Computer-Aided Detection of Metastatic Brain Tumors: Comparison between MP-RAGE and Black-Blood Imaging

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Introduction Contrast-enhanced three-dimensional T_1-weighted magnetization-prepared rapid gradient echo (MP-RAGE) imaging is commonly used for detecting brain metastases [1]. Also, application of computer-aided detection as a decision support system in detecting metastases has been studied, and was generally reported as increasing radiologists' diagnostic accuracies [2]. However, despite the lack of toxicity and non-invasiveness as a screening method for brain metastases, a major drawback of CE MP-RAGE imaging is that contrast agents in tumor and blood vessels both produce hyper-intensities, causing difficulties in lesion detection. To overcome this, we propose an automated computer detection method for metastatic brain tumors by utilizing contrast-enhanced MR black-blood pulse sequence previously developed [3]. The black-blood sequence can selectively suppress signals from contrast materials remaining in blood while signal from tumor parenchyma is kept enhanced. The performance of the proposed detection method using MR black-blood imaging and comparison with conventional MP-RAGE is given.

Figure 1. Representative images from metastatic brain tumor patient data. a,b) Conventional contrast-enhanced MPRAGE images. c,d) T1-weighted black-blood images. Arrows indicate metastatic brain tumor positions
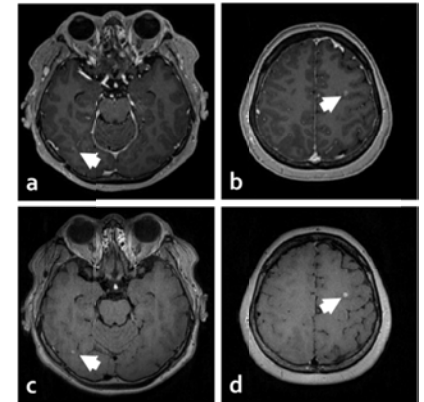
Methods From 26 clinical cases of patients, 41 tumors of sizes ranging between 3mm ~ 11mm verified by an experienced radiologist was used in this study. All imaging was performed on a 3T scanner (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany) with an eight-channel head coil, with the following imaging parameters: 3D MP-RAGE (TR/TE/inversion time = 2200/4.4/900ms, flip angle = 10º, resolution = $1.0 \times 1.0 \times 1.0 mm^3$ and imaging time = 8.5min), T_1-weighted, black-blood, single-slab, 3D turbo/fast SE (TR/TE$_{eff}$ = 650/11.7ms, VFA (α_1 = 180º), resolution = $1.0 \times 1.0 \times 1.0 mm^3$ and imaging time = 8.5min). Comparison of representative image slices of each sequence is shown in Figure 1. Central brightening effect was corrected by creating a low-frequency component image and dividing it from the original image. Residual signal from blood in dural venous sinuses, ventricles, internal carotid arteries, and also from skull were eliminated during brain extraction process using 3D-Segmentation Tool in Analyze (Mayo Clinic) to prevent unnecessary tumor candidates from degrading the CAD system's accuracy. Next, tumor candidates were generated by 3D template matching method [4]. The degree of similarity was measured by normalized cross-correlation coefficient (NCCC) [5]. From the candidates, various features were extracted for classification. To optimize classifier's discriminative power, principal component analysis (PCA) was performed. Then, true tumors were distinguished from false candidates using artificial neural network. The proposed detection process took approximately 13 minutes per patient data on a standard PC. Example images from each processing step are shown in Figure 2.

Figure 2. Example slices from each processing step. Actual processing is done as a 3D volume. a) Input black-blood image. b) Image after B1 inhomogeneity correction. c) Result of brain extraction using. d) NCCC 'map' created from 3D template matching process. Regions with high NCCC value appear bright in the map. e) Result of clustering representative voxel (voxel with NCCC value above threshold) with neighboring voxels.

Results and Discussion Performance of the proposed detection method was measured by comparing classifier outputs (Table 1) and respective receiver operating characteristic curve (Figure 3). MP-RAGE data gave a total of 2619 tumor candidates during template matching, and the classifier outputs are summarized in Table 1. The proposed method gave 64.7% (22/34) sensitivity and 99.8% (2582/2585) specificity, with AUROC=0.9568 for MP-RAGE data. With data acquired with black-blood sequence as the input, 1052 candidates were generated. Sensitivity and specificity was 90.2% (37/41) and 99.6% (1007/1011), and AUROC = 0.9892. The threshold value for the template matching in the MP-RAGE case was significantly lower than that of the black-blood case since most of the tumors did not have well-expressed tumor-brain boundaries and were difficult to find. Lower threshold value increased the survival rate of true tumors during template matching (by letting tumors with low NCCC value survive the cut below threshold) but also increased the generation of false candidates and processing time. In this sense, comparison of actual number of classifier outputs rather than sensitivity/specificity maybe more reasonable. As shown in the confusion matrices, although 41 actual tumors were included in the study, only 34 of them were found during template matching in the MP-RAGE case, which means that 7 of the tumors were lost before classification. In comparison, all 41 tumors were found in the process in the black-blood case. There were few types of tumors which were difficult to detect in the proposed method. First was large tumors (>11mm), for which the template sizes were too small and the system prompted multiple candidates from a single tumor. Increasing the template size can correctly detect these tumors, but calculating NCCC value of a large template can be computationally expensive and they were considered obvious enough for detection with human eye. Second common source were tumors near white/gray matter or brain/skull boundaries. This is due to the fact that included features were not able to give accurate description for these tumors during feature extraction process. However, by including diverse gray-level information in the feature extraction can correct this issue.

Figure 3. Receiver Operating Characteristic (ROC) curves for a) MP-RAGE data and b) black-blood data

MP-RAGE		Black-Blood	
TP	FP	TP	FP
22	3	37	4
FN	TN	FN	TN
12	2582	4	1007

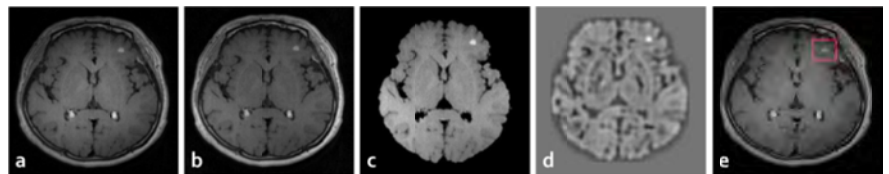**Table 1.** Confusion matrix for classifier outputs

Conclusion An automated computer-aided detection algorithm for metastatic brain tumors using CE black-blood imaging is described. Compared to conventional detection with CE MP-RAGE, the proposed method can detect tumors of various sizes located in the input image volume with significantly less false candidates and increased accuracy. The proposed method is currently focused on limited number of relatively fair-sized tumors, and is heavily dependent on the quality of brain segmentation result. Also, features extracted from candidates for classification were insufficient in describing tumors located in the boundaries. These issues will be addressed in our future work, along with extended detection algorithm for detection of increased number of tumors including small sized (<3mm) tumors as well.

Reference [1] Peretti-Viton P et al., Neuroradiol 1998; 40:783-787. [2] Doi K et al., Brit J Radiol 2005; 78:S3-S19.
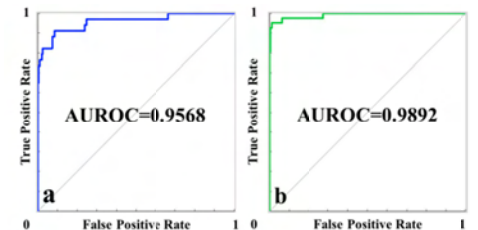
[3] Park J et al., Magn Reson Med 2010; 63:553-561. [4] Ambrosini RD et al., J Magn Reson Imaging 2010; 31:85-93. [5] Lewis JP., Vision Interface 1995.