Multiparametric Imaging Analysis
Magnetic Resonance Spectroscopy

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DISCUSSION OF PROBLEM/CLINICAL PRESENTATION

MRS allows the qualitative and quantitative assessment of specific metabolites in the brain parenchyma or intracranial extra-axial spaces. MRS analysis of brain tumors can be performed using 1H (proton) MRS or, less frequently, with 31P (phosphorus) or 13C (carbon) MRS techniques.

For 1H MRS, the most common metabolites evaluated in routine clinical practice include N-acetyl aspartate (NAA), choline-containing compounds (Cho), creatine (Cr), myo-inositol (mI), lipid (Lip), and lactate (Lac) (Table 1). NAA is considered a neuronal metabolite and is decreased in processes with neuronal destruction or dysfunction.1 Cr is a metabolite related to the cellular energy metabolism and is considered relatively stable in different pathologic processes affecting the central nervous system and useful as a reference metabolite. Cho are related to membrane turnover and their elevation is indicative of a process that results in increased glial proliferation and membrane synthesis (as seen with cellular proliferative disorders).2,3 Lip peaks are often indicative of areas of necrosis and Lac peaks are directly originated from processes resulting in anaerobic metabolism. mI can be a marker of astrocytic metabolism and can be seen elevated in certain pathologic processes (see Table 1).

Common diagnostic problems encountered in routine clinical brain tumor imaging can be summarized as follows.

Is It Neoplastic or Not?

Non-neoplastic processes, including malformations of cortical development (such as focal...
cortical dysplasia) (Fig. 1), hamartomas, cerebral infarcts, infectious pathologies, inflammatory diseases (including demyelinating and vasculitic processes), and vascular pathologies (including capillary telangiectasias and cavernous malformations), can be difficult to differentiate from intra-axial or extra-axial intracranial neoplastic processes in conventional magnetic resonance (MR) studies (Table 2). MRS is a useful imaging tool to help in the differentiation and characterization of these pathologies. Neoplastic processes have metabolic byproducts related to their mitotic activity (Cho) and neuronal dysfunction (NAA) that can be detected by MRS and improve the accuracy of the clinical diagnosis (Fig. 2). The closer the MR spectrum is to a normal spectrum the more likely that the intracranial lesion is a benign process or developmental anomaly (see Fig. 1).

There is significant overlap in the Cho/NAA ratios, however, between non-neoplastic processes, such as tumefactive demyelinating lesions, infarcts, and infectious processes with neoplastic pathologies. Specific metabolic markers have been identified that may make this distinction more reliable (eg, glutamate/glutamine [Glx] for demyelination or 2-hydroxyglutarate [2HG] for isocitrate dehydrogenase [IDH] 1–mutant gliomas).

**Is the Lesion a Primary or a Secondary Brain Tumor?**

Several studies have shown the utility of MRS, particularly using the multivoxel technique for differentiation of glioblastoma from an intracerebral metastasis. The assessment of normal-appearing brain parenchyma in the immediate

**Table 1**

Metabolites evaluated with magnetic resonance spectroscopy in brain tumor imaging

<table>
<thead>
<tr>
<th>Metabolite</th>
<th>Peak Configuration</th>
<th>Resonance (ppm)</th>
<th>Best Echo Time for Detection</th>
<th>Clinical Associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAA</td>
<td>Singlet</td>
<td>2.0</td>
<td>Short or long TE</td>
<td>Neuronal marker (not seen in non-neural brain tumors)</td>
</tr>
<tr>
<td>Cho</td>
<td>Singlet</td>
<td>3.22</td>
<td>Short or long TE</td>
<td>Membrane turnover marker and cellular proliferation</td>
</tr>
<tr>
<td>Cr</td>
<td>Singlets</td>
<td>3.03 and 3.9</td>
<td>Short or long TE</td>
<td>Cellular energy byproduct. Lower in necrosis</td>
</tr>
<tr>
<td>ml</td>
<td>Multiplets</td>
<td>3.56</td>
<td>Short TE</td>
<td>Low-grade gliomas, gliomatosis</td>
</tr>
<tr>
<td>Lip</td>
<td>Broad peaks</td>
<td>0.9, 1.3</td>
<td>Short TE</td>
<td>Tuberculomas, PCNSL, radiation necrosis</td>
</tr>
<tr>
<td>Lac</td>
<td>Doublet</td>
<td>1.33</td>
<td>1.5T = inverted at 3T = 288 ms</td>
<td>Anaerobic metabolism marker Prominent if necrosis or hypoxia</td>
</tr>
<tr>
<td>Glx</td>
<td>Multiplets</td>
<td>2.1–2.4 ppm; 3.7 ppm</td>
<td>Short TE</td>
<td>Detected in GBM, astrocytomas and oligodendrogliomas</td>
</tr>
<tr>
<td>Taurine</td>
<td>Triplets</td>
<td>3.4</td>
<td>Short TE</td>
<td>Medulloblastomas</td>
</tr>
<tr>
<td>Alanine</td>
<td>Doublet</td>
<td>1.47</td>
<td>1.5 T = 144 ms</td>
<td>Meningiomas</td>
</tr>
<tr>
<td>Citrate</td>
<td>Multiplets</td>
<td>2.6</td>
<td>3T = 35 ms and inverts at 97 ms</td>
<td>Gliomas, particularly aggressive pediatric types</td>
</tr>
<tr>
<td>Gly</td>
<td>Singlet</td>
<td>3.55</td>
<td>3T = 160 ms67</td>
<td>Low-grade gliomas, central neurocytomas</td>
</tr>
<tr>
<td>2HG</td>
<td>Multiplets</td>
<td>1.85, 2.01, 2.28, and 4.05</td>
<td>Best seen with spectral editing techniques 3T = 97 ms68</td>
<td>IDH mutations</td>
</tr>
</tbody>
</table>

vicinity of the tumor has been shown reliable, with glioblastoma cases showing higher Cho/NAA ratios compared with metastatic lesions (Figs. 3 and 4).

**Is It a High-Grade or Low-Grade Tumor?**

Multiple studies have shown the value of MRS for predicting the histologic grade of glial tumors. Higher Cho/NAA ratios have been associated with higher World Health Organization (WHO) grades among glial tumors (see Figs. 2 and 3). The Cho/Cr ratio seems more accurate for the differentiation of high-grade versus low-grade gliomas (with sensitivity and specificity values of 80% and 76%, respectively).

**Where Is the Best Target for Surgery or Treatment?**

MRS can provide a general overview of the metabolic profile of a brain tumor and indicate areas of higher clinical aggressiveness or histologic grade (with higher Cho/Cr ratios). Multivoxel MRS can guide the neurosurgeon for sampling the anatomic sites with the highest histologic grade in low-grade tumors and increases the diagnostic accuracy of stereotactic and excisional biopsies (see Fig. 3). There is also growing evidence of the potential use of 3-D volumetric MRS imaging (MRSI) to guide radiation treatment. MRS can potentially identify areas with abnormal Cho/NAA ratios that can extend beyond the tumoral margins defined by conventional MR sequences (see Fig. 3).

**Radiation-Induced Changes or Recurrent High-Grade Tumor?**

MRS, particularly when using multivoxel techniques, has been shown useful for the differentiation of radiation necrosis and recurrent high-grade glioma and recommended as an evidence level II diagnostic modality for this differentiation. In general, areas with recurrent glioma have higher Cho/NAA ratios with variable Lip peaks. Pure radiation necrosis shows prominent Lip with relative decrease of the remaining metabolites compared

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*Fig. 1. Focal cortical dysplasia. A 13-year-old male patient presenting with nocturnal generalized seizures. Coronal (A) and axial (D) FLAIR images, axial T2-weighted images with corresponding intermediate (TE = 144 ms) TE spectra of a right parietal cortical dysplasia (B, C) and contralateral normal brain parenchyma (E, F). There is no significant difference in the metabolite ratios between the lesion compared with the ipsilateral surrounding and contralateral brain parenchyma. The yellow arrows point to the lesion.*
<table>
<thead>
<tr>
<th>Pathology</th>
<th>N-Acetyl Aspartate</th>
<th>Choline</th>
<th>Myo-inositol</th>
<th>Glutamate/ Glutamine</th>
<th>Glycine</th>
<th>Lactate</th>
<th>Lipid</th>
<th>Taurine</th>
<th>Alanine</th>
<th>Amino Acids</th>
<th>Succinate</th>
<th>2-Hydroxyglutarate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glioblastoma and anaplastic gliomas</td>
<td>--/---</td>
<td>++++/++</td>
<td>/</td>
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<td>/</td>
<td>/</td>
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<td>/</td>
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<td>/</td>
<td>Necrotic areas with high Lac and Lip</td>
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<tr>
<td>Diffuse astrocytoma</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Pilocytic astrocytoma</td>
<td>--</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Decreased Cr</td>
</tr>
<tr>
<td>Medulloblastoma</td>
<td>--</td>
<td>++/+++</td>
<td>+</td>
<td>+/++</td>
<td>+</td>
<td>+</td>
<td>+/++</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Groups 3 and 4 show high taurine, lower Lip, and high Cr. SHH tumors show high Cho and Lip, with minimal taurine. Also phosphocholine</td>
</tr>
<tr>
<td>Ependymoma</td>
<td>++/+++</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
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<td>Also glycerophosphocholine in vitro</td>
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<td>Intracranial metastases</td>
<td></td>
<td>++</td>
<td>++</td>
<td></td>
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<td>Relatively normal metabolites in the parenchyma surrounding the lesion Absent NAA within the lesion</td>
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<tr>
<td>PCNSL</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>+++</td>
<td>MRS obtained from non-necrotic lesions</td>
</tr>
<tr>
<td>Epidermoid cysts</td>
<td>--</td>
<td>++</td>
<td></td>
<td>+</td>
<td></td>
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<td></td>
<td>Aminoacids: valine, isoleucine and glycine</td>
</tr>
<tr>
<td>Meningioma</td>
<td>--/---</td>
<td>++</td>
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<td></td>
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<td>Alanine (up to 90% of cases)</td>
</tr>
<tr>
<td>Piogenic abscess</td>
<td>--/---</td>
<td>++/++</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Aminoacids, Lac, alanine, and acetate</td>
</tr>
<tr>
<td>Tuberculoma</td>
<td>--</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td>Higher Cho/Cr and ml/Cr in tumors. Also peak at 3.8 ppm, possibly guanidinoacetate</td>
</tr>
<tr>
<td>Tumefactive demyelinating lesion (TDL)</td>
<td>--/---</td>
<td>++/++</td>
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<td></td>
<td>Higher Cho/Cr and ml/Cr in tumors</td>
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<tr>
<td>Radiation necrosis</td>
<td></td>
<td>+</td>
<td>++</td>
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with the contralateral normal appearing brain parenchyma (Fig. 5). Relative ratios of intralesional Cho to contralateral Cr have also been shown to be a good marker to distinguish between radiation necrosis and recurrent high-grade tumor. This distinction is not always black and white, however, because many cases have concurrent areas of neoplastic involvement and postradiation changes. In addition, elevated Lip can also be seen in high-grade gliomas near areas of central necrosis.

**How to Identify Infiltrative (Recurrent) Tumor in Patients with Glioblastoma Treated with Antiangiogenic Treatment**

Patients receiving antiangiogenic medications, such as bevacizumab, show rapid decrease or resolution of the intratumoral abnormal enhancement and the conventional MR sequences are difficult to interpret during the follow-up imaging of these cases. MRS has the potential to identify abnormal metabolic patterns suggestive of tumoral infiltration in progressive areas of fluid-attenuated inversion recovery (FLAIR) hyperintensity in patients treated with bevacizumab, despite the lack of abnormal enhancement. A multicenter trial by the American College of Radiology Imaging Network demonstrated increased NAA/Cho and decreased Cho/Cr levels 8 weeks into the treatment with bevacizumab in patients with recurrent glioblastoma correlated with increased progression free survival rates.

**Can Treatment Response or Outcomes Be Predicted with Magnetic Resonance Spectroscopy?**

Multiple studies have highlighted the potential role of MRS to predict treatment responses and outcome after treatment. The identification of 2HG in glial tumors with IDH1 mutations and glutamate in pediatric medulloblastomas is associated with better overall survival rates. The decrease
of 2HG within glial tumors after treatment also correlate with functional status. MRS, specifically the Lac-to-NAA ratio, may also be helpful in the prediction of potential sites of glioblastoma recurrence. Increased Cho/NAA values 3 weeks after radiation treatment are associated with higher probability of early glioblastoma progression.

PHYSICS

The MR spectra are derived from characteristic radiofrequency (RF) signals produced by certain nuclei when stimulated by an oscillating RF pulse in a static magnetic field. The nuclei that have been used for MRS include hydrogen (1H) (high gyromagnetic ratio and abundance), phosphorus-31 (31P), and carbon-13 (13C), among others. These nuclei within different molecules produce different RF signatures depending on their electron densities, chemical structure, and magnetic properties of surrounding nuclei. The differences in the local magnetic field surrounding these individual nuclei during MRS are known as chemical shifts and are measured in parts per million (ppm) in relation to a reference compound (tetramethylsilane). Tetramethylsilane has a chemical shift of 0 ppm. The chemical shift of different compounds is plotted along the X axis in the MR spectra. A large water peak is typically obtained at 4.7 ppm on 1H-MRS that needs to be suppressed to appreciate smaller peaks related to other metabolites with a lower concentration in the brain parenchyma. MRS can be acquired using a single volume of interest using a single-voxel spectroscopy (SVS) or as 2-D or 3-D volumes of interest with multiple subdivisions known as multivoxel MRS, MRSI, or chemical
shift imaging (CSI). The CSI spectra can be displayed as an individual spectrum from a single subdivision, multiple spectra overlayed on conventional MR images (spectral maps), or concentration-dependent color-coded maps overlayed on conventional images (metabolic maps). Echo times (TEs) can have significant impact on the visualization of different metabolites in MRS, with short TE spectra displaying metabolites with short-echo and long-echo T2 relaxation times whereas long TE spectra only display metabolites with long T2 relaxation times (often with suppression of ml, Glx, and Lip peaks). Intermediate TEs (135–144 ms) are helpful for visualization of Lac that appears as an inverted doublet at 1.3 ppm.

The most common methods for spatial localization of MRS signals include the stimulated-echo acquisition mode (STEAM) and point-resolved spectroscopy (PRESS) techniques. Over the past decade, there has been increasing availability of faster MRS sequences using echo-planar techniques (echo-planar spectroscopic imaging) and spiral techniques.

**IMAGING PROTOCOLS**

MRS can be performed as a single-voxel acquisition or as a multivoxel acquisition. The choice of the best imaging protocol for a specific clinical case depends on the size of the lesion (large homogeneous lesions can be assessed with SVS but large heterogeneous lesions can be more accurately evaluated with 2-D or 3-D multivoxel MRS), anatomic location (pathologies located in the spinal cord, brainstem, and anterior temporal lobes near the skull are difficult to image with multivoxel MRS), and acquisition times (multivoxel MRS sequences usually take longer to acquire but recently developed spiral MRS sequences have markedly decreased the acquisition times). A reference spectrum is often acquired from the contralateral cerebral or cerebellar parenchyma when SVS techniques are used.

The choice of TEs depends on the specific clinical question and magnetic field strength. If MRS is needed as a metabolic screen for metabolic disorders or if short T2 relaxation metabolites are important for the clinical diagnosis (ml, Glx, Lip,
and so forth), a short TE spectrum should be acquired. If the MRS is performed for detection of Lac peaks, then an intermediate (at 1.5T) or long TE (at 3T) spectrum is ideal. Acquisition of MR spectra at 3T is usually preferred due to higher signal-to-noise ratios but susceptibility artifacts are more prominent at 3T making the acquisition of MRS near the skull base more challenging. MRS has been shown valuable in the noninvasive diagnosis and follow-up imaging of brain tumors, with a sensitivity of approximately 80% and a sensitivity of 78.5%. CSI seems more sensitive than SVS but the latter seems more specific. The appropriate choices of the MRSI protocol and TE values are important to obtain the best possible imaging data.27

**SPECIFIC PATHOLOGIES AND MAGNETIC RESONANCE SPECTROSCOPY FINDINGS**

**Glial Tumors**

Multiple studies have documented a good correlation of WHO grade and metabolite ratios (Cho/NAA, Cho/Cre, and Lip-Lac/Cre) (see Table 2). A variety of gliomas may display high levels of citrate (not present in normal brain), particularly in the pediatric population. A subgroup of glial tumors harboring IDH1 and carrying a better prognosis can now be identified using spectral-editing and 2-D correlation MRS techniques through the detection of an oncometabolite, called D-2HG (Fig. 6). Pilocytic astrocytomas have been shown to have decreased Cr levels and variable degrees of Cho/Cre ratios.36

**Intracranial Metastases**

There are significant differences in peritumoral metabolite ratios (lower Cho/Cre, lower Cho/NAA, and higher NAA/Cre) around intracerebral metastases compared with high-grade gliomas (see Figs. 3 and 4).

**Medulloblastomas**

There are 4 major molecular subgroups of medulloblastoma based on their gene expression profile.
and clinical characteristics: WNT, SHH, group 3, and group 4. MRS is becoming a promising noninvasive tool for the differentiation and identification of these subgroups, with metabolic profiles markedly different between groups 3 and 4 (with high taurine, lower Lip, and high Cr) (Fig. 7) and SHH tumors (high Cho and Lip and minimal taurine). The presence of glutamate has been associated with increased survival rates. A phosphocholine peak (3.208 ppm) has also been reported as another discriminatory marker for medulloblastomas.

Fig. 6. IDH1 mutant glioma with 2HG metabolic imaging. Axial (A), coronal (B), and sagittal (C) metabolic maps of 2HG concentration in a low-grade glioma involving the left posterior frontal lobe. An individual spectral edited spectrum is also shown illustrating the position of the 2HG peak in relation to other metabolites (D). (Courtesy of Dr O. Andronesi, Charlestown, MA.)

Fig. 7. Medulloblastoma. A 5-year-old boy presenting with nausea, vomiting, and diplopia. MR imaging demonstrates a large heterogeneously enhancing mass. Pathology was consistent with a medulloblastoma. Axial T1 postcontrast (A) and axial T2-weighted (B) (with MRS voxel) (1) and single-voxel MRS (TE = 144 ms) images. MRS shows a prominent Cho peak and almost complete absence of NAA. The presence of taurine (at 3.4 ppm) is difficult to determine without spectral editing techniques.
Atypical Theratoid Rhabdoid Tumors

Atypical theratoid rhabdoid tumors are characterized by prominent Lac/Lip, increased Cho, minimal NAA.

Ependymomas

Relatively high ml and glycerophosphocholine (approximately 3.233 ppm in vitro) have been described within these tumors.

Meningiomas

The extra-axial tumors, meningiomas, demonstrate high Cho peaks and often alanine peaks. NAA is not seen or minimally detected. There are no reliable MRS findings that can be used to differentiate typical from atypical or malignant meningiomas.

Intracranial Hemangiopericytomas

Intracranial hemangiopericytomas typically show increased Cho, prominent Lip/Lac peaks, decreased Cr, and marked decrease of NAA as well as increased ml and Glx peaks.

Central Neurocytoma

Variable glycine, increased Glx, marked elevation of Cho, variable NAA, alanine/Lac.

Primary Central Nervous System Lymphoma

Lip and Lac peaks from homogeneously enhancing components are useful for differentiation between primary central nervous system lymphoma (PCNSL) and glioblastoma or metastatic lesions (Fig. 9).

PEARLS AND PITFALLS

Pearls

- Routine acquisition of multivoxel MRS using a short TE addresses most of the cases of brain tumors. Alternatively, single-voxel technique could be used if the multivoxel acquisitions are too long or not available. If single voxel is used, a contralateral spectrum should be obtained for comparison. An intermediate TE (eg, 144 ms) at 1.5T or long TE (eg, 288 ms) should be considered if the detection of Lac is important for the diagnosis. At 3 T, a TE of 288 ms is often used because at higher field...
strengths, Lac may show reduced or absent signal intensity at an intermediate TE. The MRS should be planned in advance and previous imaging studies should be reviewed to determine the target of the study and the best way to approach it. Pathologies in difficult anatomic locations (eg, brainstem, spinal cord, or near the skull base) require manual shimming during the MRS acquisition. The presence of gadolinium does not significantly seem to affect the MRS, and the MRS acquisition can be performed after the post-contrast T1-weighted images to ensure that the enhancing lesions are properly included.

**Pitfalls**

- The inclusion of bone or air-tissue interfaces in the voxel used for MRS significantly affect the technical quality of the spectra.
- MRS should always be interpreted in conjunction with the rest of the imaging findings and not as an isolated modality. Could the findings be related to artifact or suboptimal technique? Was the shimming adequate during the acquisition? Proper technique is of paramount importance for the appropriate interpretation of the clinical MRSI.

**WHAT A REFERRING PHYSICIAN NEEDS TO KNOW**

- MRS is an advanced MR technique that can be helpful in the differentiation of non-neoplastic versus neoplastic pathologies, noninvasive characterization of intracranial neoplasms, and evaluation of cases of radiation necrosis, among other clinical uses.
- MRS complements the information provided by the conventional MR imaging sequences.

Fig. 9. Lymphoma. An 80-year-old female patient with progressive left sided weakness secondary to a large homogeneous enhancing mass in the right posterior frontal lobe. Pathology was consistent with diffuse large B-cell lymphoma. Axial postcontrast T1-weighted (A), axial FLAIR (B), MRS grid showing voxel placement overlaid on a T1-weighted image (C), and multivoxel MR spectra (TE = 144 ms) (D). There are prominent Lac (yellow arrows) and Lip peaks on the multivoxel MR spectra obtained from the regions of homogeneous enhancement, favoring the diagnosis of lymphoma.
Fig. 10. 2-D COSY. Examples of in vivo 2-D LASER-COSY spectra at 3T from 2 patients, one with an IDH1-mutant anaplastic astrocytoma (A) and another with a primary glioblastoma (wild-type [wt]-IDH1) (B), compared with a spectrum obtained from a healthy volunteer (wt-IDH1) (C). There is a small peak at the 4.02/1.91 ppm intersection compatible with 2HG in the spectrum obtained from the anaplastic astrocytoma. This peak is absent in the primary glioblastoma and in the healthy control subject (green rectangle). (From Andronesi OC, Kim GS, Gerstner E, et al. Detection of 2-hydroxyglutarate in IDH-mutated glioma patients by in vivo spectral-editing and 2D correlation magnetic resonance spectroscopy. Sci Transl Med 2012;4(116):116ra4; with permission.)
and should always be interpreted in conjunction with the rest of the imaging studies.

FUTURE DIRECTIONS

Recent advances in MRSI have been focused toward shortening acquisition times. Fast MRSI has evolved from concepts related to spatial encoding using gradient switching during acquisition. The proton echo-planar spectroscopic imaging (PEPSI) sequence uses standard-phase encoding in one direction, while phase encoding in the other direction is replaced by bipolar gradients, switching during data acquisition. Spiral trajectories in k-space allow even faster encoding of spatial information due to faster gradient duty cycle. Andronesi and colleagues implemented a 3-D volumetric in vivo MRSI sequence using spiral trajectories at a spatial resolution of 1 cm³ with a total scan time of less than 2.5 min. These improvements in image quality and imaging time allow more routine acquisition of spectroscopic data in the clinical setting.

Other technical innovations include implementation of 3-D MRSI techniques with localization by adiabatic selective refocusing (LASER) pulses acquisition. This sequence is designed to better compensate for chemical shift displacement errors, spatial nonuniformity of RF excitation, and contamination with subcutaneous Lip signal from tissues outside the region of interest using adiabatic pulses.

Motion correction schemes applied in MR technology have brought many practical benefits. By using techniques, such as propeller MR imaging, it has become possible to oversample k-space and thereby compensate for motion. As an alternative to these retrospective motion-correction techniques, it is also possible to prospectively correct motion using image-based navigators.

Spectral editing techniques, such as 2-D J-resolved methods, allow for the detection of peaks that are otherwise hidden in the MR spectrum because many resonances of similar frequencies in the proton spectrum overlap. In spectral editing, selective and nonselective spin-echo spectra are acquired; the difference spectrum contains the target metabolite signal (eg, 2HG) while all other contributors are nulled. Another approach to visualize hidden MR resonances is 2-D correlation spectroscopy (COSY) and total correlation spectroscopy (TOCSY) imaging experiments. Compared with the 2-D J-resolved method, 2-D COSY and TOCSY provide increased spectral dispersion, which scales up with increasing main magnetic field strength and may have improved ability to unambiguously identify overlapping metabolites (Fig. 10).

SUMMARY

MRS is a noninvasive technique that allows the study of metabolic processes and chemical environment in the brain parenchyma and has already demonstrated a tremendous diagnostic value in many clinical scenarios, particularly in the assessment of brain tumors and their differentiation from non-neoplastic pathologies and post-treatment changes. MRS is one of the few diagnostic techniques that can be used for evaluation of low-grade neoplastic processes and for their differentiation from non-neoplastic entities. Despite many technical and reimbursement challenges to its use in routine clinical practice, MRS will continue to develop as an important and sensitive imaging tool for assessment of intracranial pathologies.

REFERENCES


