Multi-modal Hemodynamic MRI for Evaluation of Tissue Impairment in Patients with Intra-cranial Stenosis

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Introduction. The overall aim of this work is to develop and clinically implement a multi-modal 3.0T MRI protocol capable of quantitatively evaluating the relationship between tissue-level hemodynamic compensation mechanisms and stroke risk in patients with intracranial (IC) steno-occlusive disease. Recent studies have shown high ischemic stroke rates in patients with IC arterial stenosis (1); in such patients with compromised cerebral blood flow (CBF), the extent of hemodynamic compromise reflects the autoregulatory capacity of vasculature to increase cerebral blood volume (CBV) and/or develop collaterals to supplement cerebral blood flow (CBF) (2). The prevalence of CBF collateralization and CBV autoregulation, as well as changes in CBF and CBV in response to stimuli, or cerebrovascular reactivity (CVR), have been hypothesized to correlate uniquely with stroke risk; however, the extent of this correlation has been debated (3, 4). Importantly, new, noninvasive MRI techniques and analysis strategies for assessing hemodynamic impairment have been proposed, yet uncertainties in clinical interpretation and a lack of cross-modal validation studies have precluded routine clinical implementation. We evaluated IC stenosis patients with varying degrees of cerebrovascular disease with the following aims: (i) To compare temporal features (e.g. time-to-peak, TTP) of CVR using controlled, noninvasive hypercapnic BOLD fMRI with standard digital subtraction angiography (DSA) metrics, (ii) to evaluate the relationship between CBF-weighted arterial spin labeling (ASL) MRI, CVR, DSA and Modified Suzuki Score (MSS), and (iii) to assess the utility of CVR and CBF for post-operative evaluation. The fundamental hypothesis to be investigated was that CVR and CBV provide complementary information to DSA opacification times, yet with additional anatomic information. A secondary hypothesis was that a multi-modal structural and functional MRI protocol can be used to assess tissue level hemodynamics following revascularization procedures. Results emphasize the overall utility of noninvasive MRI approaches for evaluating tissue-level impairment in cerebrovascular disease and validate the contrast of these approaches against angiographic and clinical scores.

Methods. Experiment. Patients with angiographically-confirmed IC stenosis with (n=15) and without (n=6) Moyamoya disease provided informed, written consent and were scanned on (i) DSA, (ii) T2-weighted MRI (MPRAGE: 1x1x1 mm; TR/TE=8.9/4.6 ms), T2-weighted FLAIR MRI (0.9x0.9x1 mm; TR/TE=11000/120 ms), (iii) CBF-weighted pseudo-continuous ASL MRI (pCASL; 3.4x3.4x5 mm; TR/TE/TI=4000/17/1650 ms; 16 slices) and (iv) hypercapnic BOLD MRI (3.4x3.4x5 mm; TR/TE=2000/35 ms; 30 slices). All MRI scanning occurred at 3.0T with additional anatomic information. Adequate co-registration was achieved in 18/21 patients; infarcts in the remaining three patients prevented co-registration and these patients were excluded from group analyses. FIG 1. MRI and DSA data from an example IC stenosis patient (51 yr/M) with right MCA stroke. Temporal dynamics of the BOLD timecourse (e) reveal periods of high CBF with short TTP (blue), high CBF with delayed TTP (red), and negative CVR (green); ROIs shown in (FIG 1f). Evaluation of these temporal features was a key aim of this work. (f) DSA following right CCA injection reveals chronic right cervical ICA occlusion with ECA collaterals补给, yet the extent of tissue-level hemodynamic compensation reflects the autoregulatory capacity of vasculature to increase cerebral blood volume (CBV) and/or develop collaterals to supplement cerebral blood flow (CBF) (2). The prevalence of CBF collateralization and CBV autoregulation, as well as changes in CBF and CBV in response to stimuli, or cerebrovascular reactivity (CVR), have been hypothesized to correlate uniquely with stroke risk; however, the extent of this correlation has been debated (3, 4). Importantly, new, noninvasive MRI techniques and analysis strategies for assessing hemodynamic impairment have been proposed, yet uncertainties in clinical interpretation and a lack of cross-modal validation studies have precluded routine clinical implementation. We evaluated IC stenosis patients with varying degrees of cerebrovascular disease with the following aims: (i) To compare temporal features (e.g. time-to-peak, TTP) of CVR using controlled, noninvasive hypercapnic BOLD fMRI with standard digital subtraction angiography (DSA) metrics, (ii) to evaluate the relationship between CBF-weighted arterial spin labeling (ASL) MRI, CVR, DSA and Modified Suzuki Score (MSS), and (iii) to assess the utility of CVR and CBF for post-operative evaluation. The fundamental hypothesis to be investigated was that CVR and CBV provide complementary information to DSA opacification times, yet with additional anatomic information. A secondary hypothesis was that a multi-modal structural and functional MRI protocol can be used to assess tissue level hemodynamics following revascularization procedures. Results emphasize the overall utility of noninvasive MRI approaches for evaluating tissue-level impairment in cerebrovascular disease and validate the contrast of these approaches against angiographic and clinical scores.

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Results and Discussion. Adequate co-registration was achieved in 18/21 patients; infarcts in the remaining three patients prevented co-registration and these patients were excluded from group analyses. FIG 1. MRI and DSA data from an example IC stenosis patient (51 yr/M) with right MCA stroke. Temporal dynamics of the BOLD timecourse (e) reveal periods of high CBF with short TTP (blue), high CBF with delayed TTP (red), and negative CVR (green); ROIs shown in (FIG 1f). Evaluation of these temporal features was a key aim of this work. (f) DSA following right CCA injection reveals chronic right cervical ICA occlusion with ECA collaterals supplementing cerebral perfusion pressure (CPP), the extent of which can be extremely varied following surgical revascularization procedures. Results emphasize the overall utility of noninvasive MRI approaches for evaluating tissue-level impairment in cerebrovascular disease and validate the contrast of these approaches against angiographic and clinical scores.