Tracking Vascular Supply Using Bolus Tracking MRI

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Introduction: Bolus tracking MRI is widely used to obtain measures of cerebral hemodynamics. Maps of CBF, MTT, CBV and Tmax as well as a variety of other metrics are routinely used in the acute assessment of stroke patients [1]. We propose a new application of bolus tracking data that enables visualization of the likely supply route of blood for any given voxel. This information is of potential use in determining details of collateral supply as well as for selecting arterial input functions locally. The methodology is described and its use illustrated on data from 2 acute stroke patients.

Methods: The total amount of an intravascular tracer (n) delivered to a voxel at time t is given by Eq. (1) [2] Expressing the amount of tracer that arrived at time t as a fraction of the total amount of tracer it receives during the complete bolus passage simplifies the expression to eq. (2), where we term n_f the cumulative tracer fraction, CTF. Under noiseless conditions CTF is a monotonically increasing curve valued from 0 to 1. In general, seen from the perspective of a voxel, the most likely neighbor through which blood supply is reached is a voxel that has received more tracer than itself. However, when large differences in CTF exist between neighboring voxels it is unlikely that the voxels are connected. We select an average of 3 time points from the fractional tracer curves where differences in fraction of tracer received by neighboring voxels are maximized (fig 1). At the extremes of t=0 or t=+∞ there will not be any differences as $n_f(t)=0$ and 1 respectively for all voxels. The difference is maximized in the sampling points close to the peak of the arterial input function where the large vessels have received a large portion of their total tracer whereas only a small fraction has arrived at the tissue. Figure 1 shows 2 CTF curves. To track the supply route for a voxel we assume that its most likely supply route is that of slowest ascent in the CTF values. The tracking is performed for each voxel in the brain. Initially in-slice tracking is performed, and each voxel is tracked back to a local maximum of CTF, believed to be a supply vessel. Segments in which all voxels tracked back to the same voxels (sources) are identified. These common sources, believed to be arteries, are then connected by a similar procedure but cross-slice. Fig. 2 shows how groups of voxels track to the same source. The analysis is done on a dataset that is corrected for slice timing differences by linear interpolation. We defined the in plane neighborhood by a 3x3 voxel window and the cross-slice neighborhood as 5x5x3, but with no in-slice voxel selections; i.e. connectivity, if existing, is forced to be between slices. The method was applied to 2 acute stroke patients using sequence parameters: Gradient echo; TR =1.5 s, TE=45 ms. Matrix size 128x128 and voxels dimensions of x=y=1.875, z=5 mm and a gap size of 1.5 mm.

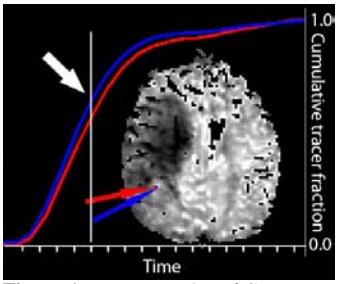

Figure 1. Two examples of CTF curves from neighboring voxels: The blue curve reflects a faster tracer delivery than the red curve. The slice inset shows the CTF early in the bolus passage (app. 3 seconds in). In this case the difference is maximized at the timepoint of the white arrow.

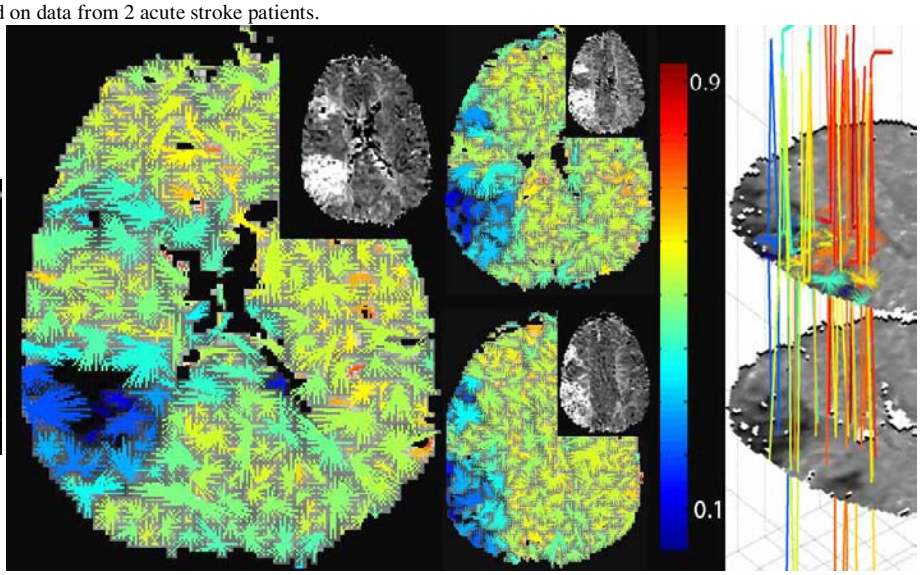

Figure 2. Patient 1: Left: Shows the starting and ending points for each tracking with MTT maps inserted for reference. The colormap shows the fraction of tracer that had arrived at this timepoint. Lowest slice magnified for visual conspicuity. **Right:** Cross slice tracking example for selected ROI only.

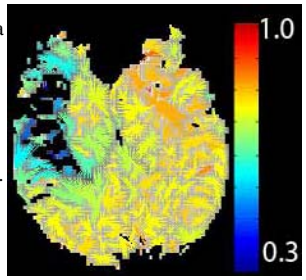

Figure 3: Patient 2: Selected slice from patient 2. Colormap as in fig 2.

Results: Fig. 2 shows results of the in-slice tracking in patient 1 for selected slices, for conspicuity the tracks are visualized as lines although the actual route is usually not completely linear; to the right is the in-slice and cross slice tracks that pass through an ROI placed in the upper slice. CTF is not unexpectedly seen to be low close the MTT deficit. The tracks appear longer close to the MTT deficit than in the contralateral hemisphere. Figure 3 shows the 2D tracks in a selected slice for patient 2, this patient had no contrast inflow in the dark areas (no inflow confirmed on CBV maps) so tracking is limited here. There is a modest tendency for longer tracks close to the areas of collapsed vasculature.

Discussion: Interestingly the tracts generally appear longer in the deficit zones as defined by conventional MTT maps, we speculate that perhaps these types of tracking maps can prove useful in determining the density of supplying arteries in a given area providing predictive information in acute stroke. Another potential use would be to use the defined territories to determine regions for local AIF search and assignment. The underlying idea of this method is that the supply route is along the slowest descent of CTF, this assumes that all tissue shares the same r(t) which is unlikely to be the case. However, it is likely that r(t) will be similar locally and thus tend to not bias the tracking. The described technique is work in progress. We believe that a combination of more advanced tracking algorithms as well as acquisitions with lower sampling time and better slice coverage can improve the technique drastically. Connecting the arteries between slices can possibly add further information about the origin of collateral supply. Our initial attempts to do this suggest that better slice coverage is needed for this; also the high velocities in larger blood vessels makes tracking difficult here as gradients will be small in these vessels. Ideally the tracking would need to be done on isotropic 3D data. Other enhancements count integration of MR-angiography data into the tracking procedure to be able to facilitate the tracking across slices.

Conclusion: The initial results show promise of a new use of bolus tracking studies with applications such as vascular territory mapping and vascular density metrics. Further development of tracking algorithms as well as simulations studies are needed to take the technique further.

(Eq. 1) $$n(t) = \frac{CBF}{CBV} \cdot \int_0^t C(t')dt'$$ (Eq. 2) $$n_f(t) = \int_0^t C(t')dt' \Big/ \int_0^\infty C(t')dt'$$

References: 1: N. Hjort et al. Stroke 2005;36 **2:** Lassen et al. Tracer kinetic methods in medical physiology, New York, Raven press 1979.