



## Title: **Magnetic Resonance Spectroscopy**

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<b>Populations</b>	<b>Interventions</b>	<b>Comparators</b>	<b>Outcomes</b>
Individuals: • With brain tumors	Interventions of interest are: • Magnetic resonance spectroscopy	Comparators of interest are: • Magnetic resonance imaging alone	Relevant outcomes include: • Test accuracy • Change in disease status • Morbid events • Functional outcomes
Individuals: • With breast cancer	Interventions of interest are: • Magnetic resonance spectroscopy	Comparators of interest are: • Magnetic resonance imaging alone	Relevant outcomes include: • Test accuracy • Change in disease status • Morbid events • Functional outcomes
Individuals: • With prostate cancer	Interventions of interest are: • Magnetic resonance spectroscopy	Comparators of interest are: • Magnetic resonance imaging alone	Relevant outcomes include: • Test accuracy • Change in disease status • Morbid events

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Populations	Interventions	Comparators	Outcomes
Individuals: • With dementia	Interventions of interest are: • Magnetic resonance spectroscopy	Comparators of interest are: • Observation	• Functional outcomes Relevant outcomes include: • Test accuracy • Change in disease status • Morbid events • Functional outcomes
Individuals: • With liver disease	Interventions of interest are: • Magnetic resonance spectroscopy	Comparators of interest are: • Liver biopsy	Relevant outcomes include: • Test accuracy • Change in disease status • Morbid events • Functional outcomes
Individuals: • With multiple sclerosis	Interventions of interest are: • Magnetic resonance spectroscopy	Comparators of interest are: • Observation	Relevant outcomes include: • Test accuracy • Change in disease status • Morbid events • Functional outcomes
Individuals: • With psychiatric disorders	Interventions of interest are: • Magnetic resonance spectroscopy	Comparators of interest are: • Standard care • Structured clinical interview	Relevant outcomes include: • Test accuracy • Change in disease status • Morbid events • Functional outcomes

## DESCRIPTION

Magnetic resonance spectroscopy (MRS) is a noninvasive technique that can be used to measure the concentrations of different chemical components within tissues. The technique is based on the same physical principles as magnetic resonance imaging (MRI) and the detection of energy exchange between external magnetic fields and specific nuclei within atoms.

## OBJECTIVE

The objective of this evidence review is to evaluate whether magnetic resonance spectroscopy improves health outcomes in patients with brain tumors, breast cancer, prostate cancer, and various non-cancer indications.

## BACKGROUND

Magnetic resonance spectroscopy (MRS) is a noninvasive technique that can be used to measure the concentrations of chemical components within tissues. The technique is based on the same physical principles as magnetic resonance imaging (MRI) and the detection of energy exchange between external magnetic fields and specific nuclei within atoms. With MRI, this energy exchange, measured as a radiofrequency signal, is then translated into the familiar anatomic image by assigning different gray values according to the strength of the emitted signal. The principal difference between MRI and MRS is that the emitted radiofrequency in MRI is based on the spatial position of nuclei, while MRS detects the chemical composition of the scanned tissue. The information produced by MRS is displayed graphically as a spectrum with peaks consistent with the various chemicals detected. MRS may be performed as an adjunct to MRI. An MRI image is first generated, and then MRS spectra are developed at the site of interest, at the level of the

voxel (3-dimensional volume X pixel). The voxel of interest is typically a cube or rectangular prism with a dimensional pixel with a volume of 1 to 8 cm<sup>3</sup>. While an MRI provides an anatomic image of the brain, MRS provides a functional image related to underlying dynamic physiology. MRS can be performed with existing MRI equipment, and modified with additional software and hardware, which are provided with all new MRI scanners. Imaging time in the scanner is increased by 15 to 30 minutes.

MRS has been studied most extensively in a variety of brain pathologies. In the brain, both 1-H (ie, hydrogen proton) and 31-P are present in concentrations high enough to detect and thus have been used extensively to study brain chemistry. Proton MRS of the brain reveals 6 principal spectra. They include those:

- Arising from *N*-acetyl groups, especially *N*-acetylaspartate (NAA): NAA is an amino acid that is generated by mitochondria and is present almost exclusively in neurons and axons in the adult central nervous system. NAA intensity is thought to be a marker of neuronal integrity and is the most important proton signal in studying central nervous system pathology. Decreases in the NAA signal are associated with neuronal loss, damage to neuronal structures, and/or reduced neural metabolism.
- Arising from choline-containing compounds (Cho), such as membrane phospholipids (eg, phosphocholine, glycerophosphocholine): an increase in Cho is considered a marker of pathologic proliferation/degradation of cell membranes and demyelination. Cho levels can increase in acute demyelinating disease, but an increase in Cho levels is most commonly associated with neoplasms. Cho levels can also be affected by diet and medication.
- Arising from creatine and phosphocreatine: In the brain, creatine is a relatively constant element of cellular energetic metabolism and thus is sometimes used as an internal standard.
- Arising from myo-inositol: myo-inositol is a polyalcohol present at high concentration in glial cells. An increase in the ratio of myo-Inositol to NAA suggests gliosis and regional neuronal damage.
- Arising from lipid.
- Arising from lactate: Normally this spectrum is barely visible, but lactate may increase to detectable levels when anaerobic metabolism is present. Lactate may accumulate in necrotic areas, in inflammatory infiltrates, and in brain tumors.

Different patterns of these spectra and others (eg, myo-inositol, glutamate/glutamine) in the healthy and diseased brain are the basis of clinical applications of MRS. MRS findings characteristically associated with non-necrotic brain tumors include elevated Cho levels and reduced NAA levels. The International Network for Pattern Recognition using Magnetic Resonance<sup>1</sup>, has developed a user-friendly computer program for spectral classification and a database of over 300 tumor spectra with histologically validated diagnoses to aid radiologists in MRS diagnosis.<sup>2,3</sup>

One limitation of MRS is that it provides the metabolic composition of a given voxel, which may include more than 1 type of tissue. For some applications, the voxels are relatively large (eg, >1 cm<sup>3</sup>), although they may be somewhat smaller using a 3-tesla MRI machine versus a 1.5-tesla

magnet. High-field strength increases the signal to noise ratio and spectral resolution. The 3-tesla technique creates greater inhomogeneities, however, which require better shimming techniques.<sup>4</sup> There are 2 types of MRS data acquisition: single-voxel or simultaneous multivoxel also called chemical shift imaging. Reliable results are more difficult to obtain from some areas, eg, close to the brain surface or in children with smaller brains because of the lipid signal from the skull. Some techniques are used to deal with these issues; various MRS techniques continue to be explored as well. A combination of MRS is often used with other MRI techniques (eg, diffusion-tensor imaging, susceptibility-weighted imaging) and other types of imaging such as positron emission tomography.

Peripheral applications of MRS include the study of myocardial ischemia, peripheral vascular disease, and skeletal muscle. Applications in non-central nervous system oncologic evaluation have also been explored. Nomograms for prostate cancer are being developed that incorporate MRI and MRS results.<sup>5</sup>

All findings reported in this evidence review refer to proton MRS unless otherwise indicated.

### **REGULATORY STATUS**

Multiple software packages for performing proton MRS have been cleared for marketing by the U.S. Food and Drug Administration (FDA) through the 510(k) process since 1993. Single-voxel MRS is available on all modern MRI scanners. FDA product code: LNH.

## **POLICY**

Magnetic resonance spectroscopy is considered **experimental / investigational**.

## **RATIONALE**

The evidence review has been updated regularly with searches of the PubMed database. The most recent literature update was performed through August 17, 2021. This review was informed in part by a TEC Assessment (2003).<sup>6</sup>

Evidence reviews assess whether a medical test is clinically useful. A useful test provides information to make a clinical management decision that improves the net health outcome. That is, the balance of benefits and harms is better when the test is used to manage the condition than when another test or no test is used to manage the condition.

The first step in assessing a medical test is to formulate the clinical context and purpose of the test. The test must be technically reliable, clinically valid, and clinically useful for that purpose. Evidence reviews assess the evidence on whether a test is clinically valid and clinically useful. Technical reliability is outside the scope of these reviews, and credible information on technical reliability is available from other sources.

## **BRAIN TUMORS**

### **Clinical Context and Test Purpose**

The purpose of magnetic resonance spectroscopy (MRS) in patients with brain tumors is to differentiate malignant from nonmalignant tumors, evaluate tumor grade, and distinguish metastatic from primary brain tumors.

The question addressed in this evidence review is: Does the use of MRS improve the net health outcome of patients with brain tumors?

The following PICO was used to select literature to inform this review.

### ***Populations***

The relevant population of interest is patients being evaluated for brain tumors.

### ***Interventions***

The intervention of interest is MRS.

### ***Comparators***

The following practice is currently being used to make decisions about managing brain tumors: standard evaluation with magnetic resonance imaging (MRI).

### ***Outcomes***

The outcomes of interest are sensitivity and specificity and the impact of the diagnosis on health outcomes. The time of interest is at biopsy, surgical resection, or clinical follow-up.

### Study Selection Criteria

For the evaluation of the clinical validity of the tests, studies that meet the following eligibility criteria were considered:

- Reported on the accuracy of the marketed version of the technology (including any algorithms used to calculate scores)
- Included a suitable reference standard
- Patient/sample clinical characteristics were described
- Patient/sample selection criteria were described
- Included a validation cohort separate from development cohort.

### Clinically Valid

A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

## REVIEW OF EVIDENCE

### Systematic Reviews

Wang et al (2014) reported on a meta-analysis of 24 studies (615 cases, 408 controls) assessing the diagnostic performance of MRS for detecting or grading of brain tumors.<sup>7</sup> Twenty-two studies assessed gliomas, and 2 studies assessed ependymomas and primitive neuroectodermal tumors. Seven studies evaluated recurrence, 9 evaluated the tumor grade, 5 evaluated the detection of tumors, 1 evaluated residual tumors, and 2 assessed tumor metastases. The meta-analysis found the overall sensitivity and specificity of MRS were 80.1% and 78.5%, respectively. The area under the receiver operating characteristics curve was 0.78.

### Complementary Magnetic Resonance Spectroscopy

Hellstrom et al (2018) evaluated whether MRS adds to the diagnostic value of MRI in differentiating low-grade tumors, high-grade tumors, and non-neoplastic lesions through the retrospective analysis of data on 208 lesions from 186 patients.<sup>8</sup> Data are summarized in Table 1. No statistically significant difference was found between MRI and MRI + MRS ( $p = .055$ ). Furthermore, additional data from MRS was found to be very beneficial, beneficial, inconsequential, or misleading in 3%, 12%, 68%, and 17% of cases, respectively. Therefore, in most cases, complementary MRS was not shown to add to the diagnostic value of MRI.

**Table 1. Clinical Validity Results for MRI vs MRI+MRS**

Confirmed Diagnosis	Actual Prevalence, N (%)	Diagnostic Accuracy	Modality	
			MRI, N (%)	MRI+MRS, N (%)
Any Diagnosis	Total, 208 (100%)	Correct	130 (62%)	134 (64%)
	Neoplastic, 138 (66%)	Indeterminate	39 (19%)	23 (11%)
	Non-neoplastic, 70 (33%)	Incorrect	39 (19%)	51 (25%)

Confirmed Diagnosis	Actual Prevalence, N (%)	Diagnostic Accuracy	Modality	
			MRI, N (%)	MRI+MRS, N (%)
		Total	208 (100%)	208 (100%)
High-grade Tumor	Total, 95 (46%)	Correct	40 (45%)	46 (52%)
		Indeterminate	23 (26%)	6 (7%)
		Incorrect	26 (29%)	37 (41%)
		Total	89 (100%)	89 (100%)
Low-grade Tumor	Total, 43 (21%)	Correct	30 (70%)	30 (70%)
		Indeterminate	5 (12%)	7 (16%)
		Incorrect	8 (18%)	6 (14%)
		Total	43 (100%)	43 (100%)
Diagnostic Agreement		Radiological Diagnostic Accuracy	MRI and MRI+MRS, N	
Matching Radiological Diagnosis		Correct	109	
		Indeterminate	12	
		Incorrect	30	

MRI: magnetic resonance imaging; MRS: magnetic resonance spectroscopy.

Data adapted from Hellstrom et al (2018).<sup>8</sup>

### Diagnosis of Pediatric Brain Tumor Type

Pediatric brain tumors are histologically more diverse than adult brain tumors and include tumor types such as embryonal tumors, germ cell tumors, pilocytic astrocytoma, and ependymomas.

Manias et al (2019) prospectively evaluated children with brain lesions aged 16 years and under (N=51) between December 2015 and 2017 via MRI and single-voxel MRS, blinded to histopathology.<sup>9</sup> MRS spectra were obtained in 47/51 eligible patients, however, only 72% of tumors were considered analyzable via MRS. Proportions of correct diagnoses and interrater agreement at each stage were assessed. The diagnostic accuracy of the principal MRI diagnosis was 69%, improving to 77% with MRS. Together, MRI and MRS resulted in a significant increase in additionally correct diagnoses compared to MRI alone ( $p = .035$ ) and a significant increase in interrater agreement ( $p = .046$ ). Patients were managed without conclusive histopathology in 25% of cases.

Manias et al (2018) reported on a multicenter U.K. study that retrospectively evaluated MRS for the noninvasive diagnosis of brain tumors.<sup>10</sup> This study analyzed 64 consecutive children who had MRI, MRS, and histopathology. The clinical information was reviewed by a tumor board, which included pediatric oncologists, pediatric radiologists specializing in neuroradiology, clinical

oncologists, neurosurgeons, and histopathologists, who arrived at consensus diagnosis and treatment planning. The reference standard was the diagnosis by the tumor board, verified through the clinical course. MRI alone was correct in 38 (59%) of 64 patients. The addition of MRS increased diagnostic accuracy to 47 (73%) out of 64, with 17 cases incorrectly diagnosed by MRI plus MRS. A subsequent study by Manias et al (2018) assessed the diagnostic accuracy of MRS alone in diagnosing children (N=26) with pilocytic astrocytoma, ependyoma, and medulloblastoma, reporting modest correct classification rates of 60%, 50%, and 80%, respectively.<sup>11</sup>

Combined MRI and MRS to diagnose the type of pediatric brain tumors were reported by Shiroishi et al (2015) in a study from multiple children's hospitals in the U. S.<sup>12</sup> MRI and MRS were performed in 120 pediatric patients as part of the usual presurgical workup, followed by biopsy or resection. For the first 60 patients (from 2001 to 2004), MRS was performed but was considered experimental and not used for diagnosis. For the next 60 patients (2005 to 2008), radiologists used information from both MRI and MRS. The percentage of correct diagnoses was reported for the first 60 patients using only MRI (63% correct). MRI scans were re-evaluated at the time of the study (71% correct), and the diagnosis at the second MRI reading did not differ significantly from the first MRI reading. These results were compared with blinded diagnosis using MRI plus MRS (87% correct,  $p < .05$ ). For the second group of 60 patients who were diagnosed using MRI plus MRS, tumor type was correctly identified in 87% of patients ( $p < .005$  vs initial diagnosis with MRI alone). Together, the results indicated an improvement (from 71% to 87% correct) in the diagnosis of tumor type when MRS was combined with MRI.

Vicente et al (2013) reported on a multicenter study that evaluated the ability of MRS to differentiate 78 histologically confirmed pediatric brain tumors (29 medulloblastomas, 11 ependymomas, 38 pilocytic astrocytomas).<sup>13</sup> Significant metabolic differences in tumor types were identified by MRS when results from short and long echo times were combined, suggesting that MRS might provide noninvasive diagnostic information. MRS has also been evaluated as a prognostic tool.

In another study, Wilson et al (2013) reported on single-voxel, proton MRS to predict survival in 115 patients with pediatric brain tumors who were followed for a median of 35 months.<sup>14</sup> Poor survival was associated with lipids and scyllo-inositol while glutamine and *N*-acetylaspartate (NAA) were associated with improved survival ( $p < .05$ ).

### **Diagnosis of Isocitrate Dehydrogenase Mutant Glioma**

A systematic review and meta-analysis of 460 patients with stage II-IV glioma by Suh et al (2018) was conducted to assess 2-hydroxyglutarate (2HG) MRS as a noninvasive and accurate diagnostic alternative to confirmation via biopsy with immunohistochemistry and/or genomic sequencing analysis.<sup>15</sup> According to the World Health Organization, isocitrate dehydrogenase (IDH) mutation status (*IDH1/IDH2*) is one of the most valuable prognostic biomarkers for appropriate clinical management of gliomas. The pooled sensitivity and specificity was 95% (95% confidence interval [CI], 85-98%) and 91% (95% CI, 83-96%), respectively.

Andronesi et al (2018) reported on an open-label phase I clinical trial investigating the utility of 2HG MRS to assess the pharmacodynamics of an investigational mutant *IDH1* inhibitor drug

(IDH305, Novartis Pharmaceuticals).<sup>16</sup> Eight patients were enrolled, and data from 5 patients were available for tumor 2HG level analysis at baseline and following 1 week of treatment with IDH305. Tumor 2HG levels were found to decrease during mutant *IDH1* inhibition, with statistically significant decreases in the ratios of 2HG to healthy creatinine (2HG/hCr), tumor creatinine (2HG/tCr), and glutamine plus glutamate (2HG/Glx). However, further study is required to validate whether these results can identify treatment response as patient clinical outcomes were not reported in the present study. Furthermore, the authors acknowledge that recent preclinical data has failed to show an effect on tumor growth with mutant *IDH1* inhibitors. Importantly, mutant *IDH1* patients have significantly longer survival compared to patients with wild-type *IDH1*, therefore the value of mutant *IDH1* treatment and response monitoring is currently unclear.

### **Differentiating Glioma Recurrence From Radiation Necrosis**

A systematic review by Zhang et al (2014) assessed the use of MRS in the differential diagnosis of glioma recurrence from radiation necrosis; it included 18 studies (N =455 ).<sup>17</sup> Only 3 studies were prospective. Fourteen of the studies used both pathology and clinical plus radiologic follow-up as the reference standard. Twelve studies examined the choline (Cho)/creatine (Cr) ratio, 9 studies calculated the Cho/NAA ratio, 5 studies calculated the NAA/Cr ratio, and 3 studies calculated the Cho/Cr ratio. Meta-analysis showed moderate diagnostic performance for MRS using the Cho/Cr and Cho/NAA ratios.

The largest prospective study included in the review was by Amin et al (2012).<sup>18</sup> This study compared MRS with single-photon emission computed tomography (SPECT) in the identification of residual or recurrent glioma versus radiation necrosis in 24 patients treated with surgery and radiotherapy. MRS and SPECT results differed in 9 cases of recurrence and were more accurate with SPECT. The specificity and positive predictive value were 100% in both MRS and SPECT; however, the sensitivity was 61.1% versus 88.8%, and negative predictive value was 46.2% versus 75%, respectively. The use of a single-voxel rather than multiple voxels was noted as a limitation in interpreting the MRS results in this study.

### **Differentiating High-Grade From Low-Grade Glioma**

Wang et al (2016) reported on a systematic review of 30 studies (N =228 ) evaluating the diagnostic performance of MRS in differentiating high- from low-grade gliomas.<sup>19</sup> The articles included used pathology or clinical follow-up as the reference standard for the identification of high-grade gliomas. Only 5 studies were prospective, sample sizes ranged from 7 to 160 patients, and there was considerable variability in the thresholds used to identify high-grade gliomas. There was also evidence of publication bias. The pooled sensitivity and specificity in the meta-analysis were 75% and 60% for the Cho/Cr ratio, 80% and 76% for Cho/NAA ratio, and 71% and 70% for NAA/Cr ratio. The areas under the receiver operating characteristic curve were 0.83, 0.87, and 0.78, respectively. Thus, MRS had moderate diagnostic accuracy in distinguishing high-grade from low-grade gliomas in the published studies. A recent study by Lin et al (2018) only noted a significant difference for the Cho/NAA ratio, with a sensitivity and specificity of 61.54% and 86.36%, respectively.<sup>20</sup>

### **Gauging Treatment Response**

The possibility of using MRS to track treatment response and failure has been explored. A small (n=16), a preliminary study by Sankar et al (2008) assessed tamoxifen treatment for recurrent gliomas and found MRS patterns differed between responders and nonresponders.<sup>21</sup> Serial MRS demonstrated that metabolic spectra stabilized after initiation of therapy among responders and then changed in advance of clinical or radiologic treatment failure. In other words, MRS might help predict imminent treatment failure. However, there are relatively few studies with small sample sizes assessing this possible use of MRS. Additionally, other types of imaging are being evaluated for the same use, including dynamic contrast-enhanced (DCE) MRI (DCE-MRI), diffusion-weighted MRI, and fluorine 18 fluorodeoxyglucose positron emission tomography. Other studies are needed, including those comparing modalities or evaluating multimodalities.<sup>22,23</sup>

### **Clinically Useful**

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

### **Direct Evidence**

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from randomized controlled trials (RCTs).

No RCTs were identified that support the clinical utility of MRS for this indication. The retrospective study by Manias et al (2018; discussed above), did report that patient management was influenced by MRS in 13 cases, including avoidance of biopsy in 10 cases, appropriate management in 1 case, and alerting to high-grade lesions in 2 cases.<sup>10</sup> The prospective study by Manias et al (2019; discussed above) reported that 25% of patients were managed without a conclusive histopathological diagnosis.<sup>9</sup>

### **Chain of Evidence**

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Because the clinical validity of MRS has not been established for this indication, a chain of evidence cannot be constructed.

### **Section Summary: Brain Tumors**

Several systematic reviews have evaluated the performance of MRS for the diagnosis and evaluation of brain tumors. A number of small studies have assessed detection, characterization, grading, prognosis, and differentiation of tumor recurrence versus necrosis. Most studies included in the meta-analyses were small, retrospective, and used various ratios of MRS spectra. The largest prospective study found that combining MRS with MRI resulted in a greater percentage of correct diagnoses of pediatric brain tumor type. This report offered limited information on the specific MRS spectra associated with the different tumor types. Prospective studies are needed to better define the spectra associated with tumor characteristics, to evaluate the diagnostic accuracy, and to determine the effect on health outcomes.

## **BREAST CANCER**

### **Clinical Context and Test Purpose**

The purpose of MRS in patients with breast cancer is to improve the specificity of breast imaging, which has a high false-positive rate.

The question addressed in this evidence review is: Does the use of MRS improve the net health outcome of patients with breast cancer?

The following PICO was used to select literature to inform this review.

### ***Populations***

The relevant population of interest is patients being evaluated for breast cancer.

### ***Interventions***

The intervention of interest is MRS.

### ***Comparators***

The following practice is currently being used to make decisions about managing breast tumors: standard evaluation with MRI.

### ***Outcomes***

The outcomes of interest are sensitivity and specificity and the effect on health outcomes. The time of interest is at biopsy, surgical resection, or clinical follow-up.

### **Study Selection Criteria**

For the evaluation of the clinical validity of the tests, studies that meet the following eligibility criteria were considered:

- Reported on the accuracy of the marketed version of the technology (including any algorithms used to calculate scores)
- Included a suitable reference standard
- Patient/sample clinical characteristics were described
- Patient/sample selection criteria were described
- Included a validation cohort separate from development cohort.

### **Clinically Valid**

A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

## **REVIEW OF EVIDENCE**

### **Diagnosis of Breast Cancer**

Baltzer et al (2013) conducted a systematic review and meta-analysis of 19 studies on MRS for detecting benign versus malignant breast lesions.<sup>24</sup> The total number of patients in the studies

reviewed was 1183 and included 452 benign and 773 malignant lesions. In the pooled estimates, the sensitivity of MRS was 73% (556/761; 95% CI, 64% to 82%) and the specificity was 88% (386/439; 95% CI, 85% to 91%). The area under the receiver operating characteristic curve for MRS detecting breast cancers versus benign lesions was 0.88. There was significant heterogeneity between studies and evidence of publication bias.

### **Treatment Response**

Bayoumi et al (2019) conducted a prospective study evaluating the additive role of MRS and MRI in the confirmation of pathological complete response after neoadjuvant chemotherapy of breast cancer in 47 patients.<sup>25</sup> Patients were evaluated via MRI and MRS at baseline and following treatment with 4 cycles of anthracycline-based chemotherapy administered at 3 week intervals. Pathological response to neoadjuvant chemotherapy was confirmed via histopathological evaluation following surgical excision. A Cho peak at 3.2 ppm was considered positive. The mean tumor size before and after treatment was  $4.21 \pm 0.99$  cm and  $0.9 \pm 0.44$  cm, respectively, with corresponding mean Cho signal-to-noise ratios of  $9.53 \pm 1.7$  ppm and  $2.53 \pm 1.3$  ppm. MRI detected a complete response in 22/47 patients, corresponding to a sensitivity of 83.3%, specificity of 65.7%, positive predictive value (PPV) of 45.5%, negative predictive value (NPV) of 92%, and a diagnostic accuracy of 70.2%. In contrast, combined MRI and MRS demonstrated a sensitivity of 75%, specificity of 97.1%, PPV of 75%, NPV of 91.9%, and an improved diagnostic accuracy of 91.5%. The cut-off for differentiating between complete response and residual disease was 1.95 ppm with a corresponding diagnostic accuracy of 85.11%. Patient characteristics and eligibility criteria were not specified.

### **Clinically Useful**

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

### **Direct Evidence**

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified that support the clinical utility of MRS for this indication.

### **Chain of Evidence**

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Because the clinical validity of MRS has not been established for this indication, a chain of evidence cannot be constructed.

### **Section Summary: Breast Cancer**

The evidence on MRS to determine whether breast lesions are benign or malignant includes a systematic review. Pooled estimates of sensitivity and specificity were 73% and 88%, respectively. There was evidence of publication bias, limiting interpretation of findings.

## **PROSTATE CANCER**

### **Clinical Context and Test Purpose**

The purpose of MRS in patients with prostate cancer is to improve the evaluation of prostate cancer. There are several potential applications of MRS for prostate cancer, including diagnosis, recurrence assessment, and localization for biopsy and treatment planning.

The question addressed in this evidence review is: Does the use of MRS improve the net health outcome of patients with prostate cancer?

The following PICO was used to select literature to inform this review.

### ***Populations***

The relevant population of interest is patients being evaluated for prostate cancer.

### ***Interventions***

The intervention of interest is MRS.

### ***Comparators***

The following practice is currently being used to make decisions about managing prostate cancer: standard evaluation with MRI.

### ***Outcomes***

The outcomes of interest are sensitivity and specificity and the effect on health outcomes.

### **Study Selection Criteria**

For the evaluation of the clinical validity of the tests, studies that meet the following eligibility criteria were considered:

- Reported on the accuracy of the marketed version of the technology (including any algorithms used to calculate scores)
- Included a suitable reference standard
- Patient/sample clinical characteristics were described
- Patient/sample selection criteria were described
- Included a validation cohort separate from development cohort.

### **Clinically Valid**

A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

## **REVIEW OF EVIDENCE**

### **Systematic Reviews**

A meta-analysis by Cai et al (2019) reviewed 19 studies utilizing MRS imaging for the diagnosis of prostate cancer.<sup>26</sup> In a health technology assessment, Mowatt et al (2013) systematically reviewed 51 studies to evaluate image-guided prostate biopsy with MRS and other enhanced MRI techniques (ie, dynamic contrast-enhanced MRI, diffusion-weighted MRI) compared with T2-MRI and transrectal ultrasound.<sup>27</sup> In these studies, the patients had a suspicion of prostate cancer due to elevated prostate-specific antigen levels, despite a previous negative biopsy. Characteristics and results of these reviews are summarized in Tables 2 and 3.

**Table 2. SR & M-A Characteristics for Prostate Cancer**

Study	Dates	Trials	Participants <sup>1</sup>	N (Range)	Design	Duration
Cai et al (2019) <sup>26</sup> ,	2004-2017	19	Studies applying MRS for the diagnosis of PC. Individuals with clinical suspicion of PC and diagnosis confirmed with pathology. Studies with diagnostic accuracy data.	1406 (20-346)	Prospective cohort Retrospective cohort Cross-sectional	NR
Mowatt et al (2013) <sup>27</sup> ,	NR	51	Men with suspected PC and elevated PSA but previously negative biopsy. Studies utilizing MRS, standard MRI, and other imaging modalities for PC diagnosis.	>10000 (NR)	NR	NR

M-A: meta-analysis; MRI: magnetic resonance imaging; MRS: magnetic resonance spectroscopy; NR: not reported; PC: prostate cancer; PSA: prostate-specific antigen; SR: systematic review.

<sup>1</sup> Key eligibility criteria.

**Table 3. SR & M-A Results for Prostate Cancer**

Study; Subgroup	Sensitivity	Specificity	PPV	NPV
Cai et al (2019) <sup>26</sup> ,				
MRS				
Total N	NR	NR	777	581
Pooled effect (95% CI)	84% (75-91%)	79% (69-87%)	64% (NR)	88% (NR)
$I^2$ (95% CI)	85.77% (80.33-91.21%)	88.35% (84.15-92.56%)	NR	NR
Range of effect sizes	14-100%	29-100%	NR	NR
Mowatt et al (2013) <sup>27</sup> ,				
MRS				
Total N	438	438	220	218
Pooled effect (95% CI)	92% (86-95%)	76% (61-87%)	66% (NR)	94% (NR)
$I^2$ (95% CI)	NR	NR	NR	NR
Range of effect sizes	71-100%	44-96%	NR	NR
Standard MRI				

Study; Subgroup	Sensitivity	Specificity	PPV	NPV
Total N	620	620	356	264
Pooled effect (95% CI)	86% (74-93%)	55% (44-66%)	47% (NR)	85% (NR)
$I^2$ (95% CI)	NR	NR	NR	NR
Range of effect sizes	48-100%	17-86%	NR	NR

CI: confidence interval; M-A: meta-analysis; MRI: magnetic resonance imaging; MRS: magnetic resonance spectroscopy; NPV: negative predictive value; NR: not reported; PPV: positive predictive value; SR: systematic review.

### Randomized Controlled Trials

A single-institution RCT published by Sciarra et al (2010) compared a second randomly selected biopsy (group A) with a biopsy selected partly based on MRS and DCE-MRI results (group B).<sup>28</sup> The participants were selected from 215 consecutive men with an elevated prostate-specific antigen level (between 4 ng/mL and 10 ng/mL), an initial negative biopsy result, and a negative digital rectal examination; 180 patients participated in the study. Cancer was detected in 24.4% of group A patients and 45.5% of group B participants. Fifty patients from group A with 2 negative biopsy results agreed to undergo biopsy a third time using MRS and DCE-MRI results; 26 more cancers were found. Overall, 61.6% of the cancers detected had Gleason scores of 7 (4+3) or more. The cancers detected after using MRS and DCE-MRI also aligned with the suspicious areas detected on imaging. Given the concerns about potential overtreatment among patients with early-stage prostate cancer, the benefits of detecting these additional cancers must be evaluated by examining clinical outcomes for these patients. In a similar report from the same institution and author group, 150 patients with a negative prostate biopsy, despite prostate-specific antigen elevations, were randomized to MRS or MRS plus DCE-MRI to locate prostate cancer foci for a second targeted biopsy<sup>29</sup> (see also Panebianco et al [2012]<sup>30</sup>). Characteristics, results, and limitations of these studies are summarized in Tables 4-7.

**Table 4. Summary of Key Prostate Cancer Trial Characteristics**

Study; Trial	Study Design	Countries	Sites	Dates	Participants <sup>2</sup>	Interventions <sup>1</sup>	
						Active	Comparator
Sciarra et al (2010) <sup>28</sup>	RCT	EU	1	2007-NR	Men with initial negative prostate biopsy, elevated PSA, and negative initial transrectal ultrasound-guided biopsy.	MRS + DCE-MRI Targeted Biopsy: 90	Random Biopsy: 90
Panebianco et al (2010) <sup>29</sup>	Prospective	EU	1	2007-NR	Men with persistently high PSA levels and with a negative finding on initial transrectal ultrasound-guided biopsy.	MRS+DCE-MRI Targeted Biopsy: 150	Random Biopsy: 150

DCE-MRI: dynamic contrast-enhanced magnetic resonance imaging; MRS: magnetic resonance spectroscopy; NR: not reported; PSA; prostate-specific antigen; RCT: randomized controlled trial.

<sup>1</sup> Number randomized; intervention; mode of delivery; dose (frequency/duration).

<sup>2</sup> Key eligibility criteria

**Table 5. Summary of Key Prostate Cancer Trial Results**

Study; Subgroup	Sensitivity (95% CI)	Specificity (95% CI)
Sciarra et al (2010) <sup>28</sup> ,		
MRS	92.3% (NR)	88.2%
MRS+DCE-MRI	92.6%	88.8%
Panebianco et al (2010) <sup>29</sup> ,		
MRS	82.8% (NR)	91.8% (NR)
MRS+DCE-MRI	93.7% (NR)	90.7% (NR)

CI: confidence interval; DCE-MRI: dynamic contrast-enhanced magnetic resonance imaging; MRS: magnetic resonance spectroscopy; NR: not reported.

**Table 6. Study Relevance Limitations**

Study	Population <sup>a</sup>	Intervention <sup>b</sup>	Comparator <sup>c</sup>	Outcomes <sup>d</sup>	Duration of Follow-Up <sup>e</sup>
Sciarra et al (2010) <sup>28</sup> ,			1-2. Not clearly defined; not standard or optimal (vs DRE).	1. Key health outcomes not addressed.	1-2. Not sufficient duration for benefit or harms.
Panebianco et al (2010) <sup>29</sup> ,			1-2. Not clearly defined; not standard or optimal (vs DRE).	1. Key health outcomes not addressed.	1-2. Not sufficient duration for benefit or harms.

DRE: digital rectal examination.

The study limitations stated in this table are those notable in the current review; this is not a comprehensive gaps assessment.

<sup>a</sup> Population key: 1. Intended use population unclear; 2. Clinical context is unclear; 3. Study population is unclear; 4. Study population not representative of intended use.

<sup>b</sup> Intervention key: 1. Not clearly defined; 2. Version used unclear; 3. Delivery not similar intensity as comparator; 4. Not the intervention of interest.

<sup>c</sup> Comparator key: 1. Not clearly defined; 2. Not standard or optimal; 3. Delivery not similar intensity as intervention; 4. Not delivered effectively.

<sup>d</sup> Outcomes key: 1. Key health outcomes not addressed; 2. Physiologic measures, not validated surrogates; 3. No CONSORT reporting of harms; 4. Not establish and validated measurements; 5. Clinical significant difference not prespecified; 6. Clinical significant difference not supported.

<sup>e</sup> Follow-Up key: 1. Not sufficient duration for benefit; 2. Not sufficient duration for harms.

**Table 7. Study Design and Conduct Limitations**

Study	Allocation <sup>a</sup>	Blinding <sup>b</sup>	Selective Reporting <sup>c</sup>	Data Completeness <sup>d</sup>	Power <sup>e</sup>	Statistical <sup>f</sup>
Sciarrà et al (2010) <sup>28</sup> ,	3. Allocation concealment unclear.	1-2. Blinding unclear.	1. Not registered.	6. No intent to treat analysis.	1. Power calculations not reported.	3. Confidence intervals and/or p values not reported.
Panebianco et al (2010) <sup>29</sup> ,	3. Allocation concealment unclear.	1-2. Blinding unclear.	1. Not registered.	6. No intent to treat analysis.	1. Power calculations not reported.	3. Confidence intervals and/or p values not reported.

The study limitations stated in this table are those notable in the current review; this is not a comprehensive gaps assessment.

<sup>a</sup> Allocation key: 1. Participants not randomly allocated; 2. Allocation not concealed; 3. Allocation concealment unclear; 4. Inadequate control for selection bias.

<sup>b</sup> Blinding key: 1. Not blinded to treatment assignment; 2. Not blinded outcome assessment; 3. Outcome assessed by treating physician.

<sup>c</sup> Selective Reporting key: 1. Not registered; 2. Evidence of selective reporting; 3. Evidence of selective publication.

<sup>d</sup> Data Completeness key: 1. High loss to follow-up or missing data; 2. Inadequate handling of missing data; 3. High number of crossovers; 4. Inadequate handling of crossovers; 5. Inappropriate exclusions; 6. No intent to treat analysis (per protocol for noninferiority trials).

<sup>e</sup> Power key: 1. Power calculations not reported; 2. Power not calculated for primary outcome; 3. Power not based on clinically important difference.

<sup>f</sup> Statistical key: 1. Analysis is not appropriate for outcome type: (a) continuous; (b) binary; (c) time to event; 2. Analysis is not appropriate for multiple observations per patient; 3. Confidence intervals and/or p values not reported; 4. Comparative treatment effects not calculated.

### Clinically Useful

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

### Direct Evidence

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified that support the clinical utility of MRS for this indication.

### Chain of Evidence

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Because the clinical validity of MRS has not been established for this indication, a chain of evidence cannot be constructed.

### Section Summary: Prostate Cancer

Although a number of studies have examined the use of MRS for diagnosing prostate lesions, localizing prostate cancer for biopsy, and monitoring of patients with prostate cancer, the cumulative evidence remains uncertain. Data comparing the diagnostic accuracy of MRS with alternative imaging strategies are limited. Additionally, the impact of MRS imaging compared with other imaging strategies on clinical management and health outcomes is unknown.

## **DEMENTIA**

### **Clinical Context and Test Purpose**

The purpose of MRS in patients with dementia is to improve the diagnosis and management of dementia.

The question addressed in this evidence review is: Does the use of MRS improve the net health outcome of patients with dementia?

The following PICO was used to select literature to inform this review.

### ***Populations***

The relevant populations of interest is patients being evaluated for dementia.

### ***Interventions***

The intervention of interest is MRS.

Use of positron emission tomography (PET) in Alzheimer disease is addressed separately in evidence review 6.01.55.

### ***Comparators***

The following practice is currently being used to make decisions about managing dementia: observation.

### ***Outcomes***

The outcomes of interest are sensitivity and specificity and the effect on health outcomes. The time of interest is at the initial evaluation or at clinical follow-up.

### **Study Selection Criteria**

For the evaluation of the clinical validity of the tests, studies that meet the following eligibility criteria were considered:

- Reported on the accuracy of the marketed version of the technology (including any algorithms used to calculate scores)
- Included a suitable reference standard
- Patient/sample clinical characteristics were described
- Patient/sample selection criteria were described
- Included a validation cohort separate from development cohort.

### **Clinically Valid**

A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

## REVIEW OF EVIDENCE

### Systematic Reviews

Piersson et al (2020) conducted a systematic review of 24 studies to clarify the relationship between neurochemical changes and MRS metabolite levels against validated Alzheimer's disease (AD) biomarkers.<sup>31</sup> Decreased levels of N-acetylaspartate (NAA), NAA/creatine (NAA/Cr), and NAA/myo-inositol (NAA/mI), and increased mI, mI/Cr, choline/Cr (Cho/Cr), and mI/NAA were detected in the posterior cingulate cortex and precuneus. Increased NAA/mI and decreased NAA/Cr was associated with increased tau levels. NAA and glutathione levels are reduced in apolipoprotein E (APOE) ε4 carriers. The authors conclude that large, longitudinal studies are necessary to elucidate the effect of APOE ε4 on brain metabolites.

Research continues on the use of MRS to identify dementia, especially in its early stages. In a review, Zhang et al (2014) identified 30 studies since 2007 on low-field (<1.5 tesla) MRS and 27 studies on high-field (>3.0 tesla) MRS that compared results from patients with Alzheimer's dementia (AD), mild cognitive impairment (MCI), and healthy controls.<sup>32</sup> While metabolite changes are heterogeneous across brain regions, most studies focused on detecting changes in individual metabolites or their ratios. Reviewers concluded that to characterize Alzheimer's disease-associated with neurochemical changes effectively, future approaches should interactively analyze multiple quantifiable metabolites from different brain regions.

Tumati et al (2013) conducted a systematic review and meta-analysis of 29 studies on MRS for MCI.<sup>33</sup> Included in the analysis were 607 MCI patients and 862 healthy controls. Patterns in metabolite concentration, including NAA, Cr, Cho, and myo-inositol, were identified in various regions of the brain; they were associated with MCI. For example, levels of Cr were found to be significantly lower in the hippocampus and paratrigenal white matter. NAA was found to be most associated with MCI, but other markers including myo-inositol, Cho, and Cr may also contribute to MCI.

### Clinically Useful

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

### Direct Evidence

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified that support the clinical utility of MRS for this indication.

### Chain of Evidence

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Because the clinical validity of MRS has not been established for this indication, a chain of evidence cannot be constructed.

### **Section Summary: Dementia**

Although a number of studies have examined the use of MRS for identifying and monitoring cognitive impairment and dementia, the cumulative evidence does not support any role for MRS outside of the research setting. There are no clear criteria for diagnosing cognitive impairment or dementia with MRS, and there are insufficient data on diagnostic comparators. Additionally, the impact of MRS on clinical management and health outcomes is unknown.

## **LIVER DISEASE**

### **Clinical Context and Test Purpose**

The purpose of MRS in patients with liver disease is to improve the diagnosis and management of liver disease.

The question addressed in this evidence review is: Does the use of MRS improve the net health outcome of patients with liver disease?

The following PICO was used to select literature to inform this review.

#### ***Populations***

The relevant populations of interest is patients being evaluated for liver disease.

#### ***Interventions***

The intervention of interest is MRS.

#### ***Comparators***

The following practice is currently being used to make decisions about managing liver disease: liver biopsy.

#### ***Outcomes***

The outcomes of interest are sensitivity and specificity and the effect on health outcomes. The time of interest is at the initial evaluation or at clinical follow-up.

### **Study Selection Criteria**

For the evaluation of the clinical validity of the tests, studies that meet the following eligibility criteria were considered:

- Reported on the accuracy of the marketed version of the technology (including any algorithms used to calculate scores)
- Included a suitable reference standard
- Patient/sample clinical characteristics were described

- Patient/sample selection criteria were described
- Included a validation cohort separate from development cohort.

### **Clinically Valid**

A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

## **REVIEW OF EVIDENCE**

### **Diagnostic Accuracy Studies**

MRS has been evaluated as a noninvasive alternative to liver biopsy in the diagnosis of hepatic steatosis. It has been compared with other noninvasive imaging procedures such as computed tomography, dual-gradient echo MRI (DGE-MRI), and ultrasonography with liver biopsy as the reference standard. In a prospective study of 161 consecutive potential living liver donors, DGE-MRI was reported to be the most accurate test for diagnosing hepatic steatosis. While DGE-MRI and MRS were similar for hepatic steatosis 5% or greater, DGE-MRI outperformed MRS for hepatic steatosis 30% or greater, with a sensitivity and specificity of 90.9% and 94%, respectively<sup>34</sup>, (see also Taouli et al [2009]<sup>35</sup>).

### **Clinically Useful**

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

### **Direct Evidence**

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified that support the clinical utility of MRS for this indication.

### **Chain of Evidence**

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Because the clinical validity of MRS has not been established for this indication, a chain of evidence cannot be constructed.

### **Section Summary: Liver Disease**

The available evidence does not support the utility of MRS for assessment of hepatic steatosis.

## **MULTIPLE SCLEROSIS**

### **Clinical Context and Test Purpose**

The purpose of MRS in patients with MS is to improve the diagnosis and management of multiple sclerosis (MS).

The question addressed in this evidence review is: Does the use of MRS improve the net health outcome of patients with MS?

The following PICO was used to select literature to inform this review.

### ***Populations***

The relevant population of interest is patients being evaluated for MS.

### ***Interventions***

The intervention of interest is MRS.

### ***Comparators***

The following practice is currently being used to make decisions about managing MS: observation.

### ***Outcomes***

The outcomes of interest are sensitivity and specificity and the effect on health outcomes. The time of interest is at the initial evaluation or at clinical follow-up.

### **Study Selection Criteria**

For the evaluation of the clinical validity of the tests, studies that meet the following eligibility criteria were considered:

- Reported on the accuracy of the marketed version of the technology (including any algorithms used to calculate scores)
- Included a suitable reference standard
- Patient/sample clinical characteristics were described
- Patient/sample selection criteria were described
- Included a validation cohort separate from development cohort.

### **Clinically Valid**

A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

## **REVIEW OF EVIDENCE**

### **Prospective Studies**

MS is a chronic disease with variable prognosis and clinical course. Predictors of future disease course might help select patients who would benefit most from disease-modifying treatments.<sup>36</sup>

Solanky et al (2020) published a cross-sectional analysis of 119 patients with secondary-progressive MS recruited from the MS-Secondary Progressive Multi-Arm Randomization Trial (MS-SMART).<sup>37</sup> The relationship between neurometabolites and various clinical disability measures

was examined via Spearman rank correlations. Significant associations were further analyzed via multiple regression models adjusted for age, sex, disease duration, T2 lesion load, normalized brain volume and history of recent relapse occurrence. Significant associations in normal-appearing white matter were found for tNAA and Nine-Hole Peg Test (9HPT) ( $r = 0.23$ ; 95% CI, 0.06 to 0.40), tNAA and Paced Auditory Serial Addition Test (PASAT) ( $r = 0.21$ ; 95% CI, 0.03 to 0.38), tNAA/tCr and PASAT ( $r = 0.19$ ; 95% CI, 0.01 to 0.36), and mIns/tCr and PASAT ( $r = -0.23$ ; 95% CI, -0.39 to -0.05). No significant associations were found for any neurometabolite levels and the Expanded Disability Status Scale (EDSS) or Timed 25-Foot Walk (T25FW) tests following multiple regression analysis.

Llufriu et al (2014) published a study assessing the use of MRS in a preliminary data set of 59 patients with MS and 43 healthy controls, and in a confirmatory independent data set of 220 patients.<sup>38</sup> Change in brain volume and measures of disability were obtained annually. The myo-inositol to NAA ratio in the normal-appearing white matter was found to be a predictor of brain volume change over 4 years ( $p=.02$ ) and of clinical disability (eg, a decrease in the Multiple Sclerosis Functional Composite evolution scale of -0.23 points annually,  $p=.01$ ). Effect sizes in this study were low, indicating that the measure is not sufficiently reliable to predict the future disease course in individual patients.

### **Clinically Useful**

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

### **Direct Evidence**

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified that support the clinical utility of MRS for this indication.

### **Chain of Evidence**

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Because the clinical validity of MRS has not been established for this indication, a chain of evidence cannot be constructed.

### **Section Summary: Multiple Sclerosis**

Future research is needed that includes larger cohorts with progressive MS, serial measurements of outcomes, and complementary measures of disease activity.<sup>36</sup>

## **PSYCHIATRIC DISORDERS**

### **Clinical Context and Test Purpose**

The purpose of MRS in patients with psychiatric disorders is to improve the diagnosis and management of psychiatric disorders.

The question addressed in this evidence review is: Does the use of MRS improve the net health outcome of patients with psychiatric disorders?

The following PICO was used to select literature to inform this review.

### ***Populations***

The relevant populations of interest are patients being evaluated for psychiatric disorders.

### ***Interventions***

The intervention of interest is MRS.

### ***Comparators***

The following practices are currently being used to make decisions about diagnosing and managing psychiatric disorders: standard care (eg, unstructured clinical interview and observation) or structured clinical interviews (ie, application of Diagnostic and Statistical Manual of Mental Disorders, 5th Edition [DSM-5] criteria).

### ***Outcomes***

The outcomes of interest are sensitivity and specificity and the effect on health outcomes. The time of interest is at the initial evaluation or at clinical follow-up.

### **Study Selection Criteria**

For the evaluation of the clinical validity of the tests, studies that meet the following eligibility criteria were considered:

- Reported on the accuracy of the marketed version of the technology (including any algorithms used to calculate scores)
- Included a suitable reference standard
- Patient/sample clinical characteristics were described
- Patient/sample selection criteria were described
- Included a validation cohort separate from development cohort.

### **Clinically Valid**

A test must detect the presence or absence of a condition, the risk of developing a condition in the future, or treatment response (beneficial or adverse).

### **Review of Evidence**

Research use of MRS continues to evolve and test correlations between brain biomarker levels and various psychiatric disorders (eg, major depressive disorder, bipolar disorder, schizophrenia, post-traumatic stress disorder, psychosis risk, and others) to inform diagnosis or patient management.<sup>39,40,41,42,43,44,45,46,47,</sup>

### **Prospective Studies**

Henigsberg et al (2019) evaluated 48 patients with unipolar depression from recovery onset until recurrence of depression or until discontinuation of antidepressant maintenance therapy.<sup>48</sup> Depressive symptom remission was confirmed with a Montgomery-Asberg rating Scale (MARDS) score  $\leq 10$ . 1H MRS scans were performed at the onset of recovery and after 6 months. N-acetylaspartate, Cho, and glutamine/glutamate and GABA metabolic spectra were obtained from the left amygdala region. Patients were evaluated with psychiatric interviews and MARDS assessments during the study period at regular intervals of 6 months or less, for up to 7 years. Twenty patients experienced recurrence, 23 patients achieved antidepressant discontinuation, and follow-up data was missing for 5 patients. Cho levels at the beginning of recovery and subsequent changes conveyed the highest risk for earlier recurrence. Patients with higher amygdala Cho after recovery were found to be at significantly lower risk for depression recurrence (hazard ratio [HR] 0.32; 95% CI, 0.13 to 0.77). Patients were managed on various antidepressant medications, and criteria for antidepressant discontinuation were unclear.

Godlewska et al (2019) published a study assessing the use of MRS to track and predict treatment response to lamotrigine in 21 patients with bipolar depression.<sup>49</sup> Before starting lamotrigine and after 10 to 12 weeks of treatment, patients underwent MRS scanning to determine levels of glutamate (Glx) in the anterior cingulate cortex. Baseline levels of Glx did not predict response to lamotrigine ( $p = .49$ ). Responders to lamotrigine showed a significant increase in Glx levels from baseline ( $p = .012$ ), however, the size of this increase was small ( $14.8 \pm 1.3$  to  $14.3 \pm 0.98 \mu\text{mol/g}$ ). The significance between final Glx levels in responders and nonresponders was not reported.

### **Clinically Useful**

A test is clinically useful if the use of the results informs management decisions that improve the net health outcome of care. The net health outcome can be improved if patients receive correct therapy, or more effective therapy, or avoid unnecessary therapy, or avoid unnecessary testing.

### **Direct Evidence**

Direct evidence of clinical utility is provided by studies that have compared health outcomes for patients managed with and without the test. Because these are intervention studies, the preferred evidence would be from RCTs.

No RCTs were identified that support the clinical utility of MRS for this indication.

### **Chain of Evidence**

Indirect evidence on clinical utility rests on clinical validity. If the evidence is insufficient to demonstrate test performance, no inferences can be made about clinical utility.

Because the clinical validity of MRS has not been established for this indication, a chain of evidence cannot be constructed.

### **Section Summary: Psychiatric Disorders**

Although a number of studies have examined the use of MRS for identifying and understanding psychiatric disorders, the present evidence does not support any role for MRS outside of the research setting. Numerous methodologies for the use of MRS in this setting have been described, with inconsistent diagnostic validity results. Additionally, preliminary studies have thus

far failed to demonstrate the successful application of MRS for the prediction of treatment response. Furthermore, the impact of MRS on health outcomes for this indication is unknown.

### **Other Indications**

MRS has also been evaluated for other uses, such as tracking disease changes among patients with systemic lupus erythematosus,<sup>50</sup> assessing carotid plaque morphology,<sup>51</sup> identifying biomarkers of traumatic brain injury,<sup>52,53</sup> and predicting long-term neurodevelopmental outcome after neonatal encephalopathy.<sup>54,55,56,57</sup> MRS has also been used to evaluate pediatric patients with seizures,<sup>58</sup> and other applications in children.<sup>59</sup> Additional evidence on these applications is needed.

### **Summary of Evidence**

For individuals who have brain tumors who receive MRS, the evidence includes a number of small studies and systematic reviews. Relevant outcomes are test accuracy, change in disease status, morbid events, and functional outcomes. Small studies have evaluated detection, characterization, grading, prognosis, and differentiation of tumor recurrence versus necrosis. Most studies included in the meta-analyses were small, retrospective, and used various ratios of MRS spectra. The largest prospective studies found that combining MRS with MRI resulted in a greater percentage of correct diagnoses of pediatric brain tumor type. These reports had limited information on the specific MRS spectra associated with different tumor types. Additional study is needed to better define the spectra associated with tumor characteristics, to evaluate the diagnostic accuracy, and to determine the effect on health outcomes. The evidence is insufficient to determine that the technology results in an improvement in the net health outcome.

For individuals who have breast cancer, prostate cancer, dementia, liver disease, MS, or psychiatric disorders who receive MRS, the evidence includes prospective studies on diagnostic accuracy and systematic reviews. Relevant outcomes are test accuracy, change in disease status, morbid events, and functional outcomes. A number of studies have examined the use of MRS for localized prostate cancer for biopsy, for diagnosis, and for the monitoring of patients with prostate cancer. However, the cumulative evidence remains uncertain. Data comparing the diagnostic accuracy of MRS with alternative imaging strategies are limited. A systematic review of MRS to identify dementia concluded that to characterize Alzheimer disease-associated neurochemical changes effectively, future approaches need to analyze interactively multiple quantifiable metabolites from different brain regions. A study of MRS as a noninvasive alternative to liver biopsy indicated that dual-gradient echo MRI outperforms MRS. Data on the use of MRS in MS has indicated that the measure is not sufficiently reliable to predict the future disease course. Research assessing MRS for the management of bipolar disorder has thus far failed to demonstrate its ability to predict treatment response. The evidence is insufficient to determine that the technology results in an improvement in the net health outcome.

### **SUPPLEMENTAL INFORMATION**

The purpose of the following information is to provide reference material. Inclusion does not imply endorsement or alignment with the evidence review conclusions.

### **Clinical Input From Physician Specialty Societies and Academic Medical Centers**

While the various physician specialty societies and academic medical centers may collaborate with and make recommendations during this process, through the provision of appropriate reviewers, input received does not represent an endorsement or position statement by the physician specialty societies or academic medical centers, unless otherwise noted.

### **2008 Input**

In response to requests, input was received from 3 physician specialty societies and 1 academic medical center while this policy was under review in 2008. Input received disagreed with the conclusions in the policy statement. In particular, the information provided supported the use of magnetic resonance spectroscopy in differentiating radiation necrosis from recurrent tumor and in the differential diagnosis of certain central nervous system tumors from nontumors.

### **Practice Guidelines and Position Statements**

Guidelines or position statements will be considered for inclusion in 'Supplemental Information' if they were issued by, or jointly by, a US professional society, an international society with US representation, or National Institute for Health and Care Excellence (NICE). Priority will be given to guidelines that are informed by a systematic review, include strength of evidence ratings, and include a description of management of conflict of interest.

### **National Comprehensive Cancer Network**

The National Comprehensive Cancer Network (NCCN) clinical guidelines on central nervous system cancers (v.1.2021) identifies magnetic resonance spectroscopy (MRS) as one of several modalities that can be considered to rule out radiation necrosis, as compared with recurrence of brain tumors.<sup>60</sup> The guidelines also state that MRS may be helpful in grading tumors or assessing response and that the most abnormal area on MRS would be the best target for biopsy. The limitations include tumors near vessels, air spaces, or bone, and the extra time required in a magnetic resonance imaging machine.

The NCCN clinical guidelines on prostate cancer (v.2.2021) list MRS as an advanced imaging technique but make no recommendations for its use.<sup>61</sup>

The NCCN clinical guidelines on breast cancer (v.6.2021) do not mention MRS.<sup>62</sup>

### **American Association of Neurological Surgeons et al**

The American Association of Neurological Surgeons and Congress of Neurological Surgeons (2015) gave a level III recommendation (level C) for the addition of MRS to anatomic imaging for the management of diffuse low-grade glioma because the diagnostic accuracy is not well-defined and the role in clinical practice is still being defined.<sup>63</sup>

### **Congress of Neurological Surgeons**

The Congress of Neurological Surgeons (2016) published an evidence-based guideline on preoperative imaging assessment of patients with suspected nonfunctioning pituitary adenomas.<sup>64</sup> The Congress found that although the results were promising, there was insufficient evidence to recommend the use of MRS formally.

### American College of Radiology et al

The American College of Radiology, American Society of Neuroradiology, and Society for Pediatric Radiology (2019 ) updated their joint practice parameters on MRS of the central nervous system.<sup>65</sup> Most of the update addressed the actual performance of MRS, but it also listed 25 possible indications for MRS when magnetic resonance imaging or computed tomography is inadequate for answering specific clinical questions.

MRS of the head without IV contrast is considered "usually not appropriate" in dementia (including cognitive decline and suspected Alzheimer disease), head trauma in adults and children, movement disorders, and neurodegenerative diseases.<sup>66</sup>

### National Institute for Health and Care Excellence

The National Institute for Health and Care Excellence (NICE) guidance on primary brain tumors and brain metastases in adults, updated in 2021, includes the following recommendations regarding the use of MRS:<sup>67</sup>

- In patients undergoing imaging for suspected glioma, advanced magnetic resonance imaging (MRI) techniques, such as MR perfusion and MRS may be considered to assess the potential of a high-grade transformation in a tumor appearing to be low grade on standard structural MRI.
- In patients undergoing follow-up for glioma or brain metastases, advanced MRI techniques such as MR perfusion, diffusion tensor imaging and MRS may be considered if findings from standard imaging are unclear regarding whether there is recurrence and early identification is potentially clinically useful.

The NICE guidance on Parkinson's disease in adults, amended in 2017, states that MRS should not be used in the differential diagnosis of parkinsonian syndromes.<sup>68</sup>

### U.S. Preventive Services Task Force Recommendations

Not applicable.

### Ongoing and Unpublished Clinical Trials

Some currently ongoing and unpublished trials that might influence this review are listed in Table 8.

**Table 8. Summary of Key Trials**

NCT No.	Trial Name	Planned Enrollment	Completion Date
<i>Ongoing</i>			
NCT02388659	Clinical Development of Cancer-Specific MRS Biomarkers in Malignant Gliomas	105	Dec 202 1 (recruiting)
NCT02731521	Clinical Development of MR Spectroscopy and Imaging in Brain Cancers	175	Dec 202 1 (recruiting)

<b>NCT No.</b>	<b>Trial Name</b>	<b>Planned Enrollment</b>	<b>Completion Date</b>
<i>Ongoing</i>			
NCT03324360	Role of Hyperpolarized 13C-Pyruvate MR Spectroscopy in Patients with Intracranial Metastasis Treated with Stereotactic Radiosurgery	156	Jan 2022 (recruiting)
NCT00581906	Dynamic Contrast Enhanced MRI (DCE-MRI), Diffusion-Weighted MRI (DW-MRI), and Magnetic Resonance Spectroscopy (MRS) of Head and Neck Tumors	272	Feb 2022 (ongoing)
NCT02714894	Response to Clozapine in Treatment Resistant Schizophrenia: A Longitudinal Magnetic Resonance Spectroscopy Study	108	Mar 2022 (recruiting)
NCT02137759 <sup>a</sup>	Quantitative Magnetic Resonance Spectroscopic Imaging (MRSI) to Predict Early Response to Standard Radiation Therapy (RT)/Temozolomide (TMZ) ± Belinostat Therapy in Newly-Diagnosed Glioblastomas (GBM)	29	Sep 2021 (ongoing)
NCT04540107 <sup>a</sup>	Metabolic Imaging of Patients With Lower Grade Glioma Using Hyperpolarized 13C Pyruvate	300	Jan 2024 (recruiting)
NCT03952598	Studying the Biology of IDH-mutant Gliomas Via Longitudinal Observation of 2-Hydroxyglutarate (2-HG) Using MR Spectroscopy	270	Dec 2025 (recruiting)
NCT03677999	Spectroscopic Magnetic Resonance Imaging of Glioma (MEGA-PRESS)	304	Sep 2025 (recruiting)
NCT00474604	MRI Evaluation of Breast Tumor Growth and Treatment Response	250	Dec 2025 (recruiting)
<i>Unpublished</i>			
NCT00184210	Magnetic Resonance (MR) Spectroscopy of Breast Cancer Tissue	1000	Dec 2020 (terminated)
NCT01653093	Imaging of the Prostate Gland Using High Field Strength 3T MRI	280	Dec 2020 (unknown)
NCT03619694	Role of MR Spectroscopy in Brain Tumors	100	Oct 2018 (unknown)
NCT00067821	A Comparative Study of Pediatric CNS Tumor Activity as Assessed by [18]F-FDG PET Imaging and Proton Magnetic Resonance Spectroscopic Imaging([1]H-MRSI)	79	NR (completed)

NCT: national clinical trial; NR: not reported.

<sup>a</sup> Denotes industry-sponsored or cosponsored trial.

**CODING**

**The following codes for treatment and procedures applicable to this policy are included below for informational purposes. This may not be a comprehensive list of procedure codes applicable to this policy.**

**Inclusion or exclusion of a procedure, diagnosis or device code(s) does not constitute or imply member coverage or provider reimbursement. Please refer to the member's contract benefits in effect at the time of service to determine coverage or non-coverage of these services as it applies to an individual member.**

**The code(s) listed below are medically necessary ONLY if the procedure is performed according to the "Policy" section of this document.**

**CPT/HCPCS**

76390            Magnetic resonance spectroscopy

**ICD-10 DIAGNOSES**

Experimental / Investigational for all diagnoses related to this medical policy.

<b>REVISIONS</b>	
06-16-2009	Added policy to bcbsks.com web site.
02-24-2012	Description updated.
	Rationale updated.
	References updated.
03-26-2013	Updated Description section.
	Updated Rationale section.
	Updated Reference section.
09-17-2014	Updated Rationale section.
	Updated Reference section.
06-23-2015	Updated Description section.
	Updated Rationale section.
	Updated references.
04-25-2016	Description section updated
	Rational section updated
	References updated
12-19-2018	Description section updated
	Rational section updated
	References updated
05-18-2020	Description section updated
	Rational section updated
	References updated
12-2-2021	Updated Description Section
	Updated Rationale Section
	Updated References Section

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