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Detection of Acute Intracerebral Hemorrhage on MR Imaging: Ineffectiveness of Prolonged Interecho Interval Pulse Sequences

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MR imaging at 0.6 T was performed in 22 patients with acute (<7 days) intracranial hemorrhage to determine the efficacy of prolongation of the interecho interval, which has been demonstrated to enhance T2 shortening *in vitro*, as a method to improve the detection of hemorrhage in clinical imaging. The protocol included 750/33 (TR/TE), 2150/60,120 (short interecho interval of 60 msec), and 2150/120 (long interecho interval of 120 msec) sequences. Visual comparisons of the 2150/120 images obtained with the short and long interecho intervals demonstrated no difference in the degree of hypointensity in 21 of 22 cases. Quantitative comparisons demonstrated no statistically significant difference in the degree of maximal hypointensity, in the ease of detectability of hypointensity, or in the overall image contrast in 16 of 22 cases.

We conclude that prolongation of the interecho interval is not a clinically useful technique to improve the detection of acute hemorrhage.

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MR imaging has become an important technique in the evaluation of intracranial hemorrhage. A characteristic finding in acute hemorrhage is hypointensity relative to white matter on long repetition time (TR) sequences [1, 2]. In certain clinical circumstances hypointensity can be subtle, and various techniques have been developed to enhance the sensitivity of MR imaging in its detection [3, 4]. One strategy that in theory would be expected to increase the degree of hypointensity is prolongation of the interecho interval (IEI) [5]. In a multiecho sequence, the IEI is defined as the time between 180° pulses; in a single-echo sequence, the IEI is equivalent to the echo time (TE). For example, a 2150/120 (TR/TE) image can be obtained as the second echo of a 2150/60,120 sequence, which has an IEI of 60 msec. Alternatively, the same 2150/120 image can be obtained with a single echo, which has the same overall TE as the double-echo sequence, but a longer IEI of 120 msec. The IEI is distinctly different from the TE, which is the time between the center of the 90° pulse and the center of the spin-echo production.

A longer IEI enhances T2 shortening *in vitro* [5]. Direct extension of this finding to *in vivo* imaging leads to the prediction that the degree of hypointensity on long TR sequences should be more pronounced, and the visualization of hemorrhage facilitated, with the use of longer IEIs. This study was undertaken to evaluate the efficacy of prolongation of the IEI as a technique to enhance the detection and delineation of acute hemorrhage in clinical MR imaging.

Subjects and Methods

The study population consisted of 22 patients with acute intracranial hemorrhage, 16-82 years old, who presented in the 1-year time period between September 1988 and September 1989. All patients were imaged within 1 week of ictus: three within 24 hr, seven between 1 and 3 days, and 12 between 3 and 7 days. The hematomas resulted from trauma in seven cases; from infarct in five; from tumor in four; and from amyloid angiopathy, hypertension,

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and unknown causes in two cases each. Clinical histories and radiographic findings were the bases for these determinations. Seventeen patients had intraaxial hemorrhage, three had extraaxial hemorrhage, and two had hemorrhage in both compartments.

Spin-echo MR imaging was performed on a 0.6-T Technicare unit using short TR/short TE, 750/33, and long TR/double-echo TE, 2150/60,120 (IEI = 60 msec), sequences. Immediately following these sequences, a long TR/single-echo TE sequence, 2150/120 (IEI = 120 msec), was obtained in all patients. The 2150/120 images obtained with these two techniques were imaged at the same window width and level in each patient. The MR scans were acquired with a 7.5-mm slice thickness, a 2.5-mm interslice gap, a 256×128 matrix size, a 25-cm field of view, and two excitations.

The primary purpose of this experiment was to determine if alterations in IEI produced *visual* changes in hematoma intensity. Hence, the 2150/120 images at the same anatomic level in each respective patient obtained with the short (60 msec) and long (120 msec) IEIs were visually compared by two of the authors for differences in hematoma intensity. Special attention was given to whether the hemorrhagic nature of those lesions in which hypointensity was subtle became more obvious with prolongation of the IEI.

Objective quantitative evaluations were also performed since it was noted that there were visual differences in intensity, and therefore in overall image contrast, of normal intracranial structures between the short and long IEI images. Specifically, the MR signal intensity and standard deviation were measured from several regions of interest (ROIs) on the pair of corresponding 2150/120 images in which the epicenter of the hematoma was depicted. In general, two intensity measurements in each hematoma were acquired, one from the most hypointense ("dark") region and one from the hyperintense periphery. ROI measurements were also obtained from three internal standards, the cortical gray matter, the periventricular white matter, and the CSF in the occipital horn of the lateral ventricle. Intensity measurements from the internal standards were not acquired when these structures were not present on the 2150/120 slice pair containing the epicenter of each hematoma. In addition, intensity values were acquired from each of the four quadrants composing the background in each image pair. In order to ensure that the intensity measurements were from the same ROI in each set of short and long IEI scans, both images were displayed simultaneously on the CRT and a cursor was placed in the same position on the two images. The cursor contained from five to 21 pixels, depending on the area of interest being measured; the number of pixels in the cursor remained constant in any given set of 2150/120 images.

With these intensity measurements, several comparative ratios were calculated, all of which were corrected for background. Dark/dark and periphery/periphery ratios of these regions on the short compared with the long IEI images were obtained. The ratio of the periphery of each hematoma compared with its dark portion was calculated in order to assess whether significant intrahematoma contrast differences that could affect the conspicuity of the hematoma existed between the short and long IEI images. A ratio of each of the two regions in each hematoma (dark and periphery) compared with CSF in the occipital horn of the lateral ventricle was acquired in order to quantify the intrinsic contrast differences between the short and long IEI images. CSF was the preferred internal standard because it was hyperintense compared with any region in any hematoma, resulting in a hematoma/CSF intensity ratio that was always between zero and one. The occipital horn was chosen as the locus for CSF intensity measurements because of its relatively homogeneous character and minimal amount of motion compared with the CSF in the other parts of the ventricular system, thus avoiding partial-volume and pulsation effects as causes of spurious intensity measurements. Lastly, gray/white and gray/CSF intensity ratios from comparable

short and long IEI images were also obtained as additional measurements of intrinsic contrast differences between these two techniques. From these ratios, the percent difference in image contrast was calculated.

Results

In 21 patients, there was no visible difference in hematoma intensity between corresponding areas on the 2150/120 images obtained with the short and long IEIs (Fig. 1). Regions in each hematoma that were hypointense on the long IEI images were equally hypointense on the short IEI images. Moreover, regions that demonstrated subtle hypointensity at the short IEI did not demonstrate more pronounced or more extensive hypointensity at the long IEI. Finally, areas that were hyperintense on the short IEI images were equally hyperintense on the long IEI images. These findings were observed irrespective of the degree of homogeneity or heterogeneity in appearance of each hematoma. In one patient, slightly greater hypointensity was seen by both observers on the long compared with the short IEI images (Fig. 2), though differences in slice position due to patient motion during the study may have accounted for this finding.

Quantitative measurements of MR signal intensity and contrast ratios were obtained from several areas in 16 of 22 patients. These measurements were corrected for background, which on average measured 35.4 ± 1.2 , which was statistically the same to within 2.5 SD for both the short and long IEI images. Six studies did not lend themselves to quantitative measurements because of image degradation due to motion artifacts, though these studies did undergo visual comparisons. In these 16 individual sets of 2150/120 images, gray and white matter internal standards were present in all image pairs, whereas CSF in the occipital horn of the lateral ventricle was present in 12.

The average hematoma dark/dark ratio, or the average intensity of the most hypointense region on the short IEI image compared with the long IEI, was 0.91 ± 0.18 . Of the 16 cases that underwent quantitative comparisons (Fig. 3), the dark region was more hypointense on the long IEI images (ratio > 1) in six and the dark region was more hypointense on the short IEI images (ratio < 1) in 10. Propagation of statistical errors for image contrast, calculated as the ratio of MR signal intensity normalized to the MR signal from either the CSF in the occipital horn or the gray matter, yielded a percent fractional error of $5.1 \pm 2.4\%$.

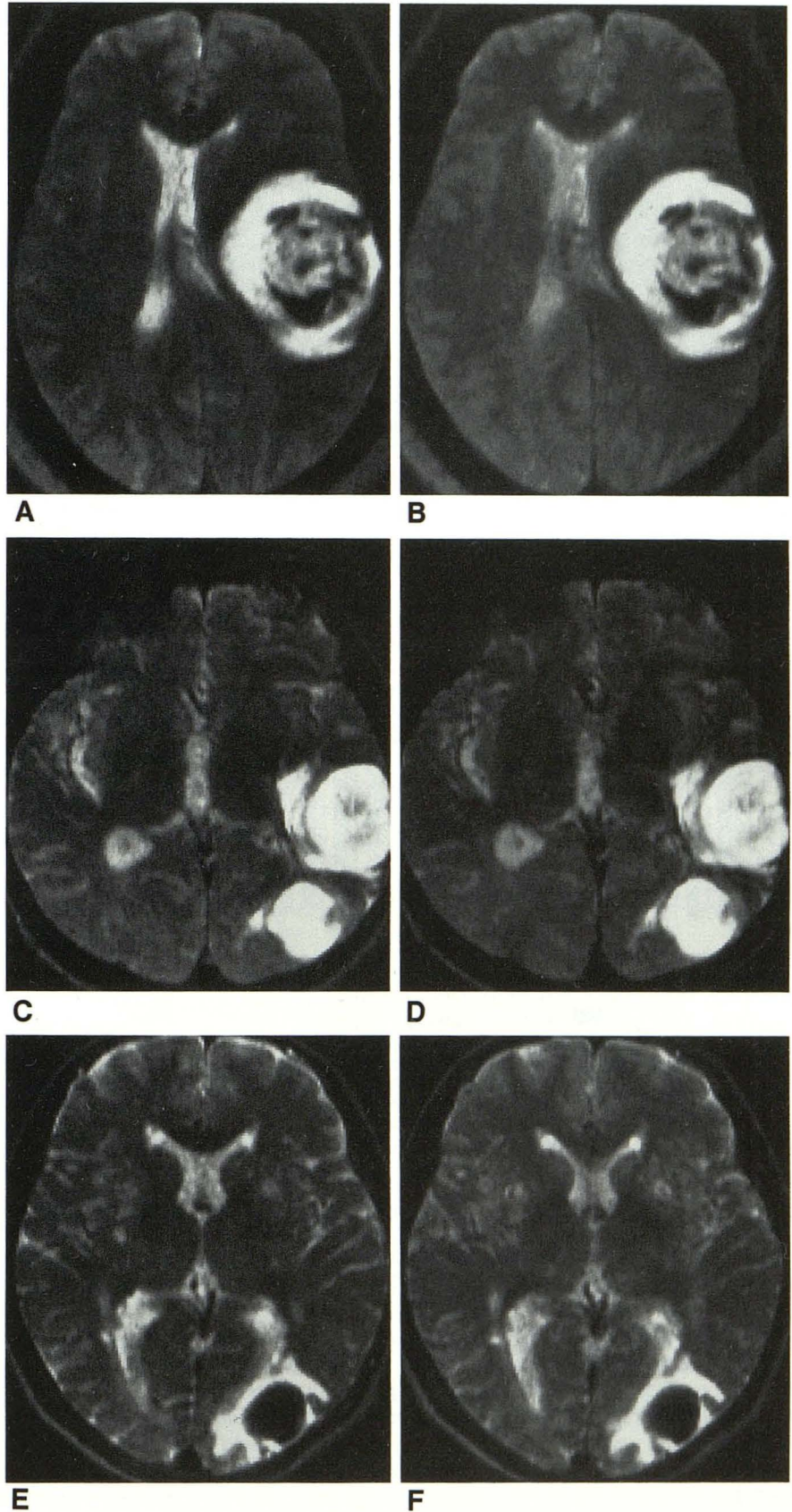
The long IEI resulted in a 14% average increase in absolute MR signal intensity in the periphery of the hematomas, that is, this region was on average 0.86 ± 0.11 as hyperintense on the short as on the long IEI images (Fig. 3). However, these intrahematoma differences in peripheral hyperintensity and central hypointensity compensated each other, in that the average change in contrast of the periphery compared with the dark region between the two IEIs was not statistically significant (3.12 and 3.28 for the short and long IEIs, respectively) (Table 1 and Fig. 4).

The average dark/CSF, periphery/CSF, gray/white, and gray/CSF contrast ratios indicate that the average difference

Fig. 1.—2150/120 images show no effect of prolongation of interecho interval (IEI) on intensity of acute hematoma.

A, C, and E, Short IEI images. Hemorrhage resulted from tumor in A, amyloid angiopathy in C, and hypertension in E.

B, D, and F, Long IEI images corresponding to A, C, and E, respectively. Prolongation of IEI fails to increase conspicuity or degree of hypointensity.



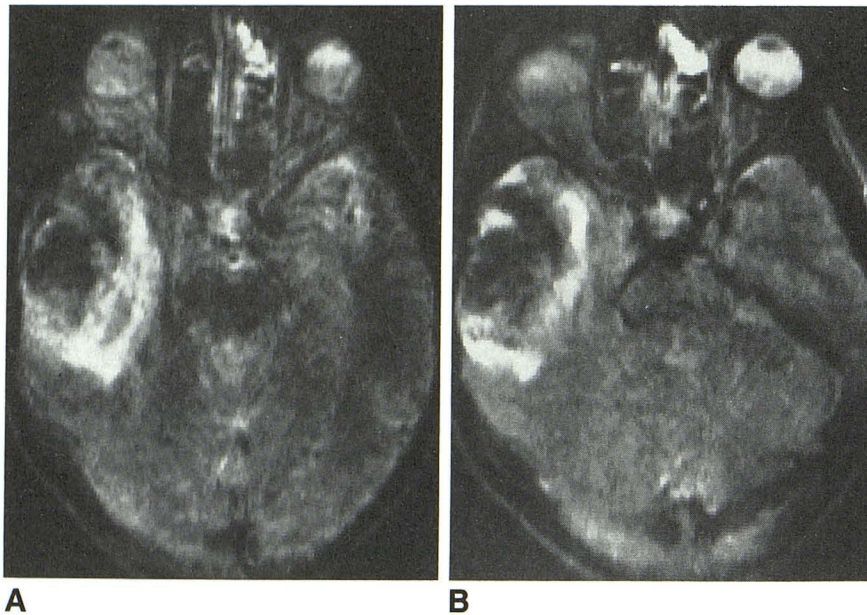


Fig. 2.—A and B, 2150/120 images of intratumoral hemorrhage obtained with short (A) and long (B) interecho intervals. The more apparent hypointensity in B compared with A may be due in part to differences in slice position from patient motion and partial-volume effects.

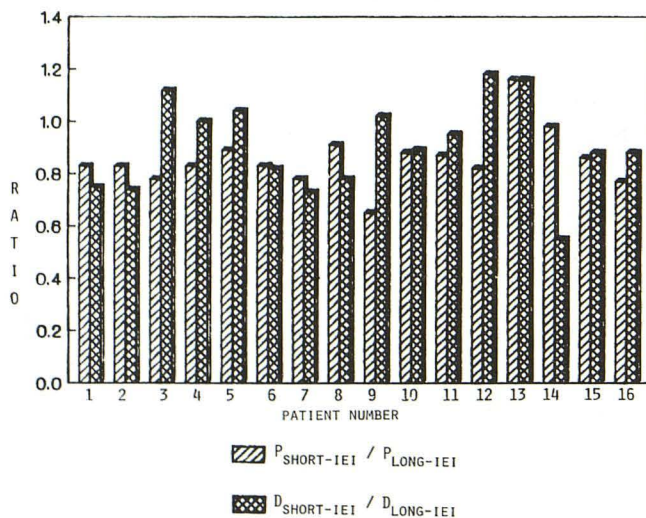


Fig. 3.—Interhematoma intensity ratios of corresponding periphery (P) and dark (D) regions in 16 short and long interecho-interval (IEI) image sets. A ratio of >1 indicates that the region of interest (ROI) is more hypointense on the long IEI image; a ratio of <1 indicates that the ROI is more hypointense on the short IEI image.

in image contrast between the short and long IEI images were all within the expected statistical error based on the standard deviations of the measured ROIs (Table 1). In addition, the average percent difference in contrast between the short and long IEI images for the 16 individual studies was not statistically significant. Thus, the ease of detectability of hypointensity (periphery/dark ratio), the relative degree of hematoma hypointensity (dark/dark ratio), and the overall image contrast (gray/white and gray/CSF ratios) on the short compared with the long IEI images were statistically the same to within 1.5 SD.

TABLE 1: Average Intensity Ratios and Standard Deviations of Short and Long Interecho-Interval (IEI) Images

Region	No. of Image Sets	Short IEI	Long IEI
Periphery/dark	16	3.12 ± 2.40	3.28 ± 2.50
Dark/CSF	12	0.61 ± 0.32	0.62 ± 0.33
Periphery/CSF	12	1.41 ± 0.23	1.38 ± 0.20
Gray/white	16	1.37 ± 0.15	1.49 ± 0.21
Gray/CSF	12	0.72 ± 0.09	0.72 ± 0.15

Discussion

The presence of hemorrhage in an intracranial lesion can be an important indicator of its underlying cause as well as a significant factor affecting patient treatment. Consequently, enhancement of the ability of a diagnostic technique to reliably detect or exclude hemorrhage is a clear-cut goal of neuroimaging. Extensive investigations of the MR appearance of acute intracranial hemorrhage have revealed several characteristic intensity patterns, one of which is the development of hypointensity on long TR images [1, 2]. This finding is seen prior to the development of hyperintensity on short TR images, and therefore is an early marker of the hemorrhagic nature of a lesion.

The routine development of hypointensity on long TR images in hemorrhage has been attributed to intravoxel dephasing by water protons diffusing through regions of microscopic field inhomogeneities [6, 7]. These local field variations, or susceptibility effects, are produced by the application of an external magnetic field to regions in which deoxyhemoglobin and methemoglobin are contained within intact RBCs. In vitro MR spectroscopy has demonstrated that prolongation of the IEI from 2 to 64 msec enhances T2 shortening [5]. This phenomenon has been attributed to the greater time during which the water protons can diffuse through local field inho-

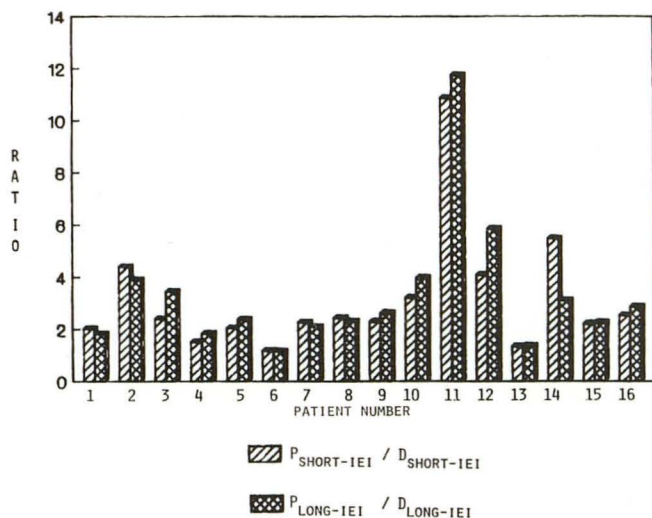


Fig. 4.—Intrahematoma intensity ratios of periphery (P) compared with dark (D) regions in 16 short and long interecho-interval (IEI) image sets. The P/D ratio is a measure of image contrast and hematoma conspicuity.

mogeneities, resulting in a greater loss of transverse phase coherence. Since the T2 relaxation time reflects the rate of loss of transverse phase coherence, the net effect of prolongation of the IEI in vitro is enhancement of T2 proton relaxation and more pronounced hypointensity on long TR images.

The logical extension of this in vitro data to in vivo imaging leads to the prediction that prolongation of the IEI should be useful when enhanced T2 shortening is desirable, such as in hyperacute (<24 hr) hemorrhage at all field strengths and in acute (<7 days) hemorrhage at intermediate (0.2–0.6 T) and low (<0.2 T) field strengths. This maneuver should increase the conspicuity of hypointensity on long TR sequences and thereby facilitate the detection of hemorrhage.

The qualitative and quantitative data from this clinical study do not support this prediction. In 21 of 22 cases, there was no visually detectable difference in the degree of hematoma hypointensity between the short and long IEI images. In addition, in 16 of 22 cases, there was no statistically significant difference in the ease of detectability of hypointensity, in the relative degree of hematoma hypointensity, or in the overall image contrast between the short and long IEI images.

Further evidence of the inability of prolongation of the IEI to increase the conspicuity of acute blood in vivo comes from an animal model of hemorrhage [8]. In these experimentally created hematomas, variations in the IEI from 25 to 100 msec did not result in any apparent effect on hematoma intensity at either 0.6 or 1.5 T.

Several explanations can be offered to account for the discrepancy between the in vitro MR spectroscopic data and

our clinical findings. The correlation time for diffusion of water protons across the erythrocyte membrane, which is a measure of the ease of diffusion, has been calculated by Gomori et al. [5] to be 10 msec and by Thulborn et al. [9] to be 0.6 msec. These in vitro measurements indicate rapid motion and fast diffusion of water protons across the RBC membrane. Both of the reported correlation times are significantly shorter than the IEIs routinely used in clinical practice. Therefore, it is likely that the effects of diffusion on T2 proton relaxation enhancement, and hence on image hypointensity, are maximal prior to the shortest IEIs used in clinical imaging, and further prolongation of the IEI would not be expected to enhance T2 shortening. Moreover, recent in vitro work [10, 11] has implicated other processes in addition to proton relaxation enhancement from diffusion and heterogeneous magnetic susceptibility contributing to T2 shortening in acute hematomas in vitro. However, further work needs to be done to define the role of these mechanisms in vivo.

In summary, prolongation of the IEI is not a useful technique to improve the detection or delineation of acute intracranial hemorrhage in clinical MR imaging.

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