Real-Time Tracking of the Contrast Bolus Leading Edge in Time-Resolved Continuously Moving Table CE-MRA

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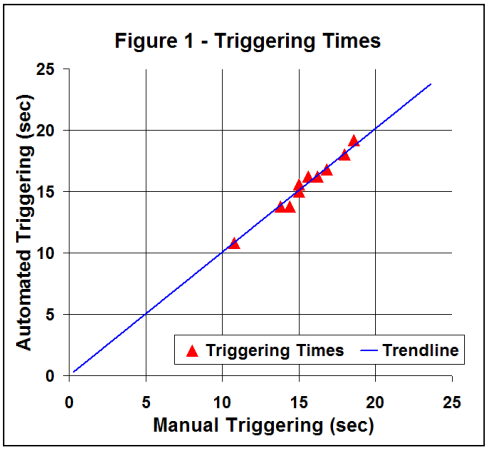
Introduction

The acquisition of diagnostic quality CE-MRA bolus-chase studies of the peripheral arterial tree is critically dependent on accurate arterial timing. Following contrast injection, the close temporal proximity of arterial and venous filling phases necessitates that acquisitions be performed with very high temporal accuracy to ensure that the arterial phase of contrast propagation is imaged. Semi-automated triggering procedures such as MR SmartPrep [1] and Auto-Triggered Elliptic Centric Sequences [2] require precise placement of a monitoring window over the vessel of interest by the operator and are generally not robust to motion. Manual fluoroscopic triggering methods [3] allow for precise triggering of the bolus chase sequence and are inherently invariant to motion, but they require continuous monitoring and interaction by the operator. For peripheral vascular MRA these limitations are compounded because with significant variability in blood velocity across the peripheral vascular tree, it is impossible to prescribe a single table velocity which can accurately track the leading edge of the contrast bolus across all vascular regions. We have developed fully autonomous algorithms for both the triggering of the bolus chase sequence as well as real-time tracking of the leading edge of the propagating bolus throughout the entire peripheral vasculature during continuous table motion. In addition to offering locally-maximal venous suppression across the entire imaged region and robustness to patient motion, our method removes all operator-based input to the bolus-chase sequence.

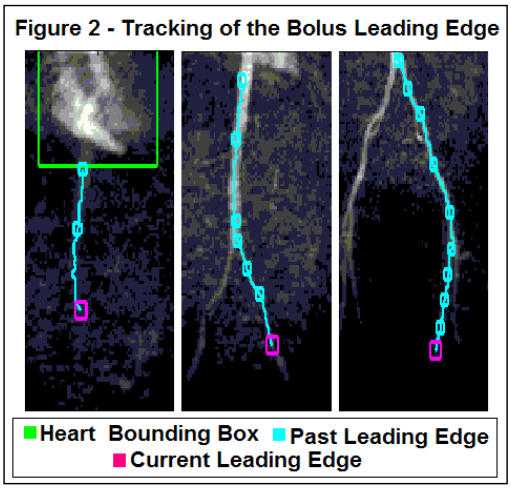
Methods

Our algorithm exploits the sequential propagation of the blood-bound contrast bolus through key anatomical landmarks. Simultaneous analysis of spatial and temporal changes in coronal MIP images and dynamic generation of respective noise models [4] allows detection of contrast arrival at the various anatomical stages with only a minimal increase of signal intensity above the calculated noise levels. Following detection of bolus arrival into the right atrium, the heart is tagged and tracked until contrast enters the left ventricle. A search window is then dynamically placed below the heart, with its size and position continuously updated to account for thoracic motion and further cardiac filling. The use of optimized graph search procedures coupled with spatiotemporal pattern matching within the search window allows detection of the leading edge of the contrast bolus in the thoracic aorta immediately after it exits the left ventricle and passes through the aortic arch. On catching the first arrival of the contrast bolus in the thoracic aorta, the bolus chase sequence is triggered, table motion is initiated, and tracking of the bolus leading edge is activated. As the presence of table motion no longer allows fixed-scene temporal analysis, we utilize predictive methods to compensate for the absence of this information in this stage. Given known past positions of the bolus leading edge along with their respective arrival times, future positions are estimated and a dynamically-minimized search window is placed around this location. A graph search is employed within this minimized search window to extract the current location of the leading edge of the bolus. With the current spatial location of the bolus edge known along with past bolus acceleration trends, the patient table velocity can be adjusted to keep the leading edge in the center of the scanner bore's "sweet spot" at all times during the acquisition. With all acquisitions occurring when the contrast bolus has just entered the spatial region of interest, accurate arterial timing and minimal venous contamination is guaranteed for that region.



Results

All of our studies employ 3D time-resolved continuously moving table sequences [5] adapted to per-frame acquisition times of 0.6s. Ten normal volunteer study cases have been analyzed post-acquisition and tested using our automated triggering method, comparing the results to those done by standard manual fluoroscopic triggering. Figure 1 shows the results. Our algorithm has a mean lag of only 0.12s behind fluoroscopic triggering. In its current Matlab simulation state on a 1.4 GHz Pentium 4 system with 1GB of RAM, our algorithm runs in under 0.5s, allowing easy completion within the acquisition timeframe and thus potential real-time implementation. Evaluation of the tracking portion of the algorithm is still in its preliminary stages, with present work focusing on increasing the effectiveness of prediction and incorporating detection of the aortic bifurcation. Figure 2 shows several frames taken during one tracking test case following automated triggering of the sequence, with each box representing a 0.6s time interval.



Conclusion

We have developed a method for automated triggering of the bolus-chase sequence and subsequent real-time tracking of the leading edge of the contrast bolus through the peripheral vasculature. On knowing the position of the contrast bolus at all acquisition points and using this information to image the leading edge of the bolus, local arterial timing is inherently optimized, effectively yielding high quality MRA signal across the entire acquired volume.

References

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[4] Gravel et al,. IEEE Trans. Med. Imag. 2004, 23:1221-1232 [5] Madhuranthakam et al., MRM 2004, 51:568-76