Multiparametric MRI Tissue Characterization in Clinical Stroke With Correlation to Clinical Outcome

Part 2

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Background and Purpose—Multiparametric MRI generates different zones within the lesion that may reflect heterogeneity of tissue damage in cerebral ischemia. This study presents the application of a novel model of tissue characterization based on an angular separation between tissues obtained with the use of an objective (unsupervised) computer segmentation algorithm implementing a modified version of the Iterative Self-Organizing Data Analysis Technique (ISODATA). We test the utility of this model to identify ischemic tissue in clinical stroke.

Methods—MR parameters diffusion-, T2-, and T1-weighted imaging (DWI, T2WI, and T1WI, respectively) were obtained from 10 patients at 3 time points (30 studies) after stroke: acute (≤12 hours), subacute (3 to 5 days), and chronic (3 months). The National Institutes of Health Stroke Scale (NIHSS) was measured, and volumes were obtained from the ISODATA, DWI, and T2WI maps on patients at each time point.

Results—The acute (≤12 hours) multiparametric ISODATA volume was significantly correlated with the acute (≤12 hours) DWI (r=0.96, P<0.05; n=10) and chronic (3 months) T2WI volume (r=0.69, P<0.05; n=10). The ISODATA-defined tissue regions exhibited MR indices consistent with ischemic and/or infarcted tissue at each time point. The acute (≤12 hours) multiparametric ISODATA volumes were significantly correlated (r=0.82, P<0.009; n=10) with the final NIHSS score. In comparison, the acute (≤12 hours) DWI volumes were less correlated (r=0.77, P<0.05; n=10) and T2WI volume (≤12h) exhibited a marginal correlation (r=0.66, P<0.05; n=10) with the final NIHSS score.

Conclusions—The integrated ISODATA approach to tissue segmentation and classification discriminated abnormal from normal tissue at each time point. The ISODATA volume was significantly correlated with the current MR standards used in the clinical setting and the 3-month clinical status of the patient. (Stroke. 2001;32:950-957.)

Key Words: cerebral ischemia, focal ■ diagnostic imaging ■ diffusion imaging ■ magnetic resonance imaging ■ signal processing, computer assisted, ISODATA ■ stroke, acute ■ stroke classification

Changes in the state of tissue water reflect physiological alterations that can be visualized by MRI. For example, diffusion-weighted imaging (DWI) generates images based on a quantitative assessment of the random brownian movement of water protons (diffusion) within tissues.1–6 Cytotoxic edema, secondary to energy depletion, and the loss of ionic homeostasis at the cellular level are believed to be major contributing factors to the changes seen on DWI during acute stroke.2–7 Clinical studies have shown that acute lesion volumes visualized on DWI scans in stroke patients have a strong correlation with final infarct volumes and clinical neurological outcomes.8 T2- and T1-weighted imaging (T2WI and T1WI, respectively) are part of the standard protocol for stroke imaging. A typical T2WI sequence obtained after stroke includes a proton density–weighted image and a T2WI. At later times after stroke, T2WI is a marker of vasogenic edema and is considered the diagnostic “gold standard” in the clinical setting for identification of cerebral infarction.9–12 Similarly, T1WI reflects vasogenic edema within the ischemic brain.13–15 In clinical practice, DWI, T2WI, and T1WI are often acquired during acute stroke, and integration of these MRI data may provide complementary information about the
status of the tissue. Therefore, the introduction of an objective computerized segmentation of the MRI would assist in the identification and classification of brain tissue. Specifically, in this study we present unsupervised segmentation of stroke using the Iterative Self-Organizing Data Analysis Technique (ISODATA) method of postprocessing analysis.16–18 Objective computerized segmentation of multiparametric MRI has not been used to identify and classify ischemic tissue damage over time in the clinical setting after stroke.

This study presents the application of a novel model of tissue characterization using the angular separation of tissue signature vectors from the segmentation of multiparametric MRI.17,19 This model was validated in the experimental setting of cerebral ischemia.17,19 We test the utility of this approach to identify ischemic tissue in clinical stroke. To this end, segmented volumes of ischemic tissue damage were compared with quantitative volumes of the DWI, apparent diffusion coefficient of water (ADC), and T2WI maps from acute (≤12 hours) to chronic (3 months) times after stroke and compared with the neurological outcome of the patient as defined by the National Institutes of Health Stroke Scale (NIHSS) at each time point.

**Subjects and Methods**

**Clinical Subjects**

All patients (n=10; 30 total studies) underwent a standard stroke MRI at 3 different time points: acute (0 to 12 hours), subacute (72 to 168 hours), and chronic (3 months). The acute stroke protocol...
consists of sagittal T1, axial multi-spin-echo T2WI, pregadolinium and postgadolinium T1WI, DWI, and circle of Willis 3-dimensional phase contrast MR angiography. All MRIs were performed on a 1.5-T General Electric Signa MRI unit. This protocol takes approximately 35 minutes to complete. The MRI parameters were as follows: T1 sagittal image (repetition time/echo time [TR/TE]=600/14 ms), axial T2WI (TR/TE=2500/30, 60, 90, 120 ms; number of excitations [NEX]=1), and T1WI 3-dimensional inversion recovery (TR/TE/inversion time=450/250/500 ms; NEX=2), with field of view=23×23 cm; matrix=256×192; and slice thickness=6 mm. Axial DWI (TR/TE=10 000/101 ms; b value=1000, 600, 300, and 0 s/mm²; field of view=46×23; matrix=128×128; slice thickness=6 mm/no slice gap; NEX=1; on 3 orthogonal axes) was obtained. Throughout the acquisition of the images, the patient was clinically monitored with the neurology service in attendance. A neuroradiologist (S.P.) blinded to the ISODATA segmentation interpreted all MRI examinations. In addition, the clinical status of each patient was estimated by the NIHSS at each time point (P.M., S.S.). All studies were approved by the Human Institutional Review Committee at our facility. Signed informed consent forms were obtained for each study from patients or appropriate family member or legal guardian.

**MR Image Preprocessing and Analysis**

MR image analysis was performed with a SUN UltraSPARC2 workstation (Sun Microsystems Inc). MRI data were processed with Eigentool image analysis software. Eigentool has a comprehensive set of functions for displaying, restoring, enhancing, and analyzing images. The complete toolbox consists of image analysis algorithms and advanced functions such as morphological image operators, registration, and warping methods.

After reconstruction, preprocessing was performed on the MR data. Preprocessing consisted of subimaging and noise reduction. Subimaging of the intracranial volume was done with the use of thresholding and morphological operations to segment the image background, skull, and scalp from brain tissue. Finally, the images were restored with the use of a nonlinear restoration filter that reduces white noise while preserving edges and partial volume effects. Maps of the trace ADC and T2 were created for each time point using a least-squares fit from the slope of the signal intensity on a pixel-by-pixel basis.

**Coregistration and Warping**

Coregistration and warping of the MR data were accomplished by a previously reported 2-step methodology. This method consists of a modified head and hat surface-based registration algorithm that registers the temporal MRI to a reference MRI (acute T2WI), followed by nonlinear thin plate spline warping by deformable contours to compensate for distortions between the T2WI and DWI. In this study, for registration and warping, T2 was used as the head data set with the other temporal MRI as the hat data set. After coregistration, warping was performed on the DWI to exactly match the reference T2WI.

**MRI Data Analysis**

The ISODATA Technique

The ISODATA technique is an unsupervised segmentation method related to the K-means algorithm with additional splitting and merging steps that allow for the adjustment of cluster centers and their number. The ability to adjust the number of clusters is the main advantage of the ISODATA method because it requires no initial training or a priori knowledge of the exact number of clusters (tissue classes) before segmentation. The modified ISODATA algorithm consists of 4 main steps that are summarized as follows: (1) Clustering parameters are put into the program. (2) MR data are partitioned into random clusters. (3) The pixels are grouped into clusters the lie closest to each other, as defined by the intra-Euclidean distance (the clusters and cluster centers are vectors). Inter-Euclidean distances are calculated between pixel vectors and cluster centers. (4) Splitting and merging of the clusters are performed on the basis of intra- and inter-Euclidean distances computed. Steps 3 and 4 are repeated until the algorithm converges or reaches the maximum number of iterations. For a complete description, refer to the companion article (part 1) in this issue of *Stroke*.

The MRI data set used in the ISODATA model consists of 2 T2WI (TR=30, 90 ms), 1 T1WI, and 2 DWI (b=600, 1000 s/mm²). These MR images were selected because each parameter provides different contrast between tissue types during the evolution of stroke, which leads to better separation of the tissue classes and increases the likelihood of tissue class discrimination. The selected MR data set allows correlation with animal experiments conducted in our laboratory. By integrating these parameters into a 5-dimensional feature space, the volume of tissue damage reaches the maximum number of iterations. A representative MR data set used in the ISODATA model is shown in Figure 1. Typical signature vectors used on the MR data set are demonstrated in Figure 2.

**Volume and Quantitative MRI Measurements**

Lesion volumes from each patient were obtained from a DWI (b=1000 s/mm²) and a T2 map. The volume measurements were accomplished by placing a region of interest (ROI) within the area of signal intensity abnormality on the DWI and T2 map. Statistics (mean and SD) were obtained from the gray level values within the ROI. The DWI and T2 images were thresholded at the 95% CI to determine the area of signal abnormality. The parametric outline of...
increased signal intensity from the DWI was confirmed by a neuroradiologist (S.P.) blinded to the ISODATA segmentation. These DWI volumes were overlaid onto the ADC map to obtain quantitative values. Further editing was done to remove any sulci or cerebrospinal fluid present underneath the ROI that would have increased the ADC value. Volume measurements similar to those described above were performed on the T2 map. Volume analysis was performed on the multiparametric ISODATA segmented ischemic regions using the regions of abnormal and normal tissue defined by angular separation between the different tissue types. Total lesion volumes were measured by summing the number of pixels from each region in each slice defined by the ISODATA angle model within the ischemic lesion and multiplying by the slice thickness.

Comparisons between the ISODATA, acute (≤12 hours) DWI, and chronic (3 months) T2 map volumes were performed. Correlation between the ISODATA volume and clinical outcome, as defined by the NIHSS, was obtained. The NIHSS evaluation was completed (P.M., S.S.) before the ISODATA segmentation by investigators blinded to the ISODATA segmentation. Intrareliability and interreliability measurements with the use of ISODATA have been previously reported. In addition, the defined ISODATA ROIs of ischemic regions used for volume measurements were overlaid onto the ADC and T2 maps to obtain quantitative measurements. Similar ROI analysis was performed for normal tissue by reflecting the ROI around the vertical axis. The MR estimates of ADC and T2 from the ischemic lesion were normalized to the homologous, noninvolved contralateral hemisphere and expressed as ratios of ADC (ADCr) and T2 (T2r), respectively.

**Statistical Analysis**

Paired t tests were used to determine statistical significance between the ISODATA volumes and the DWI and T2WI volumes. Linear regression analysis was performed to test the correlation between the volume measurements of ISODATA, DWI, and T2 maps. All parametric map values are presented as mean±SD. Statistical significance was assigned for P<0.05.

**Results**

The multiparametric ISODATA identified different regions of tissue damage at each time point after stroke. Figures 3 and 4 demonstrate the multiparametric ISODATA segmentation of ischemic tissue damage and corresponding DWI (b=1000 s/mm²) and ADC maps, along with the T2 maps at different times after stroke in representative patients. In Figure 3, a 63-year-old woman presented acutely (≤12 hours) with a right hemispheric infarct extending from the frontal to the occipital lobe, and she had no therapeutic intervention. The multiparametric ISODATA segmented several different regions of ischemic tissue damage and distinguished an old infarction on the left frontal lobe near the inferior frontal gyrus. These different regions of tissue damage were not visualized on the DWI, ADC, and T2 maps. However, the old infarct was clearly visualized on the ADC and T2 maps as a hyperintense signal in the inferior frontal gyrus region. Within 3 to 5 days, the ischemic region of tissue damage grew to encompass most of the right hemisphere, including the basal ganglia. The multiparametric ISODATA segmentation showed recruitment of new areas of ischemic damage as distinct tissue classes. These new areas of infarction were seen on the MR images; however, the different characteristic tissue classes were not clearly demonstrated. At the chronic time point (3 months), the ischemic tissue damage was noted on all the MR and ISODATA images. The multiparametric ISODATA approach clearly segmented the lesion into different components, which were not obvious from the DWI, ADC, and T2 maps.

In all patients, the average angular separation of abnormal and normal tissue was 9.0±3.0° (range, 4.2° to 12.5°) at the acute phase of stroke (≤12 hours after ictus). The angular separation between abnormal and normal tissue continued to increase to 13.2±2.4° (range, 9.6° to 17.8°) at subacute time points and to 13.1±2.9° (range, 10.7° to 19.5°) at chronic time points. The ISODATA segmentation demonstrated recruitment of new and different tissue classes within the volume of ischemic tissue damage, as shown in Figures 3 and 4 at all time points.

The patients’ demographic data, time to MRI, angular measurements, infarct volumes, clinical information, and NIHSS scores at each time point are summarized in Table 1. The ISODATA-segmented ischemic tissue volumes had significant correlation with the MRI-defined volumes at each time point. The acute (≤12 hours) multiparametric ISODATA volume exhibited excellent correlation (r=0.96, P<0.05; n=10) with the acute DWI volume. Moreover, the early (≤12 hours) ISODATA volume demonstrated excellent correlation (r=0.69, P<0.05; n=10) with the 3-month infarct volume defined by the T2 map. The chronic (3 months) ISODATA volume exhibited significant correlation with the 3-month volume defined by the T2 map (r=0.96, P<0.05; n=10).

MR indices of ADC and T2, are shown in Table 2. Acutely (≤12 hours), the average ADC, was decreased (0.73; P<0.05; n=10) in all patients, with a corresponding increased T2 (1.17; P<0.05; n=10). Within 3 to 5 days after stroke, the mean ADC, was decreased (0.72; P<0.05; n=10) in all patients; however, in 1 patient the ADC, was increased over unity (1.12). The average T2, values continued to increase (1.48; P<0.05; n=10). At 3 months, both the mean ADC, (1.84; P<0.05; n=10) and T2, (1.70; P<0.05; n=10) were elevated above normal. The temporal evolutions of ADCr and T2r, values from the ISODATA volumes were consistent with MR indices of ischemic tissue damage at each time point.

Table 3 summarizes comparisons between the ISODATA, DWI, and T2WI volumes with the NIHSS score at each time point. The acute (≤12 hours) multiparametric ISODATA volume had superior correlation (r=0.82, P<0.009; n=10) with the 3-month NIHSS score, outperforming both the acute (≤12 hours) DWI and T2 volumes at this time point. The acute (≤12 hours) DWI volume demonstrated good correlation (r=0.77, P<0.05; n=10); however, the acute (≤12 hours) T2 volume exhibited marginal correlation (r=0.66, P<0.05; n=10) with the 3-month NIHSS score.

**Discussion**

In this report, the primary finding was that the volume of ischemic tissue damage defined by the integrated ISODATA angle approach was highly correlated with the final clinical status of the patient at each time point. The ISODATA angle model–defined volumes of damaged tissue outperformed both the DWI- and T2WI-defined volumes at all time points in correlation with the patients’ functional outcome after stroke, supporting previous findings in experimental animal...
models of stroke.\textsuperscript{18} This integrated model of ischemic tissue damage may be useful in determining the volume of tissue damage in clinical stroke. This is the first study to use the integrated ISODATA model in a clinical setting over a temporal course of stroke and demonstrates that ISODATA may be useful in defining the volume of tissue damage, which is highly correlated with the initial and final clinical status of the patients. Moreover, this report demonstrates that computer-assisted unsupervised segmentation using ISODATA of multiparametric MRI can detect heterogeneous zones within ischemic lesions during the evolution of clinical stroke. These heterogeneous regions were not clearly identified on the DWI, ADC map, and/or T2 map. In addition, the ISODATA model can distinguish between white and gray matter and cerebrospinal fluid while segmenting partial volume effects as distinct classes in feature space.\textsuperscript{16}

The average angular separations between abnormal and normal tissue types were similar to the experimental results in a rat model of cerebral ischemia.\textsuperscript{19} In those reports, there was a clear tissue classification into normal and different gradations of abnormal tissue characteristics with the use of the angle model; however, the interpretation of tissue classifications in animals should be tempered with the knowledge that the progression of ischemic tissue damage varies over species. This initial clinical study demonstrates that the angular separation between abnormal and normal tissue is useful in defining the volume of tissue damage and that the volume of tissue damage is highly correlated with the initial (\(\leq 12\) hours) and final (3 months) clinical status of the patients.

The MR parameters used in this study were based on our experimental results in a model of cerebral ischemia.\textsuperscript{19} In these studies it was demonstrated that the combined MR data set consisting of T2WI, T1WI, and DWI used in the ISODATA segmentation was highly correlated with the histological status of the tissue. Since histological specimens are not routinely available in the clinical setting, we selected the functional outcome of the patient, as defined by the NIHSS score, to test the ISODATA model. The heterogeneous tissue regions segmented by the multiparametric ISODATA methodology exhibited the characteristics of evolving cerebral ischemia at each time point.\textsuperscript{3,5,6} Acutely (\(\leq 12\) hours), the average ADC, was decreased in all the patients studied, with a corresponding increased T2\(_r\). However, there were heterogeneous regions containing both increased and decreased ADC, throughout the ischemic volume, confirming previous findings.\textsuperscript{30} Moreover, between 3 and 5 days, 1 patient exhibited hypernormalized ADC, suggesting that progression of ischemic damage is highly variable and depends on several factors, such as location, duration, and mechanism of the ischemic event.\textsuperscript{31} At 3 months, both ADC, and T2, were elevated in the ISODATA-defined volumes. Nonetheless, the multiparametric ISODATA segmentation discriminated abnormal from normal tissue and detected their heterogeneous distribution and revealed that in human stroke, the concept of an infarcted core surrounded by potentially viable ischemic tissue may not be valid (Figures 3 and 4).

The multiparametric ISODATA overcomes several limitations of our previously reported tissue signature model,\textsuperscript{6,19,32,33} as clearly described in part 1 of this report.\textsuperscript{19} The integrated ISODATA provides an objective classification of the tissue clusters independent of time, with the defined volumes consisting of multiple tissue classes of ischemic tissue being significantly correlated with NIHSS score at each time point. Tong et al\textsuperscript{8} reported a correlation \((r=0.67, P=0.03)\) between acute DWI volumes and NIHSS scores at 24 hours in 10 patients who were imaged at hyperacute time points (\(<6.5\) hours). The present study found a similar result \((r=0.72, P<0.009)\) at 3 to 5 days. However, to the best of our knowledge, our report for the first time extends the correlation of clinical outcome determined by NIHSS score with DWI, T2WI, and the integrated ISODATA volumes to several time points after stroke. The acute (\(\leq 12\) hours) multiparametric ISODATA volume had excellent correlation \((r=0.82, P<0.009; n=10)\) with the final 3-month NIHSS score, outperforming both the DWI and T2 volumes at each time point, which supported previous experimental results.\textsuperscript{18}

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age, y</th>
<th>Time to MRI</th>
<th>Clinical Localization</th>
<th>Mechanism</th>
<th>Angular Measurements,(^\circ)</th>
<th>Volumes, mm(^3), and NIHSS Scores at Acute ((\leq 12) h)</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ISODATA</td>
<td>DWI</td>
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<td>1</td>
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<td>72</td>
<td>9</td>
<td>L hemispheric</td>
<td>Undetermined</td>
<td>4.2</td>
<td>13.7</td>
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<tr>
<td>2</td>
<td>M</td>
<td>73</td>
<td>10</td>
<td>L hemispheric</td>
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<td>12.5</td>
<td>19.5</td>
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<td>3</td>
<td>F</td>
<td>51</td>
<td>9</td>
<td>R hemispheric</td>
<td>Undetermined</td>
<td>10.2</td>
<td>11.1</td>
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<tr>
<td>4</td>
<td>F</td>
<td>63</td>
<td>10</td>
<td>R hemispheric</td>
<td>Atherosclerotic</td>
<td>10.7</td>
<td>16.9</td>
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<tr>
<td>5</td>
<td>M</td>
<td>68</td>
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<td>L frontoparietal</td>
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<td>6</td>
<td>M</td>
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<td>9</td>
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<td>M</td>
<td>69</td>
<td>12</td>
<td>R subcortical</td>
<td>Cardioembolic</td>
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<td>8</td>
<td>F</td>
<td>69</td>
<td>8</td>
<td>L hemispheric</td>
<td>Atherosclerotic</td>
<td>5.9</td>
<td>12.1</td>
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<tr>
<td>9</td>
<td>M</td>
<td>62</td>
<td>5</td>
<td>R internal capsule</td>
<td>Lacunar</td>
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<tr>
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<td>R frontoparietotemporal</td>
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<td>10.9</td>
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<td>60.1</td>
<td>8.8</td>
<td></td>
<td></td>
<td>9.0</td>
<td>13.1</td>
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</table>

L indicates left; R, right.
This study demonstrates the advantages of using multiparametric MRI data to identify ischemic tissue and to correlate the lesion with the clinical status of the patient. Our data also support the concept that a single MRI parameter is not sufficient to characterize the status of the tissue. In addition, the power of the ISODATA methodology to discern different regions of tissue damage within the lesion area not visible on conventional MRI is illustrated. ISODATA has the advantage of utilizing all the discriminating information implicitly available within the data for segmentation.

Bernarding et al recently applied a supervised histogram-based methodology to multiparametric MR data to characterize ischemic tissue in 10 stroke patients at different time points ranging from 1 day to 4 months using DWI, ADC, T2WI, and T1WI in various combinations; longitudinal studies were not performed. Determination of normal tissue was accomplished interactively by drawing regions around surrounding clusters with the use of visualization and windowing techniques. They reported that at acute times after stroke, DWI should be included in the MR data set if T2WI or T1WI did not show any signal intensity changes. In addition, T1WI was needed to assist in the segmentation of normal tissue and, if hemorrhage was present in the brain, in the segmentation of ischemic tissue. This observation of the need to include DWI at early time points and T1WI for normal tissue differentiation is consistent with the findings of our studies. Taken together, their findings and our study demonstrate that multiparametric MRI and computer-assisted image processing provide a means for characterizing stroke in clinical applications.

Investigations are ongoing to incorporate other MRI parameters, such as perfusion-weighted imaging, into ISODATA. Recent reports have suggested that the combination of DWI and perfusion-weighted imaging may be useful in defining “tissue at risk.” The addition of perfusion-weighted imaging into the ISODATA model may increase the

TABLE 2. Ratios of MR Indices: ADC and T2 From Defined ISODATA Regions at Each Time Point

<table>
<thead>
<tr>
<th>Patient</th>
<th>Acute (≤12 h)</th>
<th>Subacute (72–168 h)</th>
<th>Chronic (3 mo)</th>
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<tr>
<td></td>
<td>ADCr</td>
<td>T2r</td>
<td>ADCr</td>
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<tr>
<td>1</td>
<td>0.73</td>
<td>1.10</td>
<td>0.58</td>
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<tr>
<td>2</td>
<td>0.59</td>
<td>1.31</td>
<td>0.58</td>
</tr>
<tr>
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<td>0.76</td>
<td>1.22</td>
<td>0.73</td>
</tr>
<tr>
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<td>0.73</td>
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<td>0.78</td>
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<td>5</td>
<td>0.65</td>
<td>1.00</td>
<td>0.81</td>
</tr>
<tr>
<td>6</td>
<td>0.68</td>
<td>1.32</td>
<td>0.76</td>
</tr>
<tr>
<td>7</td>
<td>0.72</td>
<td>1.14</td>
<td>0.58</td>
</tr>
<tr>
<td>8</td>
<td>0.76</td>
<td>1.09</td>
<td>0.53</td>
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<tr>
<td>9</td>
<td>0.94</td>
<td>1.10</td>
<td>0.73</td>
</tr>
<tr>
<td>10</td>
<td>0.76</td>
<td>1.22</td>
<td>1.12</td>
</tr>
<tr>
<td>Mean</td>
<td>0.73</td>
<td>1.17</td>
<td>0.72</td>
</tr>
</tbody>
</table>

ADCr indicates ADC ratio; T2r, T2 ratio.
segmentation of abnormal and normal tissue, including tissue at risk.

Conclusion
We have demonstrated that integration of multiparametric MRI data in the ISODATA model can segment ischemic tissue from normal tissue and that this segmentation is highly correlated with the clinical status of the patient.

Appendix

ISODATA Parameter Selection for Patients With Clinical Ischemia

For clinical stroke studies, the parameters are initialized for ISODATA as follows. We set the number of initial clusters (K) to K = 15 and the desired clusters to K = 5 (K = 5 was selected because there are at least 5 types of tissue clusters after the brain is subimaged: white matter, gray matter, cerebrospinal fluid, and at least 2 clusters for abnormal tissue.) Note that this number (K = 5 for desired clusters) will be automatically adjusted by ISODATA if the algorithm determines that the number of desired clusters is inadequate to represent the structure of the data. Other parameters are as follows: the minimum number of pixels in a cluster: \( \theta_0 = 5 \); the SD of white matter: \( \theta_1 \) (in human brain, white matter is the predominant tissue); the Euclidean distance between normal tissue in brain: \( \theta_2 \), ie, white and gray matter; the maximum number of cluster pairs to lump together in 1 iteration: \( \lambda = 1 \); the maximum number of iterations: \( i = 100 \); and the cluster center constant: \( \gamma = 0.25 \sigma_{\text{max}} \), where \( \sigma_{\text{max}} \) is the maximum element for each SD vector. See part 1 from ISODATA.

Table 3. Correlation Between Acute (≤12 h) ISODATA-, DWI-, and T2-Defined Infarct Volumes and NIHSS Score at Different Time Points After Stroke

<table>
<thead>
<tr>
<th>NIHSS Score</th>
<th>Acute (≤12 h)</th>
<th>Subacute (3–5 d)</th>
<th>Chronic (3 mo)</th>
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<tr>
<td>NIHSS score</td>
<td>13.5</td>
<td>11.2</td>
<td>9.5</td>
</tr>
<tr>
<td>Acute ISODATA volume</td>
<td>0.74†</td>
<td>0.79†</td>
<td>0.82†</td>
</tr>
<tr>
<td>Acute DWI volume</td>
<td>0.68*</td>
<td>0.72†</td>
<td>0.77†</td>
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<tr>
<td>Acute T2 map volume</td>
<td>0.48</td>
<td>0.55*</td>
<td>0.66*</td>
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</table>

*P<0.05; †P<0.009.

References


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