Automated Determination of the Arterial Input Function for Quantitative MR Perfusion Analysis

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Goal: To develop an automatic algorithm for identifying arterial voxels in dynamic susceptibility-contrast MRI data for constructing the arterial input function (AIF).

Introduction: Parametric maps of CBF and MTT can be derived from dynamic susceptibility changes by curve-fitting the “first-pass” tissue response then numerically deconvolving it from the AIF [1,2]. Deconvolution yields a “residue function” which is scaled by CBF. The singular value decomposition deconvolution, however, is sensitive to the shape of the AIF [1,2]. Thus, the accuracy of the input curve may determine the quality of the deconvolution, and the quality of the CBF and MTT maps. AIF is typically determined by manual identification of “arterial” pixels in the images according to their anatomic location. This task is made difficult by the poor spatial resolution and poor blood-to-tissue contrast of dynamic EPI scans. Although the image data are acquired as low resolution in space due to acquisition constraints, they have high tissue-contrast, temporally. Thus, we discriminate arterial from non-arterial voxels by inspecting their signals in time.

We present a two-stage method for automatically deriving an AIF from the dynamic image data based on expected characteristics of arterial concentration curves. Candidate input functions are generated by maximizing three “arterial-likelihood” metrics. Some metrics have been suggested previously [3]. The “best” of the three candidate curves is chosen by a scoring system based on the first four moments of the AIF distributions. After fitting, AIF curves chosen automatically and manually appear comparable and yield comparable CBF results.

Methods: Acquisition: Test data presented here were acquired on a 1.5T MRI system retrofitted for echo-planar imaging (TR = 2 sec, TE = 100 msec) following an intravenous dose of the contrast agent. Gd-DTPA”[4]. The data were analyzed with software integrated into the analysis package, MEDx (Sensor Systems, Sterling, VA).

Preprocessing: Time-series data were motion-corrected if necessary [5]. Images were masked to eliminate non-brain voxels. Susceptibility signals at each voxel were converted to concentration, C(t) = k/TE*ln[30(S0/S1)] and smoothed in time. Stage 1: “Arterial-likelihood” metrics: Three metrics are calculated from the concentration curves; each is a function of one or more dimensionless parameters: peak height (H0), bolus arrival time (T0), peak width (W0), and initial slope (S0).

![Figure 1](https://example.com/figure1.png)

Figure 1. (i) Inferior slice of map of arterial likelihood metric, M1, with auto-selected pixels in white. (ii) Input curve (F) fitted to data (A) from pixels in (i) and mean (M) of all brain pixels. (iii) CBF map based on max value of deconvolved residue function.

Automated Arterial Likelihood Metric

- $M_1 = H_0 / (W_0 \cdot T_0 \cdot S_0)$
- $M_2 = H_0 / (W_0 \cdot T_0 \cdot S_0)$
- $M_3 = H_0 / \omega$

Stage 2: Comparing moments of the AIF curves: The best AIF is selected by a scoring system designed to reward curves that are large, and narrow, peak early and rise sharply. Points are awarded for desirable properties of each AIF distribution between take-off and recirculation.

<table>
<thead>
<tr>
<th>Ideal AIF Characteristic</th>
<th>$P_1$, $P_2$ place points</th>
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<tbody>
<tr>
<td>Large area under the curve</td>
<td>4, 2</td>
</tr>
<tr>
<td>Early “center of gravity” in time</td>
<td>4, 2</td>
</tr>
<tr>
<td>Low variance in time</td>
<td>2, 1</td>
</tr>
<tr>
<td>Large positive skew in time</td>
<td>2, 1</td>
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Results: Figure 1(iii) shows results for a case where metric M1 was selected as yielding the most likely AIF. Many of the top-scoring (26) pixels (shown in white) are found in the inferior slice in (i). The AIF curve (fitted to a gamma-variate) is shown in (ii) and the resulting CBF image for another slice of the volume is in (iii). The mean tissue curve is shown in (ii) for comparison. Figure 2 (i-iv) gives comparable results for same data as in Fig. 1 and a manual AIF. 2(ii) shows a close-up of the selected pixels in the Circle of Willis drawn on a map of arterial likelihood metric, M2.

Discussion: In most cases, one or more of the “arterial-likelihood” metrics successfully identifies voxels corresponding to the major cerebral arteries. In general, metric #1 is the most robust. Metric #2, although appealing theoretically, appears most sensitive to noise because of its derivative term (S0). Behavior of all three metrics is best when data are motion-corrected and/or masked to eliminate edge artifacts. While least sensitive to noise, Metric #3 is also most likely to select veins (which peak later than arteries) because no temporal information is used. Nevertheless, inclusion of this metric assures that the overall algorithm will not fail when metrics #1 and #2 yield poor results. We have found M1 to be the most fruitful metric for guiding a user in selecting arterial voxels manually because M2 maps consistently present high contrast between vascular and tissue voxels.


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