Adaptive Model for Direct Estimation of Hemodynamic Parameters in MR Perfusion Studies: Comparison and Evaluation Using CT Perfusion and Singular Value Decomposition Technique

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Target Audience: Neuroradiologists, neurologists, and medical physicists who are interested in Dynamic Susceptibility Contrast (DSC) perfusion imaing, estimation of hemodynamic maps and compartmental modeling.

Purpose: This study introduces a model trained adaptive model (AM) for estimation of hemodynamic parameters in Dynamic Suceptipility (DSC) MR perfusion studies. The performance and accuracy of the proposed technique (AM) is compared with the Singular Value Decomposition (SVD) technique. Computed Tomography Perfusion (CTP) technique was used as the gold standard for the method of comparision. DSC-perfusion technique with bolus injection is one of the most common imaging techniques for performing the MR Perfusion (MRP)[1]. This imaging method generates maps of hemodynamic based on the signal intensity change in T_2^*-weighted images due to the passage of a paramagnetic contrast agent in the brain[1]. Various techniques have been developed and are being widely used to estimate the hemodynamic parameters such as relative cerebral blood flow (rCBF), relative cerebral blood volume (rCBV), and mean transit time (MTT)[2]. However, none of these methods generate unbiased measure of the hemodynamic parameters. Therefore, the application and the exact role of the estimated parameters in evaluation of the diagnosis and treatment efficacy of brain diseases like stroke and tumor remains controversial[2]. Unlike MR perfusion techniques, CT perfusion has limited coverage and requires the use of both iodinated contrast material and ionizing radiation. However, CT perfusion can provide, high-resolution, low-cost, and truly quantitative maps compared to MR perfusion[1,2]. In addition, the time trace of contrast agent (CA) concentration in CT is linear, which is not the case in MRI. Thus, the hemodynamic maps produced by CT perfusion can be used as the references for evaluating the techniques employed in MR perfusion analysis. In this study, an Adaptive Neural Network (ANN) is trained using a residue function with an exponential kernel for direct estimation of MTT in MR perfusion studies. The ANN was trained and tested using an analytical model of residue function with an exponential kernel at different levels of Signal to Noise Ratio (SNR). The trained ANN was applied to the DSC experimental data of four patients having MRP and CTP studies. Results imply that the proposed method is capable of providing a reliable, more accurate and more stable estimate of the hemodynamic maps compared to the SVD methods.

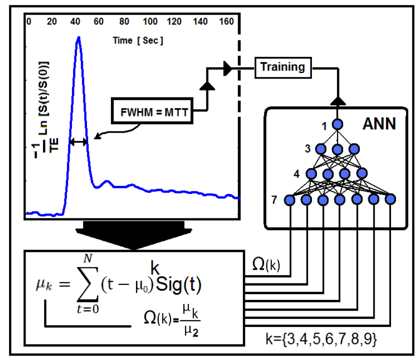

Figure-1: The ANN and the six normalized moments as its training features set.

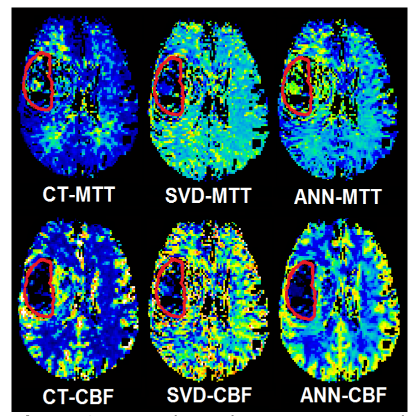

Figure-2: Hemodynamic maps generated by CTP technique, SVD, and ANN.

Region	ANN	SVD	CT
White Matter	3.48 ± 0.73	2.59 ± 0.54	4.46 ± 1.29
Enh. Lesion	4.35 ± 1.75	3.11 ± 1.14	4.40 ± 1.44
Gray Matter	2.25 ± 1.08	2.05 ± 0.91	2.25 ± 1.12
Edema	3.47 ± 0.95	2.89 ± 0.78	4.43 ± 1.24

Table -1 : Average MTT values [Sec] estimated by the ANN, SVD, and CT for different regions in the brain.

Materials and Methods: We hypothesized that, given a T_2^* signal analytically constructed by a residue function with an exponential kernel, an ANN can be trained to directly estimate the MTT in MR perfusion studies. The ANN training set was constructed from six different central moments (moment orders from n= 3 to 9) extracted from the analytically modeled signal. To construct a Time-to-Peak (TTP) insensitive feature set, all the extracted features were normalized to their central moment with n=2 (see Figuer1). The MTT of the modeled signal was considered as the gold standard of the training. For each MTT value, T_2* signal was modeled by varying the other independent parameters in the synthetic model of the signal (TTP and SNR). A range of Gaussian noise (SNRs of 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20) was also added to all simulated signals. To characterize the generalization error, the ANN was trained and validated by the K-Folding Cross Validation (KFCV) technique[3]. In this study, to assure a reliable estimate of the generalization error, number fold (K) was set to 25 with 10850 samples (434 in each fold). To illustrate and test the accuracy of the model trained ANN (6:4:3:1) against the experimental MR perfusion data, it was also applied to the MRP studies of four different patients (14 slices in total) with Glioblastoma tumor who had both CTP (GE Medical Systems, 8 slices, slice thickness: 5mm, 512X512, 50 ml of non-ionic contrast with rate of 4 ml/second, processed using '*CT perfusion 3.0*' software) and MRP (128X128, TE/TR=40/1900 ms, Slice thickness of 5 mm, pixel spacing=0.1875 with 95 time points with 1.95 sec time interval). Hemodynamic maps generated by CTP were co-registered to their corresponding MRP using FSL-FLIRT. In each patient, Arterial Input Function (AIF) alongside four different regions of the brain (white matter, gray matter, edema, enhanced part of the tumor) were identified in the co-registered T_1 post by an expert neuroradiologist. MTT values for these four regions were measured from the maps produced by the ANN, SVD, and the CTP techniques.

Results and conclusion: This study investigates feasibility of using a model trained Adaptive Model to estimate Mean Transit Time (MTT) and relative Cerebral Blood Flow (rCBF) in Dynamic Susceptibility (DSC) perfusion studies.. As shown in Figure-2, the MTT and CBF maps, generated by the ANN are more stable with higher SNR compared to the SVD method. The MTT measures illustrated in Table-1 also imply that the model trained ANN provides a more reliable and accurate MTT measure in different areas of the brain compared to the SVD technique. Results imply that the proposed method has a very good potential to be used as a fast and accurate hemodynamic map (MTT and CBF) estimator in DSC studies which plays an important role in quantification of physiological parameters.

References:

1. Wu O, Ostergaard L, Weisskoff RM et al.,Tracer arrival timing-insensitive technique for estimating flow in MR perfusion-weighted imaging using singular value decomposition with a block-circulant deconvolution matrix. *Magn Reson Med*. 2003;50:164–174.

2. Kohsuke K., Makoto S., Østergaard L.,et al.,Susceptibility of Tmax to tracer delay on perfusion analysis: quantitative evaluation of various deconvolution algorithms using digital phantoms, J Cereb Blood Flow Metab. 2011 March; 31(3): 908–912.

3. Bagher-EBadian H., Nagaraja TN, Paudyal R., et al., MRI estimation of contrast agent concentration in tissue using a neural network approach, *Magn Reson Med*, Volume 58, Issue 2, pages 290–297, 2007