A novel vessel segmentation technique based on clustering of dynamic first-pass MR imaging parameters

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Purpose: To develop a vessel segmentation technique for automated vessel removal in cerebral blood volume (CBV) maps derived from dynamic susceptibility contrast (DSC) MR imaging. To evaluate the effect of vessel removal on the diagnostic efficacy of glioma grading, using an established MR-based grading technique.

Background: Several studies have shown that CBV maps derived from DSC analysis can improve differentiation between high-grade (WHO grade III-IV) and low-grade (WHO grade I-II) gliomas [1]. Based on normalized (n)CBV maps, viable malignant tumor tissue can be identified as regions of elevated microvascular blood volume ('hot spots'). Recent studies have further shown that histogram analysis of nCBV values from total glioma volume may improve differentiation between these two cohorts [2,3]. However, a problem with any MR perfusion based glioma grading method is the need to exclude large vessels infiltrating the tumor region in order to avoid false positives due to artificial CBV increase from these vessels. In this study, we propose a novel vessel segmentation technique which uses several properties of the DSC response to automatically segment and remove macrovascular structures from CBV maps.

Methods: Sixty patients with histologically confirmed gliomas, (aged 15-77 yrs, mean age 48; 32 males, 28 females) have so far been included. The study has been approved by the local ethics committee and an informed consent was obtained from all patients. Imaging was performed at 1.5 T (Siemens Sonata or Avanto, Siemens AG, Germany) prior to surgery. The MR perfusion images were acquired using a first-pass gradient echo (GRE)-EPI sequence with TR=1.5s, voxel size 1.8x1.8x6.5mm^3 and i.v. bolus injection of 0.2 mmol/kg of Gadovist (Schering AG, Germany). Relative (r)CBV maps were generated from the area under the 1/T2* converted first-pass curves and the first moment of the area (fmAUC) was estimated for each pixel. The dynamic curves were fitted to gamma variate functions to reduce effects of recirculation and for estimation of contrast arrival time (To) and relative mean transit time (rMTT). The rMTT was estimated as the ratio rCBV/R2$_{max}$ where R2$_{max}$ is the peak height of the gamma variate fitted first-pass response. Prior to curve fitting, the dynamic curves were corrected for possible extra-vascular contrast agent leakage, which may lead to an under-estimation of rCBV [4]. An iterative k-means cluster algorithm [5] was applied to identify arteries and veins from the estimated parameters, nCBV, rMTT, fmAUC and To. An initial cluster analysis was performed to eliminate pixels with elevated rMTT, commonly observed in high grade gliomas. In the resulting image, arterial pixels were identified from the cluster with shortest To combined with highest rBV and veins as pixels in the cluster with the largest first moment combined with the highest rCBV. The resulting vessel mask was the combined arterial and venous clusters. nCBV maps were created by voxel-vise division of rCBV values with an unaffected white matter rCBV value in each slice. The nCBV maps were coregistered with conventional T2-w FSE and T1-w SE post-contrast images. An experienced neuroradiologist determined the total glioma region-of-interests (ROI's) based on the nCBV maps overlaid on the anatomical MR images. The glioma grade for each patient was determined from the maximum normalized peak height of nCBV distribution from the total glioma volume, under the hypothesis that a low peak implies a wide distribution of nCBV values due to the vascular heterogeneity of high-grade gliomas. Using histopathology as a reference, sensitivity, specificity, positive predictive values (PPV) and negative predictive values (NPV) of the glioma grading were obtained using the glioma ROI's with and without the vessel masks. Image analysis was performed using Matlab R2007a (MathWorks, Natick, US) and nordicICE (NordicImagingLab, Norway).

Results: Twenty-seven of the sixty patients investigated had high grade gliomas and 33 patients had low-grade gliomas. Results of the vessel masks are shown in figures 1 and 2. At equal sensitivity (78%), the specificity, PPV and NPV of the glioma grading when using the vessel mask was higher (76%, 72% and 81%, respectively) compared to the glioma grading when not using the vessel mask (70%, 68% and 79%, respectively). When only evaluating gliomas located within the region of the left or right middle cerebral artery (MCA) distributions (26 patients; 14 high-grade), the specificity, PPV and NPV at equal sensitivity (67%) increased from 64%, 69% and 62% to 83%, 82% and 67%, respectively.

Discussion: It is well known that GRE-EPI sequences are particularly sensitive to T2* effects from large vessels and this effect may cause significant T2* shortening outside the vessel boundary. Hence, vessel identification from anatomical images is likely to underestimate the true extent of the intravascular susceptibility effect in the DSC images. We propose a novel vessel segmentation technique which can be applied to parameters derived directly from the DSC data. The method is fast and provides a direct estimate of pixels which are actually affected by the vascular susceptibility effect, thereby offering a better correction for vessel-induced elevation in tumor CBV values. Even though the tumor ROI's in the current study were determined by an experienced neuroradiologist, taking care to avoid large vessels, introducing the vessel proposed segmentation technique reduced the number of false positives without increasing the number of false negatives.

Conclusion: Vessel segmentation based on dynamic first-pass parameters can improve the diagnostic efficacy of DSC imaging for glioma grading. The proposed method is attractive in that it provides a mask which covers all pixels affected by the intravascular susceptibility effect. The vessel segmentation technique may be of particular importance when evaluating gliomas located within the MCA distribution.

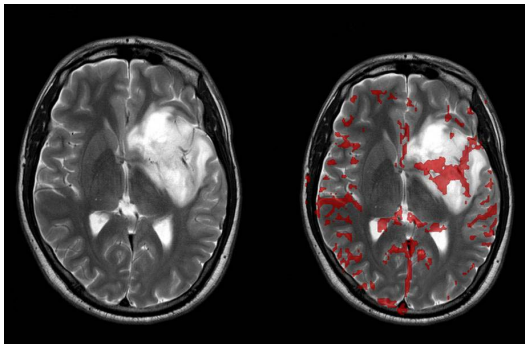

Figure 1: *Left: Axial T2-image of a low-grade astrocytoma (grade II) located within the region of the left MCA distribution. Right: Vessel mask overlaid on the axial T2-image. Note the identification of the MCA in the tumor region.*

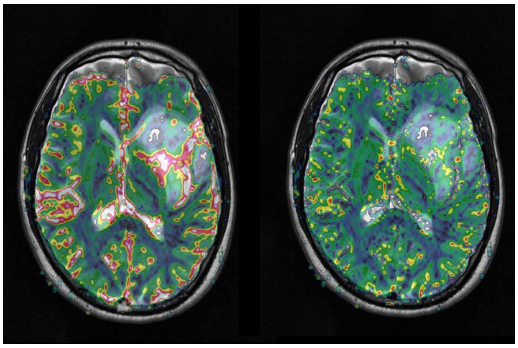

Figure 2: *Left: Unmasked, axial CBV image of the patient shown in figure 1. The falsely elevated CBV values in the tumor region due to the left MCA resulted in a misclassification of glioma grade. Right: Vessel masked, axial CBV image. The glioma is now correctly classified as a low-grade.*

References:

[1] Covarrubias DJ et al, The Oncologist, 2004;9:528-537
[2] Emblem KE et al, Radiology, In press
[3] Young R et al, JMRI, 2007;26:1053-1063
[4] Boxerman JL et al, AJNR, 2006;27:859-867
[5] Hadjiprocopis A et al, MRI, 2005;23:877-85