DUAL FEATURE BASED RECEIVER OPERATING CHARACTERISTIC ANALYSIS FOR ASSESSMENT OF ACUTE ISCHEMIC STROKE

Venkata Veerendranadh Chebrolu[1], Suresh E Joel[1], Dattesh D Shanbhag[1], Ananda Narasimha Murthy[1], Vivek Vaidya[1], Patrice Hervo[2], Marc-Antoine Labeyrie[3], Catherine Oppenheim[3,4], and Rakesh Mullick[1]

[1]*Medical Image Analysis Lab, GE Global Research, Bangalore, Karnataka, India,* [2]*GE Healthcare, Buc, France,* [3]*Departments of Radiology and Neurology, Centre Hospitalier, Sainte-Anne, Paris, France,* [4]*Université Paris Descartes, Paris, France*

Target Audience: Physicists and radiologists interested in acute ischemic stroke, infarct segmentation and quantitative diffusion neuroimaging.

Introduction: Diffusion weighted imaging (DWI) is used clinically for assessment of acute ischemic stroke. The classification of cerebral regions into normal and infarcted tissues based on DWI characteristics plays a critical role in MRI based stroke patient management [1]. Receiver Operating Characteristic (ROC) analysis was used to determine the optimal Apparent Diffusion Coefficient (ADC) threshold below which a region is classified as infarct [2-4]. ADC based tissue classification is robust to factors such as coil inhomogenities[4]. However, ADC is prone to errors/changes due to factors such as gradient non-linearity [5] and concomitant field effects [6]. Additionally, trace ADC maps may also manifest anisotropy in the event of patient motion between imaging at different diffusion encoding directions. Hence, the use of both DWI images and ADC maps may achieve better classification accuracy than using ADC or DWI alone. In this work, we present a dual feature (ADC and DWI) based ROC analysis and propose a novel acute ischemic infarct classification criteria.

Methods: *Imaging*: 65 acute ischemic stroke patients in the anterior circulation (Sainte-Anne Stroke unit, Paris) were imaged with DWI within 4.5 hours of onset on a 1.5T GE scanner (Signa HDx, GE Healthcare, Chalfont St Giles, UK) with an 8-channel head coil. The imaging parameters included: echo-time/repletion-time = 81-102/6600ms, flip-angle = 90°, NEX=2, Acquisition matrix = 256×256, FOV = 240×240 mm^2, slice thickness of 6 mm, no gap, b = 0 s/mm^2, and b = 1000 s/mm^2 with diffusion encoding along axial, sagittal and coronal directions. *Manual DWI Segmentation*: A senior radiologist manually delineated the infarcted area on DWI images with visual checking of ADC maps to ensure that no area of T_2-shine through effect or area with ADC decrease with no corresponding DWI signal change were included in the delineation (done using the READY View tool within the Advantage Workstation platform (GE Healthcare, Buc, France)). *ROC Analysis*: The DWI data of a given patient was normalized with the 98^{th} percentile of the DWI intensity within his/her own cerebrum (segmented using ATLAS based automated approach). Then, the ADC values and normalized DWI (nDWI) intensities within the regions marked as infarct were compared to the rest of the cerebrum. A two dimensional (2D) histogram was generated for each of the 65 subjects with ADC and nDWI values as the two features (dimensions). The individual 2D histograms of the 65 subjects were combined to generate a cumulative 2D histogram for the cohort. ROC analysis was performed on the cumulative histogram to identify the sensitivity (SE) and specificity (SP) of the different linear classifiers in infarct segmentation for the cohort. *Automated Infarct Segmentation:* Automated infarct segmentation using a linear classifier was done as follows: i) Generate cerebrum mask using ATLAS based approach and apply it to nDWI and ADC data of the subject. ii) Generate a binary mask for regions which satisfy the linear classification criteria (e.g.: ADC ≤ m × nDWI + n, where m is the slope and n is the intercept of the linear classifier). iii) Remove regions with volume less than 1cc and apply morphological close operation (radius 1) to obtain final infarct segmentation.

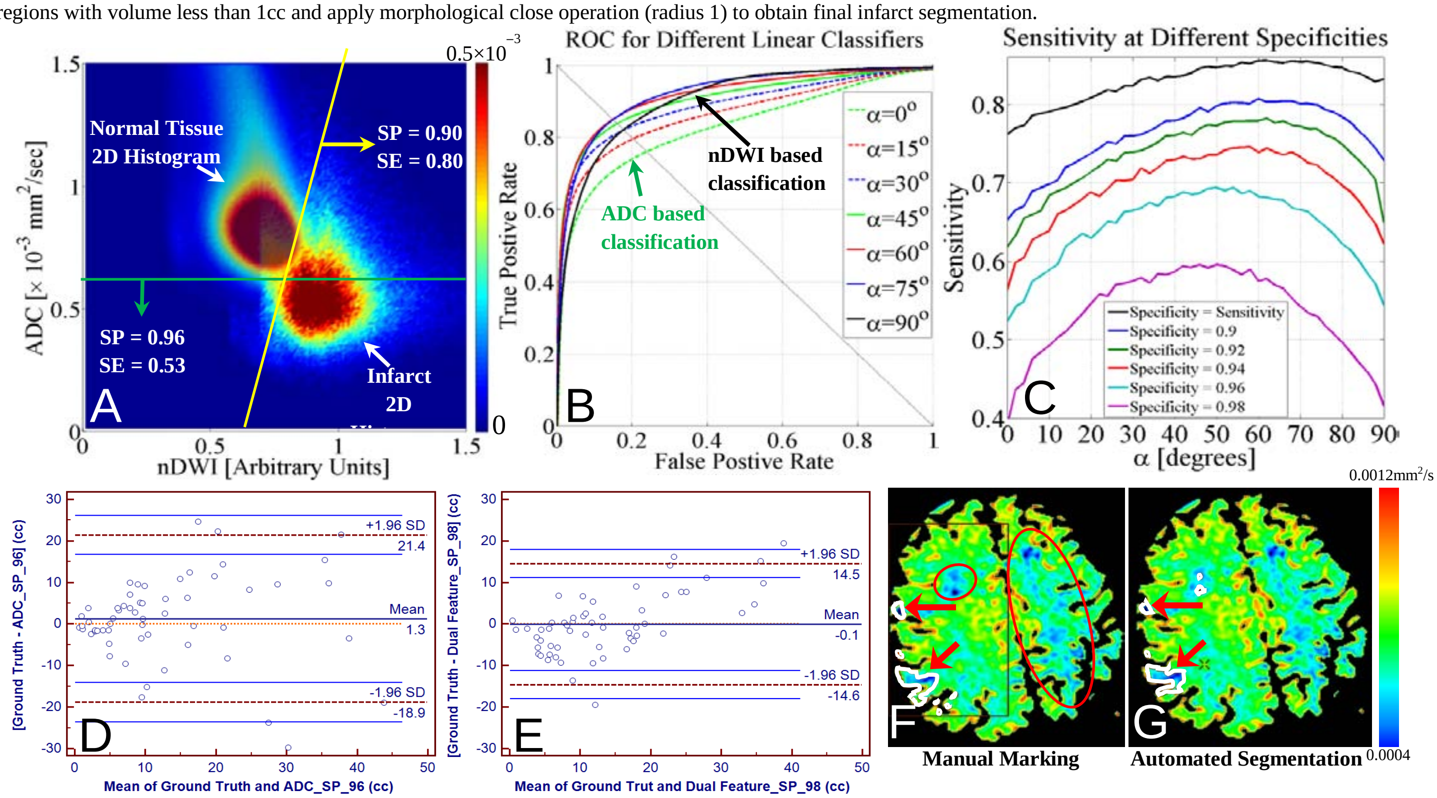

Figure 1*: A) 2D Histogram of the infarct and normal tissue in 65 subjects. ADC* [$\times10^{-3}$$mm^2/s$] *and nDWI are the two dimensions for the 2D histogram. B) ROC curves for different linear classifiers (ADC ≤ tanα × nDWI + n for α<90°; nDWI ≥ n for α=90°). C) Sensitivity achieved at different α for a given specificity is shown. D and E) Bland–Altman plots showing the comparison of ground-truth from manual marking with automated segmentation using ADC≤0.6×10*$^{-3}$*mm^2/s (ADC_SP_96) and ADC ≤ tan(50°) × nDWI – 0.45(Dual Feature_SP_98). F) Manual marking (white line) of the infarct on a case with trace ADC map manifesting anisotropy (red ellipses) G) Automated infarct segmentation (white line) using the Dual Feature_SP_98 classifier in a case manifesting trace ADC anisotropy.*

Results and Discussion: Figure 1 shows dual feature based ROC analysis, results of infarct segmentation using linear classifier *ADC ≤ tan(50°) × nDWI – 0.45* and its robustness to artifacts. Bland-Altman plots demonstrate better agreement with ground-truth using dual features (SP-98%; SE-60%) as compared to ADC alone based infarct segmentation (SP-96%; SE-53%) in 65 subjects. Significant overlap in the histograms of infarct and normal tissue resulted in the lower sensitivity for the two linear classifiers compared. The use of non-linear classifiers and/or multiple-features might be needed to achieve simultaneously better sensitivity and specificity.

References: [1] Kane I et al, J Neurol Neurosurg Psychiatry 2007;78:5 485-491. [2] Roldan-Valadez E et al, Clin Radiol 67(3):8 (2012); [3] Straka M et al, JMRI 2010; 32:1024–1037. [4] Chebrolu et al, ISMRM 2012: p. 3097 [5] Malyarenko D et al, JMRI 2012; (early view). [6] Baron CA et al, MRM 2012; 68(4): 1190-1201.