Determination of Collateral Supply Patterns Using Conventional Dynamic Susceptibility Contrast Perfusion Imaging

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Introduction

Collateral circulation plays an important role in sustaining blood flow to ischemic tissue and maintaining tissues at risk viable. It has been demonstrated that mice with good collateral flow have less ischemic damage[1]. Thus far, the gold standard for evaluating the degree of collateralization is the digital subtraction angiography (DSA) method due to its high spatial and temporal resolution. However, the routine 2D DSA method has several disadvantages, including exposure to x-ray, requirement of arterial puncture, i.e. invasiveness, and inability to localize collateralization in 3D. Dynamic susceptibility contrast (DSC) MRI is a routinely used clinical neuro-imaging method to estimate cerebral perfusion. It is fast and readily available at many clinical sites. Based on tracer dynamics, several perfusion related maps, including cerebral blood flow (CBF), mean transit time (MTT) and time-to-peak of the tissue residue function (Tmax) can be computed. Ischemic tissue supplied by collateral flow is likely to have delayed tracer arrival but relatively normal flow. Since CBF, MTT and Tmax reflect different aspects of tissue hemodynamics, we hypothesize that a method which integrates all the information provided by these three parameters may offer insight into collateral flow. In this study, we performed a simulation to examine the patterns leading to various hemodynamic alterations on CBF, MTT and Tmax. Moreover, an integrated DSC perfusion approach was developed and tested in ischemic stroke patients who also had DSA evaluation.

Methods

In the simulation, delay and dispersion were simulated for gray matter (GM) and white matter (WM) separately as previously described[2,3]. The delay was varied between 0 and 30 sec. while the dispersion between 1.25 and 17.25 sec. With delay on one axis and dispersion on the other, we were able to assess how CBF, MTT and Tmax may change for different combinations of delay and dispersion. The combinations of interest for this simulation were especially the ones which most closely represent the hypothesized collateral flow pattern [for instance, close to normal dispersion, but relatively large delay].

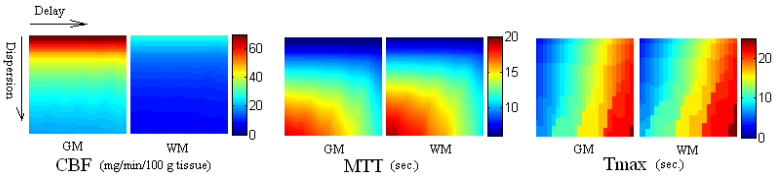

Figure 1 – Simulation results

In order to test our method *in vivo*, 1 male and 4 female patients with ages 44 through 77 were identified with both DSA and MR DSC data (within 30 hours) with MCA occlusions. The arterial input functions (AIFs) were manually chosen from the collateral MCA and circular SVD (oSVD)[4] was utilized to compute CBF, MTT and Tmax. For normalization, the CBF map was divided by the median contralateral CBF value whereas the median contralateral MTT value was subtracted from the MTT map (yielding nCBF and nMTT, respectively). No normalization was performed on Tmax. The nCBF, nMTT and Tmax maps were then thresholded to define abnormality using the following criteria: nCBF<=0.4, nMTT>=4 sec and Tmax>=3TRs. Finally, the thresholded CBF was represented by blue, MTT by red and Tmax by green so that they could be combined in an RGB image with each channel representing one of the three maps. According to this integration procedure, tissues with different hemodynamic characteristics will be represented by several distinct colors. More specifically, normal tissue will be represented by black; ischemia with severely compromised perfusion (low CBF, long MTT and Tmax) will be represented by white; the hypothesized good collateral flow pattern will be represented by green (normal CBF, normal MTT and long Tmax); and possible collateral flow/compromised perfusion will be represented by yellow (normal CBF, long MTT and Tmax). For comparison, DSA collateral scores were identified blindly by a neurointerventionalist (SS) using a technique described in the literature[5]. A score of 1-5 was given based on the degree of retrograde collateralization, with higher scores representing poor collateralization.

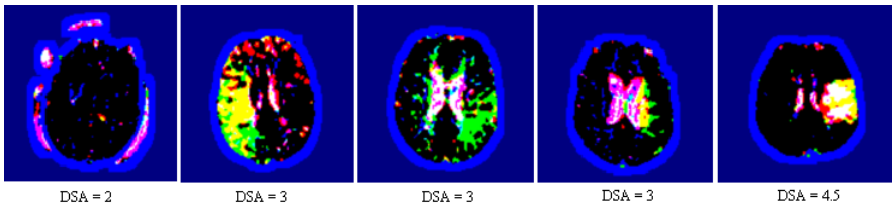

Figure 2 – Integrated RGB perfusion maps with DSA scores

Results

Figure 1 shows the simulation results. It can clearly be seen that CBF and MTT are quite insensitive to the delay in tracer arrival if the dispersion is small, while dispersion reduces CBF and prolongs MTT. However, although Tmax is also slightly influenced by dispersion, it mostly depends linearly on delay, which is consistent with a recent report[2]. The hypothesized good collateral flow should have a sustained blood flow, a delayed tracer arrival and normal or slightly larger-than-normal dispersion.

Figure 2 exhibits patients with various DSA scores. The figure is very illustrative. The patient with a DSA score of 2 shows almost normal CBF, MTT and Tmax, indicating that the collateral supply is very good without detectable tracer delay and dispersion, which is also suggested by the low DSA score. The middle three patients with DSA = 3 show regions with substantial collateral supply (marked either by green, representing the hypothesized good collateral flow, or a mixture of green and yellow colors). The fifth patient shows a large white region mixed with yellow regions and negligibly small green regions, suggesting a poor collateral supply, which is in agreement with a DSA score as high as 4.5.

Discussion and Conclusions

Consistent with previous work, our simulation demonstrated that CBF and MTT are sensitive to tracer dispersion, while Tmax is sensitive to tracer arrival delay. Under ischemic condition, all three parameters will show abnormalities. Therefore, using any of these parameters alone cannot provide sufficient information for a clear separation between ischemic tissue and tissue with collateral flow. Based on the different characteristics of these three parameters, we hypothesized that tissue with good collateral flow can show a distinct pattern in an integrated approach. We tested this hypothesis in stroke patients and demonstrated that our findings are in agreement with the gold standard DSA assessment. Validation of this method needs to be performed in a large cohort of patients with varied degrees of collateral supply in the future. The major advantage of our method is that it can offer insight into collateral flow by using DSC data which is commonly acquired in the daily clinical setting.

References

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