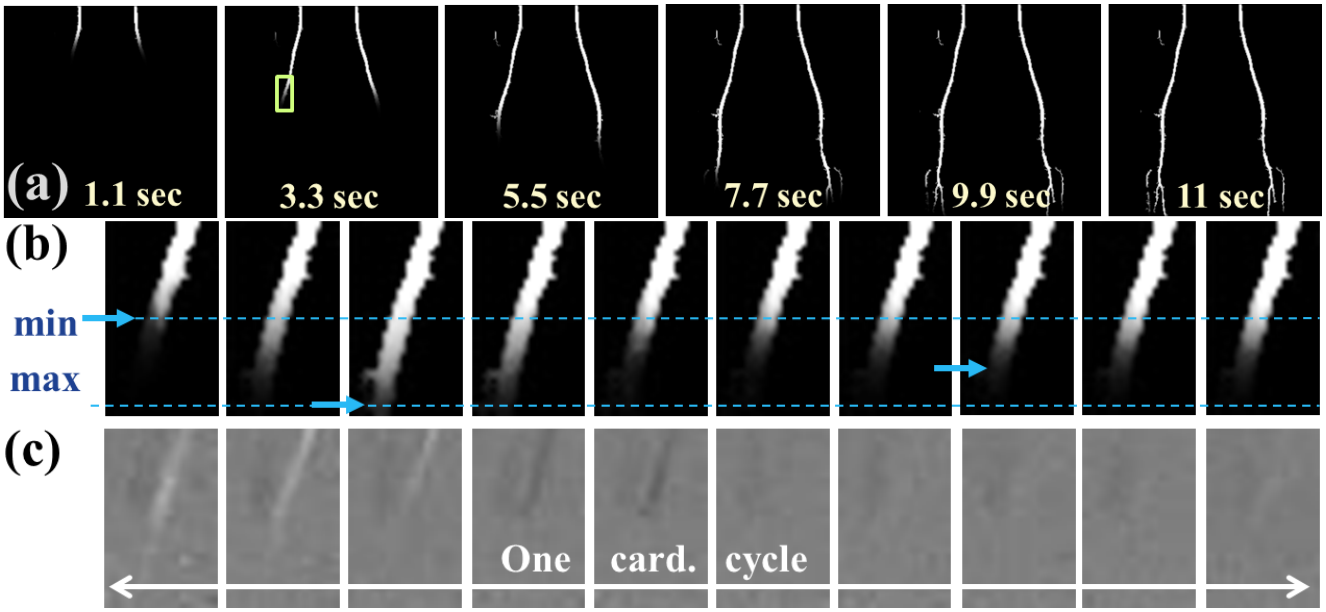

Fig. 2. *In vivo* coronal DVB of the femoral arteries (distal to the pelvis), shown with (a) maximum intensity projection (MIP) of the entire FOV at frames 2.2 sec apart, and (b) MIP of the rectangular ROI displayed at 10 frames across one cardiac cycle. Pulsatility of this healthy subject is well visualized at the temporal resolution of the acquisition, with arrows pointing to the bolus front corresponding to early-systole (min), late-systole (max) and mid-diastole. (c) The velocity images of the central slice corresponding to the same cardiac cycle are shown.