Cerebral Infarction: Assessment of Patterns Using Ultra-Fast MR Contrast Imaging

Charles Lee,[1] Bruce L. Dean,[1] John E. Kirsch,[1] Val M. Runge,[1] Robert J. Dempsey,[2] Robert S. Howard II,[1] and Luther C. Pettigrew,[3]

Summary: We describe a rapid MR imaging technique, applying functional analysis to images obtained during the tissue transit of injected contrast material into the cerebral circulation, which has potential for assessment of the altered hemodynamics in cerebral ischemia. This technique utilized turbo-FLASH imaging maximizing the T1 relaxivity properties of gadopentetate dimeglumine with positive contrast enhancement.

Index terms: Brain, infarction; Magnetic resonance, contrast enhancement

Materials and Methods

Nineteen healthy subjects and 13 patients with clinical, computed tomography (CT), and magnetic resonance (MR) evidence of stroke were studied on a 1.5 T Siemen's Magnetom 63SP (Siemens Medical Systems, Iselin, NJ) following a 0.1 mmol/kg bolus of gadopentetate dimeglumine. Turbo-FLASH imaging was performed using a rectangular profile, nonselective preparatory 180° inversion pulse with an effective inversion time of 529 ms to achieve a heavily T1-weighted scan (Fig. 1). Imaging parameters included a TR/TE/excitation of 8/4/1 and a flip angle of 10°, 1-cm thick slices, field of view = 25 cm, and a 128 × 128 matrix (in-plane spatial resolution = 2.0 × 2.0 mm).

Twenty images were obtained with an acquisition time of 1.06 sec per image, interscan delay of 1.6 sec, and a total imaging time of 51.6 sec. Four images were obtained prior to contrast injection to allow the precontrast longitudinal magnetization to reach a steady state from acquisition to acquisition, and also to establish a baseline, precontrast signal intensity.

ROI (region of interest) measurements were obtained of the gray and white matter bilaterally, and the superior sagittal sinus in the healthy and stroke patients. The normal, contralateral hemisphere was measured for comparison in the stroke patients. The resulting serial ROI measurements were used to plot a time-signal intensity curve. Signal intensity change (Δ S.I.) was expressed as a percentage change increase using the equation (6): $\Delta \text{ S.I.} = [(\text{S.I.})_{peak} - (\text{S.I.})_{baseline}]/(\text{S.I.})_{baseline} \times 100$.

A relative assessment of flow was made by calculating the rate of signal intensity change from the baseline to peak intensity. The observed signal intensity change was divided by the time required to reach maximum peak $[(\Delta \text{ S.I.}/\Delta \text{ time})_{Max}]$. The rate of signal intensity change per time unit reflects the rate at which the contrast was delivered and thus approximates flow.

Results

In the healthy group of subjects the mean Δ S.I. of gray matter was 53.1% (SD = 11.7%) on the right, and 55.9% (SD = 9.3%) on the left, and of the white matter was 10.4% (SD = 2.3%). There was no statistically significant difference between the calculated right and left gray matter Δ S.I. in the normals with a mean difference of 7% ± 3%. The *t*-value was 1.7, whereas statistically significant differences should have had a *t*-value of 2.1 at the 95% level.

In the acute strokes there was marked decrease in the Δ S.I. and the $(\Delta \text{ S.I.}/\Delta \text{ time})_{Max}$, as well as delay in the maximum signal intensity peak compared to the contralateral hemisphere. In the subacute strokes there were no delays in the signal intensity peak, and moderate decrease in the Δ S.I. and the $(\Delta \text{ S.I.}/\Delta \text{ time})_{Max}$. However, there were subacute strokes that demonstrated an increase in Δ S.I. and the $(\Delta \text{ S.I.}/\Delta \text{ time})_{Max}$ appearing as areas of increased signal on the subtraction images. Similar increase in Δ S.I. and $(\Delta \text{ S.I.}/\Delta \text{ time})_{Max}$ were also noted in the pen-

Received January 31, 1991; revision requested March 22; final revision received and accepted June 15.

Presented as a scientific paper and exhibit at the 1990 ARRS annual meeting, Washington, DC.

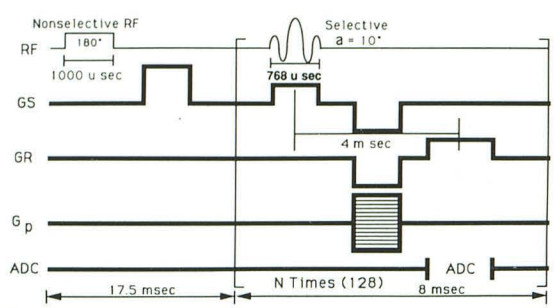
This work was supported in part by a Clinical Investigator Development Award, NINDS/NIH 1 K08 NS01505-01, held by L.C.P.

[1] Department of Diagnostic Radiology, Magnetic Resonance Imaging and Spectroscopy Center, University of Kentucky Medical Center, 800 Rose St., Lexington, KY 40636-0084. Address reprint requests to C. Lee.

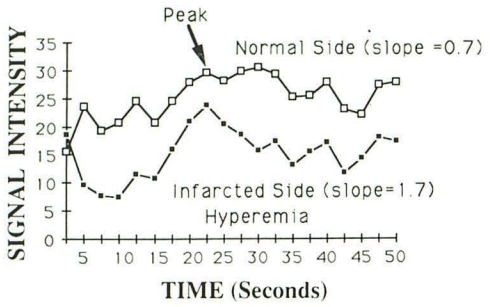
[2] Department of Neurosurgery, University of Kentucky Medical Center, Lexington, KY 40636-0084.

[3] Department of Neurology, University of Kentucky Medical Center, Lexington, KY 40636-0084.

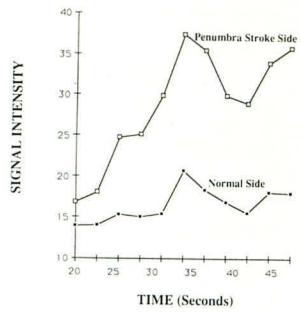
AJNR 13:277–279, Jan/Feb 1992 0195-6108/92/1301-0277



1



2

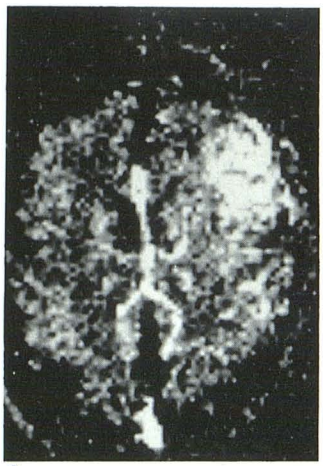


3

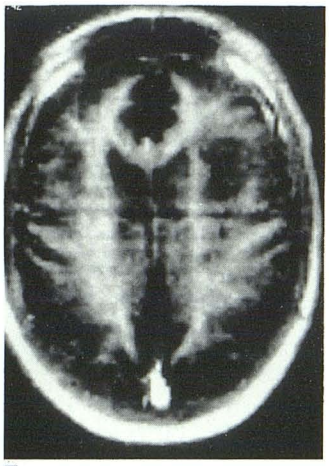
Fig. 1. Diagram of turbo-FLASH pulse sequence used with heavy T1-weighting but no spoiler gradient.

Fig. 2. Time-intensity curve comparing normal and stroke hemisphere with ROI of the gray matter of this subacute stroke with hyperemia. The first four frames were obtained prior to contrast injection. The fourth frame value is the baseline signal intensity. The longitudinal magnetization from the first 180° inversion pulse has not fully recovered by the time of the second 180° inversion pulse. The resulting signal produced by the second inversion pulse is less than the first. Contrast was injected at the beginning of the fourth frame (ie, 10 sec). There is increase in the signal intensity change and of the slope on the stroke side compared with the normal side without any differences in the time-to-peak intensity between the two hemispheres.

Fig. 3. Time-intensity curve with ROI measurement of the cortex posterior to the area of infarct (*penumbra*) which demonstrated increased signal on the subtracted image. The baseline precontrast signal intensity is the same as the normal side unlike the subacute infarct with hyperemia. The overall signal intensity change and slope is higher in the penumbra region suggesting hyperemia.



4



5

Fig. 4. Simple arithmetic subtraction showing increased signal in subacute infarct representing hyperemia.

Fig. 5. Same patient in Figure 4. Raw turbo-FLASH image shows hypodensity in the area of infarct.

umbra. No significant Δ S.I. and $(\Delta \text{ S.I.}/\Delta \text{ time})_{Max}$ were noted in the chronic strokes.

Discussion

Dynamic functional analysis of the cerebral circulation has been attempted by CT and digital subtraction angiography, analyzing the change in signal intensity in a region of the brain following a contrast agent bolus. However, the large volumes of iodinated contrast required and its attendant side effects, and the long interscan delay has limited the usefulness of this technique.

The subsecond scanning potential of ultra-fast gradient echo MR techniques with either positive (T1-weighted) or negative (T2* weighted) contrast enhancement using gadopentetate dimeglumine has the potential for correcting the shortcomings of iodinated contrast studies.

The theory behind the iodinated contrast and this turbo-FLASH technique is based on indicator dilution curve models (1, 2). Applying these techniques to a population of healthy individuals, we were able to observe the cerebral hemodynamics of the early biodistribution phase of a first-pass, blood pool of gadopentetate dimeglumine. Because of the nondiffusible properties of gadopentetate in an intact blood-brain barrier, and the relatively linear relation between the dose of contrast at 0.1 mmol/kg and the degree of T1 relaxation (3), the measured Δ S.I. correlated with the regional blood pool of contrast at the capillary level within the cerebral tissue.

From our initial experience we were able to reproduce observations made by others from CT (4, 5) and MR techniques (6, 7) regarding cerebral ischemia. In acute infarcts with mass effect and edema, we observed decreased signal and Δ S.I. in the region of stroke. The time to signal intensity peak was delayed, and the slope of the peak was markedly flattened compared to the contralateral, normal side due to compression of arteries and impaired delivery of contrast. In chronic infarcts there was no observable or else a flattened peak due to loss of capillary bed and nonviable cerebral tissue. In subacute infarcts there was a normal

time to signal intensity peak, but either a normal or decreased slope, or else an increased slope (Fig. 2). The higher than normal slope was also noted in the stroke penumbra (Fig. 3). However, the baseline signal was normal in the penumbra compared with a below normal baseline in the subacute strokes with a higher than normal slope. The increased slope may be attributed to luxury perfusion and may represent hyperemic changes. Subtraction images from the turbo-FLASH images (Fig. 4) were most helpful in identifying these regions of luxury perfusion that were not evident on either the nonsubtracted turbo-FLASH images or from the conventional T1- and T2-weighted spin-echo images (Fig. 5).

Based on our preliminary experience, we have found that turbo-FLASH MR contrast imaging has potential in the evaluation of cerebral ischemia. We are undertaking studies to determine the clinical usefulness of this technique with the following modifications—multi-slice imaging, even shorter scanning times, scanning with an external standard adjacent to the patient, and a longer scanning time (from 20 to 40 images). This will permit measurement of the jugular vein for venous concentrations, calculation of mean transit time and thus regional blood flow, conversion of signal intensity to contrast concentration, and observation of delayed peaks, although a second pass of contrast must be factored in.

Because rapid imaging occurs within the first minute following contrast injection, turbo-FLASH MR imaging is able to look at the hemodynamic portion of the contrast delivery with the contrast still contained within the arteries before extravasation through the damaged blood-brain barrier can occur, whereas previous studies with CT techniques could only evaluate the contrast extravasation portion of the indicator dilution curves.

References

1. Meier P, Zierler KL. On the theory of the indicator-dilution method for measurement of blood flow and volume. *J Applied Physiol* 1954;6:731–745
2. Zierler KL. Theoretical basis of indicator-dilution methods for measuring flow and volume. *Circ Res* 1962;10:393–407
3. Strich G, Hagan PL, Gerber KH, Slutsky RA. Tissue distribution and magnetic resonance spin lattice relaxation effects of gadolinium-DTPA. *Radiology* 1985;154:723–726
4. Traupe H, Heiss WE, Hoeffken W, Zülch KJ. Hyperperfusion and enhancement in dynamic computed tomography of ischemic stroke patients. *Journal of Computerized Axial Tomography* 1979;3:627–632
5. Drayer BP, Heinz ER, Duhovny M, Wolfson SK Jr, Gur D. Patterns of brain perfusion: dynamic computed tomography using intravenous contrast enhancement. *Journal of Computerized Axial Tomography* 1979;3:633–640
6. Finelli DA, Kiefer B, Deimling M, et al. Dynamic contrast-enhanced perfusion studies of the brain with snapshot FLASH (abstr). *Radiology* 1989;173(P):42
7. Edelman RE, Mattle HP, Atkinson DJ, et al. Cerebral blood flow: assessment with dynamic contrast-enhanced T2*-weighted MR imaging at 1.5 T. *Radiology* 1990;176:211–220