Hematoma Volume Measurement in Gradient Echo MRI Using Quantitative Susceptibility Mapping

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Background and Purpose—A novel quantitative susceptibility mapping (QSM) processing technology has been developed to map tissue susceptibility property without blooming artifacts. We hypothesize that hematoma volume measurement on QSM is independent of imaging parameters, eliminating its echo time dependence on gradient echo MRI.

Methods—Gradient echo MRI of 16 patients with intracerebral hemorrhage was processed with susceptibility-weighted imaging, $R2^*$ ($=1/T2^*$) mapping, and QSM at various echo times. Hematoma volumes were measured from these images.

Results—Linear regression of hematoma volume versus echo time showed substantial slopes for gradient echo magnitude ($0.45\pm0.31$ L/s), susceptibility-weighted imaging ($0.52\pm0.46$), and $R2^*$ ($0.39\pm0.30$) but nearly zero slope for QSM ($0.01\pm0.05$). At echo time=20 ms, hematoma volume on QSM was 0.80x that on gradient echo magnitude image ($R^2=0.99$).

Conclusions—QSM can provide reliable measurement of hematoma volume, which can be performed rapidly and accurately using a semiautomated segmentation tool. (Stroke. 2013;44:2315-2317.)

Key Words: gradient echo • hematoma volume • intracerebral hemorrhage • magnetic resonance imaging • quantitative susceptibility mapping

Gradient echo (GRE) MRI has been demonstrated to be more sensitive than computed tomography (CT) in detecting intracerebral hemorrhage, which is characterized as hypointensity on $T2^*$-weighted GRE magnitude images. $T2^*$ is sensitive to local magnetic inhomogeneities. However, $T2^*$ hypointensity is dependent on imaging parameters, including echo time (TE), field strength, and voxel size, making it difficult to estimate the hematoma volume (HV) reliably, a vital clinical predictor in managing hemorrhagic patients. Recently, a novel quantitative susceptibility mapping (QSM) technology for postprocessing GRE MRI data through deconvolution to reveal intrinsic tissue magnetism and remove imaging parameter dependence has been applied successfully as a universal measurement of the burden of cerebral microbleeds, eliminating the $T2^*$ dependence on imaging parameters. We hypothesize that QSM provides TE-independent measurement of HV in GRE MRI.

**Methods**

**Patients**

Sixteen patients with acute intracerebral hemorrhage (59±11 years; 13 men, 3 women) in stable condition within 6 hours after symptom-onset from August 7, 2009, to August 10, 2011, were recruited for MRI on a 3T scanner using a T2*-weighted 3-dimensional multiecho spoiled GRE sequence: 8 to 11 echoes with first TE=5 ms, echo spacing=4.5 to 5 ms, and TR=45 to 59 ms. The GRE magnitude and phase data at each TE were processed to generate susceptibility-weighted imaging (SWI), $R2^*$ ($=1/T2^*$) and QSM images. HVs on magnitude, SWI, $R2^*$, and QSM at each TE were measured by a semiautomated region growth segmentation method and were normalizing to the volume measured at the reference echo time (reference TE=20 ms).

**Statistical Analysis**

Linear regression was performed on HVs measured at TE measured in a given image type (magnitude, SWI, $R2^*$, QSM) versus TE to assess volume dependence on TE and among HVs measured from all image types at reference TE for correlations.

**Results**

The normalized HVs at the last echo (TE>40 ms) were 1.31±0.185 for magnitude, 1.35±0.37 for SWI, 1.24±0.14 for $R2^*$, and 1.01±0.01 for QSM. The slope of HV-TE averaged over subjects was 0.44±0.31 L/s for magnitude, 0.52±0.47 L/s for SWI, 0.39±0.31 L/s for $R2^*$, and 0.01±0.01 L/s for QSM. Figure 1 illustrates an example of the HV measurement, where the slopes of HV-TE were 0.2229 L/s ($R^2=0.88$; $P=0.06$) for magnitude, 0.2688 L/s ($R^2=0.90$; $P=0.05$) for SWI, 0.1684 L/s ($R^2=0.95$; $P=0.03$) for $R2^*$, and 0.0003 L/s ($R^2=0.05$; $P=0.77$) for QSM.

The HV of QSM at reference TE=20 ms was linearly related to that of the magnitude image (magnitude volume/QSM volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$), SWI (SWI volume/SWI volume=1.24; $R^2=0.98$; $P<10^{-3}$).
Hemorrhage volume measured on QSM ranged from 7.0 to 63.4 mL, with a median of 17.65 mL and interquartile from 11.7 to 24.2 mL.

Discussion
Our results demonstrate that QSM reduced the TE dependence of GRE MRI HV measurements from magnitude, SWI, and **R**2* images, providing a HV measurement independent of imaging parameters in GRE MRI.

This result is consistent with the report that QSM can provide a reliable measurement of the burden of cerebral microbleeds and is understood from physics underlying the GRE MRI data acquisition. Micro- and macrohemorrhages contain paramagnetic components (hemosiderins, methemoglobins, etc.) that generate magnetic fields. Fields extending beyond their source locations cause blooming artifacts in GRE magnitude images. Blooming artifacts depend on phase accumulation, which is proportional to TE and local fields. Consequently, the SWI and **R**2* images are dependent on TE, resulting in TE-dependent overestimation in HV measurements from GRE MRI. Quantitatively, the magnetic field at a point in space, measurable from GRE phase images, is determined by convolving paramagnetic sources with the dipole kernel. To eliminate blooming artifacts dependent on GRE imaging parameters, the dipole kernel deconvolution must be performed to reveal tissue magnetic properties, which is QSM technology.

This technical study is limited by the number of patients and lack of CT correlation and may be followed by a future study on a large cohort of patients with CT correlation. Many stroke centers obtain a CT then a follow-up MRI because of MRI’s unparalleled rich tissue contrast in imaging brain tissue. Therefore, estimating a precise HV by MRI in comparison with CT could be important in assessing hematoma expansion using different modalities. HV from CT=0.8* HV from the GRE magnitude image at TE=15 to 20 ms (approximately reference TE here) was reported.11 We observed QSM volume/magnitude volume=1/1.24=0.8 (inverse of the slope in Figure 2). The suggestion that the HV measured by QSM may be approximately the HV measured by CT needs to be confirmed in future study.

Efforts exist to develop efficacious treatment of intracerebral hemorrhage, which has caused increasing hospital admissions with persistently high mortality rates.12 Although HV serves as a measure for the effects of potential interventions in clinical trials, like INTERACT,13 in vivo MRI characterization of brain tissue and vasculature may allow better understanding and management of hematoma expansion14,15 and would be important in developing and applying intracerebral hemorrhage therapy. QSM of tissue magnetic property may become an essential part of a hemorrhage MRI protocol.

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Disclosures

Drs Liu and Wang are listed as inventors on patent applications related to the QSM technique. The other authors have no conflicts to report.

References

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