

OPTIMAL THRESHOLDING OF TMAX AND ABSOLUTE QUANTITATIVE CBF IMAGING IN ACUTE ISCHEMIC STROKE

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Introduction

Analysis of acute ischemic stroke DSC data often involves thresholding of T_{max} images for the purposes of identifying ischemic core or salvageable penumbra or both. T_{max} is defined as the time at which the deconvolved residue function (obtaining using conventional singular values decomposition (SVD)) maximizes. T_{max} should have a value of 0 in well perfused regions and will frequently have a non-zero value in tissue regions distal to an arterial occlusion. T_{max} was initially developed because it provided a high contrast image that succinctly encapsulated DSC microvascular flow information and because reliable determination of absolute quantitative Cerebral Blood Flow (aqCBF) has been deemed unreliable. Because aqCBF can now be reliably determined, we sought to better define the quantitative and statistical relationships between T_{max} and aqCBF. Doing so may provide insight into past successes and failures associated with using T_{max} as a predictive parameter in addition to help defining whether T_{max} should continue to be used.

Methods

We retrospectively identified DSC studies of acute ischemic stroke patients done for clinical purposes at our institution over a 3 month period. Specifically, studies performed on the first day of a new cerebrovascular ischemia event were selected. Studies that involved large hemorrhage, vasculitis, small ischemic lesions, traumatic injury, post-operative complications or that were read as normal were not used. Studies that showed pronounced head movement or poor bolus delivery were not used. This process provided 25 DSC studies. Three dimensional T_{max} and aqCBF images were produced using software of our own design which automatically identified a global arterial input function (AIF) and a global venous outflow function (VOF) using dynamic criteria. VOF data were used to scale AIFs for partial volume effect so that aqCBF could be reliably obtained. The software then performed voxel-wise SVD of measured arterial input from measured dynamic tissue concentration to produce residue data from which T_{max} (the time location of the residue maximum) and aqCBF images (the residue maximum value) were derived. For each patient, T_{max} images were segmented at various thresholds ($T_{max} > 0, 2, 4 \dots 20$ sec) and the fraction of ischemic volume within each T_{max} segment was measured (defined as the volume (i.e. number of voxels) having aqCBF less than or equal to 5 cm^3 blood per 100 g brain per min). Automated delineation of ischemic volumes (on either T_{max} or aqCBF images) is generally limited by the presence of substantial ventricular and sulcal volumes, which vary from subject to subject. Such volumes show near zero CBF and high T_{max} and thereby contribute to the total core ischemia volume. This complication was managed by removing sulcal and ventricular volumes from the brain masks used in the calculation of T_{max} and aqCBF images. Complete ischemia is also problematic for DSC analysis because completely ischemic regions receive no contrast delivery and, accordingly, it is not possible to determine aqCBF or T_{max} . This complication was managed by assigning regions within the brain mask that received insufficient contrast delivery for subsequent analysis to have aqCBF = 0 and $T_{max} = 20$.

Results

Figures 1 & 2 show selected slices from aqCBF and T_{max} images (one slice from each patient). Visual inspection of these figures indicates there is agreement between T_{max} and CBF images with respect to the brain location that is experiencing ischemia. Figure 3 shows that the probability of finding ischemic voxels ($\text{aqCBF} < 5$) progressively increases as the T_{max} threshold is increased. However the figure also shows there is no clear optimum T_{max} threshold. A subtle break in curvature between T_{max} thresholds of 8 and 10 sec suggests these threshold levels may have discriminating power. Figure 3 also illustrates that about 40% of the voxels in volumes thresholded at very high T_{max} show non-ischemic CBF.

Conclusions

Although T_{max} is statistically effective at detecting core ischemia, there does not appear to be a T_{max} threshold that detects core ischemia with a high discriminatory power. Given that absolute CBF can be reliably obtained, thresholding of CBF images may provide a more reliable means of identifying core ischemic tissue volumes. The unexpectedly large fraction of non-ischemic volume (according to the aqCBF images) within volumes thresholded at high T_{max} is likely to be related to failure of the deconvolution process due to the combination of noise and small prolonged contrast delivery distal to an arterial occlusion. The present study is limited in that thresholding was automatically performed. The expert morphological knowledge (i.e. ROI drawing) was not incorporated in the thresholding process.

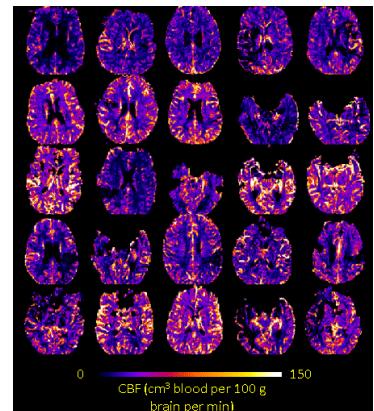


Figure 1: aqCBF images of plane having maximal T_{max} volume in 25 acute stroke patients

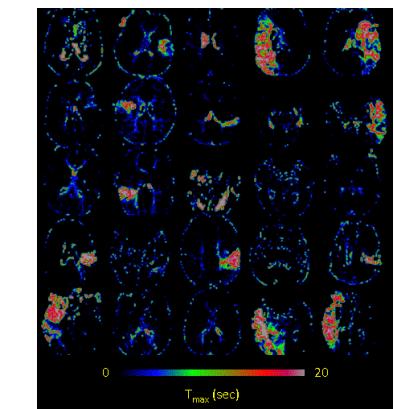


Figure 2: T_{max} images of the same planes in the same subjects.

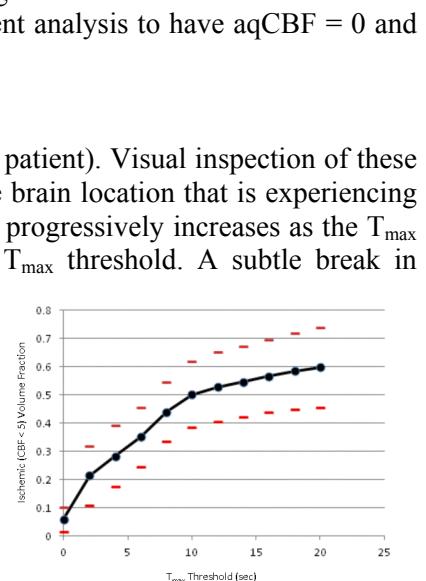


Figure 3: Relationship between T_{max} threshold and the ischemic volume fraction within the volume having T_{max} greater than the threshold (means & StDevs).