Iron and Non-Iron-Related Characteristics of Multiple Sclerosis and Neuromyelitis Optica Lesions at 7T MRI


AJNR Am J Neuroradiol 2016, 37 (7) 1223-1230
doi: https://doi.org/10.3174/ajnr.A4729
http://www.ajnr.org/content/37/7/1223
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ABSTRACT

BACKGROUND AND PURPOSE: Characterization of iron deposition associated with demyelinating lesions of multiple sclerosis and neuromyelitis optica has not been well studied. Our aim was to investigate the potential of ultra-high-field MR imaging to distinguish MS from neuromyelitis optica and to characterize tissue injury associated with iron pathology within lesions.

MATERIALS AND METHODS: Twenty-one patients with MS and 21 patients with neuromyelitis optica underwent 7T high-resolution 2D-gradient-echo-T2* and 3D-susceptibility-weighted imaging. An in-house-developed algorithm was used to reconstruct quantitative susceptibility mapping from SWI. Lesions were classified as “iron-laden” if they demonstrated hypointensity on gradient-echo-T2*-weighted images and/or SWI and hyperintensity on quantitative susceptibility mapping. Lesions were considered “non-iron-laden” if they were hyperintense on gradient-echo-T2* and isointense or hyperintense on quantitative susceptibility mapping.

RESULTS: Of 21 patients with MS, 19 (90.5%) demonstrated at least 1 quantitative susceptibility mapping–hyperintense lesion, and 11/21 (52.4%) had iron-laden lesions. No quantitative susceptibility mapping–hyperintense or iron-laden lesions were observed in any patients with neuromyelitis optica. Iron-laden and non-iron-laden lesions could each be further characterized into 2 distinct patterns based on lesion signal and morphology on gradient-echo-T2*/SWI and quantitative susceptibility mapping. In MS, most lesions (n = 262, 75.9% of all lesions) were hyperintense on gradient-echo-T2* and isointense on quantitative susceptibility mapping (pattern A), while a small minority (n = 26, 7.5% of all lesions) were hyperintense on both gradient-echo-T2* and quantitative susceptibility mapping (pattern B). Iron-laden lesions (n = 57, 16.5% of all lesions) were further classified as nodular (n = 22, 6.4%, pattern C) or ringlike (n = 35, 10.1%, pattern D).

CONCLUSIONS: Ultra-high-field MR imaging may be useful in distinguishing MS from neuromyelitis optica. Different patterns related to iron and noniron pathology may provide in vivo insight into the pathophysiology of lesions in MS.

ABBREVIATIONS: GRE = gradient-echo; NMO = neuromyelitis optica; ppb = parts per billion; QSM = quantitative susceptibility mapping; R2* = transverse relaxation rate

Multiple sclerosis and neuromyelitis optica (NMO) are distinct inflammatory disorders of the CNS with different pathophysiology and approaches to treatment.1 It is imperative to differentiate MS from NMO before the commencement of treatment, but this task can be challenging in view of the overlap in clinical manifestations and findings on conventional neuroimaging.2 Ultra-high-field imaging, by virtue of increased SNR, increased spatial resolution, and markedly improved venous and iron contrast within lesions,3 has the potential to shed light on the underlying pathophysiology of MS and NMO and help distinguish these 2 conditions.7T MR imaging studies4,5 have shown that 60%–80% of MS lesions are traversed by a central venule, while only a small minority of NMO lesions contain a central...
Iron pathology may also be different in these 2 diseases: substantially higher iron content has been observed in deep GM regions of patients with MS than in those with NMO. In MS, iron accumulation in both acute and chronic phases of lesion development has been reported, but to our knowledge, no studies have investigated whether iron is present in brain lesions of NMO.

The underlying pathology of MS lesions can be a dynamic process involving both demyelination and iron-related pathophysiology during the course of the disease. Compared with conventional T2* imaging or SWI, the recent development of quantitative susceptibility mapping (QSM) offers a useful tool for iron quantification by deconvolving the phase images. Both paramagnetic (eg, iron) and diamagnetic materials (eg, myelin) present low signal on conventional T2* or SWI; however, their susceptibility sources can be well-differentiated on QSM, with paramagnetic materials being high signal and diamagnetic material being low signal. Consequently, demyelination (diamagnetic myelin loss) and accompanying tissue water changes result in increased signal on T2* or SWI, but relatively low QSM values compared with iron deposition. Therefore, it is possible to make inferences about underlying tissue pathology associated with iron deposition and demyelination by using QSM combined with other multicontrast sequences. Moreover, QSM improves the detection and spatial distribution of subtle iron deposition that is not seen on conventional T2* imaging. This improvement makes it possible to describe patterns of iron deposition within lesions (eg, nodular versus ringlike) on the basis of their T7 MR imaging findings, which have been rarely described in the literature.

The purpose of the present study was to investigate the potential of multicontrast ultra-high-field MR imaging to distinguish patients with MS from those with NMO and to characterize T7 MR imaging lesion patterns that are associated with iron and noniron pathology in these diseases.

MATERIALS AND METHODS

Subjects

This study was conducted at 2 academic MS referral centers: New York University Medical Center, New York, and Charité University, Berlin. Both sites received approval from local institutional review boards. Written informed consent was obtained from all patients before study entry. Inclusion criteria were a diagnosis of NMO spectrum disorders (International Panel for NMO Diagnos- sis Criteria) or definite MS (McDonald Criteria). Twenty-one patients with NMO (mean age, 47.6 ± 14.2 years; all women, mean disease duration, 8.4 ± 6.7 years; range, 1–26.6 years) were enrolled in this study. All patients were NMO Ab seropositive by immunohistochemical or by enzyme-linked immunosorbent assays.

Twenty-five patients with MS were enrolled (mean age, 47.1 ± 10.3 years; 6 men/15 women; disease duration, 11.5 ± 5.9 years; range, 4–25 years). This group included patients with relapsing-remitting (n = 19) and secondary-progressive (n = 2) MS. There was no significant difference in mean age and mean disease duration between MS and NMO groups (P > .05).

Ultra-High-Field MR Imaging

All patients underwent ultra-high-field MR imaging by using identical whole-body 7T human MR imaging systems (Magne-
Table 1: Proposed histopathologic interpretation based on signal-intensity changes on MR images

<table>
<thead>
<tr>
<th>Tissue Content</th>
<th>Susceptibility Effect</th>
<th>Signal Intensity on GRE-T2*</th>
<th>Signal Intensity on SWI</th>
<th>Signal Intensity on QSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Diamagnetism</td>
<td>Hypointense</td>
<td>Hypointense</td>
<td>Hypointense</td>
</tr>
<tr>
<td>Myelin</td>
<td>Diamagnetism</td>
<td>Hypointense</td>
<td>Hypointense</td>
<td>Hypointense</td>
</tr>
<tr>
<td>Variable degree of micronecrosis, edema, gliosis, demyelination, and macromolecules</td>
<td>Diamagnetism</td>
<td>Hyperintense</td>
<td>Isointense or hyperintense</td>
<td>Isointense</td>
</tr>
<tr>
<td>Extensive degree of demyelination</td>
<td>Loss of diamagnetism (paramagnetism)</td>
<td>Hyperintense</td>
<td>Isointense or hyperintense</td>
<td>Hyperintense</td>
</tr>
<tr>
<td>Iron</td>
<td>Paramagnetism</td>
<td>Hypeintense</td>
<td>Hypeintense</td>
<td>Hyperintense</td>
</tr>
</tbody>
</table>

Table 1. On the basis of this table, we analyzed lesion signal intensity on GRE-T2*, SWI, and QSM images. Pattern A lesions were hyperintense on GRE-T2*-weighted images, hyperintense or isointense (inconspicuous) on QSM. Pattern B lesions were hyperintense on GRE-T2* and hypointense on QSM. Pattern A and B lesions were considered non-iron-enriched. On the other hand, lesions that demonstrated hypointensity on GRE-T2* and/or SWI and hyperintensity on QSM were considered “iron-laden.” These lesions were further classified as nodular (pattern C) or exhibiting a peripheral rim (pattern D). We computed QSM values from all lesions that demonstrated hyperintensity on QSM by manually drawing ROIs. Because the use of a high-pass filter while reconstructing QSM maps may reduce the effective iron content from different tissue compartments, we believe this process might have resulted in underestimation of the QSM values computed from iron- and non-iron-laden lesions. To correct for the QSM values, we used a simulation algorithm to obtain a scaling factor based on the size of the lesions. This size-dependent scaling factor was multiplied by the original QSM values to obtain corrected QSM values for each lesion.

Statistical Analysis
A \( \chi^2 \) test was performed to look for differences in proportions of lesions with central venules in patients with MS and NMO. Receiver operating characteristic analyses were performed to estimate the sensitivity and specificity of selected subject-level conditions (at least 1 lesion with a central venule, at least 1 iron-laden lesion, at least 1 QSM hyperintense lesion) as criteria for classifying patients as testing positive for MS. Clopper-Pearson confidence intervals were derived for the sensitivity and specificity associated with each condition.

All lesions providing a QSM value were classified as having a central venule. Mixed-model analysis of variance was used to compare iron-laden from non-iron-laden lesions in terms of QSM while accounting for the correlation among QSM values derived for lesions in the same patient. The covariance structure was modeled by assuming QSM values to be independent when acquired from different patients and symmetrically correlated when acquired from lesions within the same patient, with the strength of correlation dependent on whether lesions were of the same type (eg, lesions were both classified as iron-laden). A probability value < .05 was considered significant. All data analysis was performed by using SPSS for Windows, Version 15.0 (IBM, Armonk, New York).

**RESULTS**

**Distinguishing Patients with MS from Those with NMO**

A total of 345 MS and 132 NMO discrete lesions were observed in supratentorial brain regions of 21 patients with MS and 21 with NMO. The mean cross-sectional diameter for MS lesions (5.44 ± 2.66 mm) was significantly larger than that of NMO lesions (3.19 ± 1.12 mm, \( P < .001 \)). While MS lesions had variable shapes, most of the NMO lesions were round. Of 345 MS lesions, 227 (65.8%) were traversed by intralesional central venules, while only 8/132 (6.1%) NMO lesions showed this feature. All patients with MS had \( \geq 1 \) lesion traversed by a central venule. On the other hand, only 4 patients with NMO had \( \geq 1 \) lesion traversed by a central venule. The presence of at least 1 lesion with a central venule distinguished MS from NMO with a sensitivity of 100% (95% CI, 83.9%–100%) and a specificity of 71.4% (95% CI, 47.8%–88.7%).

MS lesions varied in signal intensity on GRE-T2*, SWI, and QSM. In the MS cohort, 19/21 (90.5%) patients had at least 1 hyperintense lesion on QSM, and this feature distinguished patients with MS from those with NMO with a sensitivity of 90.5% (95% CI, 69.6%–98.8%) and a specificity of 100% (95% CI, 83.9%–100%). Moreover, 11/21 (52.4%) patients had iron-laden lesions (see the “Data Analysis” section for a definition). In contrast, all NMO lesions demonstrated hyperintense signal relative to surrounding brain parenchyma on GRE-T2*-weighted images and were isointense (inconspicuous) on QSM. Thus, none of the patients with NMO had any iron-rich lesions (Fig 1). The presence of at least 1 iron-laden lesion characteristic distinguished MS from NMO with a sensitivity of 52.4% (95% CI, 29.8%–74.3%) and a specificity of 100% (95% CI, 83.9%–100%).

**Characterization of Different Lesion Patterns in MS**

Examples of 4 morphologically distinct lesion patterns seen in MS are shown in Figs 2 and 3. Signal intensity on GRE-T2*, SWI, and QSM for different lesion patterns in MS is presented in Table 2. Most of the MS lesions (826, 75.9%) were pattern A (all were hyperintense on GRE-T2*-weighted images and inconspicuous on QSM). On SWI, only 53/262 of these lesions demonstrated hyperintensity. Of 262 pattern A lesions, 148 (56.4%) were traversed by a central venule. A small number of lesions (17, 5.7%) were pattern B (hyperintensity on both GRE-T2*-weighted images and QSM). On SWI, only 11/26 of these lesions demonstrated hyperintensity. Of the 26 pattern B lesions, 22 (84%) were traversed by a central venule.

Some lesions (17, 16.5% of all MS lesions) demonstrated
hypointensity on GRE-T2*-weighted images and/or SWI, but hyperintensity on QSM; these lesions were presumed to be iron-laden. Seventeen of 57 iron-laden MS lesions demonstrated hyperintensity on GRE-T2*, and 40/57 were hypointense on GRE-T2* images. All except 1 (56/57) demonstrated hypointensity on SWI. All of these iron-laden QSM hyperintense lesions were traversed by a central venule (57/57). Furthermore, of 288 non-iron-laden MS lesions, 240 (83.3%) had ill-defined and faint margins generally, while only 12 of 57 (21%) iron-laden MS lesions had ill-defined margins (Fig 4).

The iron-laden lesions had 2 geometrically distinct susceptibility patterns: nodular if they had solid signal intensity on QSM (n = 22, 6.4%; pattern C) or ringlike if they had a distinct peripheral rim on QSM (n = 35, 10.1%; pattern D). However, all of these iron-laden lesions demonstrated hypointensity on SWI. The mean QSM was significantly higher for iron-laden lesions than for non-iron-laden lesions (P = .027; Fig 5A). The least squares mean standard error of the mean of QSM, adjusted for within-subject correlations, was 38.73 ± 4.81 parts per billion (ppb) for iron-laden lesions and 26.36 ± 2.2 ppb for lesions that were not iron-laden. Receiver operating characteristic analysis provided a threshold QSM value of 39.26 ppb to distinguish iron- from non-iron-laden lesions with a sensitivity of 70.2% and specificity of 57.7% (Fig 5B).

DISCUSSION

Early differentiation of NMO from MS is crucial for optimal management clinically.1,2 Although the recent availability of commercial testing for antibodies to Aquaporin-4 water has facilitated differentiation of NMO from MS, a correct diagnosis still remains challenging, particularly in those patients with NMO with multiple brain lesions on MR imaging. Many patients with NMO are still misdiagnosed with MS.25 Hence, development of newer imaging biomarkers that can enable objective separation of these 2 diseases is warranted. Our analysis of the morphologic and structural features of MS and NMO supratentorial lesions by using multicontrast 7T MR imaging helps to further differentiate the 2 conditions and provides insight into lesional pathology in vivo. We found that iron deposition within a lesion (hyperintense signal on QSM) distinguished patients with MS from those with NMO with a sensitivity of 90.5% (95% CI, 69.6%–98.8%) and a specificity of 100% (95% CI, 83.9%–100%). Analysis of the signal intensity of lesions on GRE, SWI, and QSM sequences allowed us to divide all lesions into 4 patterns, of which 2 were iron-enriched and 2 were non-iron-enriched (Table 2). A characteristic feature of MS was the
deposition may vary among individual lesions on the basis of their identity sources such as iron, myelin, and calcium that are present in more robust and quantitative evaluation of magnetic susceptibility heterogeneity of phase and R2* and thereby render these images and distribution of susceptibility sources that may influence the existing MS lesions.11 In these reactive lesions, demyelination and gliosis in chronic inactive lesions. A minority of non-iron-containing lesions demonstrated hyperintensity on both GRE-T2* and QSM images (pattern B), suggesting more acute and extensive demyelination (loss of diamagnetism, but less magnetic susceptibility effect than iron deposition) and inflammation compared with pattern A lesions. Because no tissue specimens were available to perform histopathologic/histochemical analysis from our patients, our interpretation of the imaging features was based on the prior correlative imaging and histopathologic studies.11,12 More work is needed to ascertain the pathologic significance of susceptibility changes.

Iron-laden MS lesions with hyperintensities on QSM were of 2 patterns: iron either deposited in the center core (nodular iron-laden lesions, pattern C) or in a ringlike fashion at the lesion edge (pattern D). Previous histochemical studies showed that iron deposits were present in a subset of chronic, demyelinating active MS lesions.11,12 The molecular pathways for iron accumulation in MS lesions are still not fully understood; however, several possible biologic mechanisms, such as iron-rich oligodendrocyte debris, iron-sequestered microglia or macrophages, and products of local microhemorrhages following venule wall damage may contribute to iron deposition.4,13 On 3T MR imaging, Chen et al18 observed lower QSM values from acute enhancing lesions (small susceptibilities) and increased QSM values from nonenhancing lesions (high susceptibilities). This observation suggests that lesion susceptibility measured by QSM is a useful biomarker for monitoring MS disease activities. Perhaps, the preponderance of non-iron-containing lesions in MS in our study is because they were imaged long after their formative stage.

Most iron-laden lesions in our study were ringlike. Histopathologically, it has been observed that maximum accumulation of iron occurs at the edges of classic, reactive, slowly expanding chronically existing MS lesions.11 In these reactive lesions, demyelination and oligodendrocyte destruction occur in a zone of variable size at the lesion border. Thus, iron-containing myelin and oligodendrocytes gradually decreased from the perilesional regions toward the lesion centers. Additionally, iron-containing microglia and macrophages that are mainly located at the edge of chronic reactive lesions undergo microglial dystrophy leading to a variable degree of iron deposition within the different compartments of the MS lesions.11,12 Moreover, iron-laden MS lesions were well-circumscribed with well-defined margins while non-iron-laden lesions had poorly defined margins and were generally larger. The reason for this observation is not clearly understood; however, it might be because of accumulation of distinct patterns of MS lesions, 2 of which were considered iron-enriched. Most non-iron-enriched MS lesions were hyperintense on GRE-T2*-weighted images and isointense and thus inconspicuous on QSM (pattern A). This pattern could be plausibly attributed to varying degrees of demyelination, edema, microcercrosis, and gliosis in chronic inactive lesions. A minority of non-iron-containing lesions demonstrated hyperintensity on both GRE-T2* and QSM images (pattern B), suggesting more acute and extensive demyelination (loss of diamagnetism, but less magnetic susceptibility effect than iron deposition) and inflammation compared with pattern A lesions. Because no tissue specimens were available to perform histopathologic/histochemical analysis from our patients, our interpretation of the imaging features was based on the prior correlative imaging and histopathologic studies.11,12 More work is needed to ascertain the pathologic significance of susceptibility changes.

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### Table 2: Signal intensity on GRE-T2*, SWI, and QSM for different lesion patterns in MS

<table>
<thead>
<tr>
<th>Lesion Pattern</th>
<th>Signal Intensity on GRE-T2*</th>
<th>Signal Intensity on SWI</th>
<th>Signal Intensity on QSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (n = 262)</td>
<td>Hyperintense</td>
<td>Isointense or hyperintense</td>
<td>Isointense</td>
</tr>
<tr>
<td>B (n = 26)</td>
<td>Hyperintense</td>
<td>Isointense or hyperintense</td>
<td>Hyperintense</td>
</tr>
<tr>
<td>C (n = 22)</td>
<td>Hyperintense or hypointense</td>
<td>Hypointense</td>
<td>Hyperintense</td>
</tr>
<tr>
<td>D (n = 35)</td>
<td>Hyperintense or hypointense</td>
<td>Hypointense</td>
<td>Hyperintense</td>
</tr>
</tbody>
</table>

variety of lesion types observed: All patients with MS had lesions of >1 type, though most lesions were of pattern A, while all NMO lesions were of 1 type only (pattern A).

Using phase imaging and transverse relaxation rate (R2*) mapping on high-field MR imaging, prior studies have assessed the iron content of MS lesions qualitatively11,12,26 and quantitatively.27 However, many confounding factors are associated with these imaging techniques, including dependence on orientation and distribution of susceptibility sources that may influence the heterogeneity of phase and R2* and thereby render these images less reliable and quantifiable. QSM, on the other hand, provides more robust and quantitative evaluation of magnetic susceptibility sources such as iron, myelin, and calcium that are present in normal and diseased brain tissues.28 Moreover, susceptibility is a physical quantity that is independent of imaging parameters and has the potential to distinguish and quantify different susceptible tissues.29 In the present study, a recently described susceptibility-weighted imaging and mapping method was used to reconstruct QSM from 3D-SWI, providing susceptibility values from different tissue compartments with high accuracy.30

Our findings on 7T MR imaging that not all MS lesions have iron deposition are consistent with the earlier, lower field studies.9 Iron deposition may vary among individual lesions on the basis of their age and inflammatory status. We observed 4 morphologically distinct patterns of MS lesions, 2 of which were considered iron-enriched. Most non-iron-enriched MS lesions were hyperintense on GRE-T2*-weighted images and isointense and thus inconspicuous on QSM (pattern A). This pattern could be plausibly attributed to varying degrees of demyelination, edema, microcercrosis, and gliosis in chronic inactive lesions. A minority of non-iron-containing lesions demonstrated hyperintensity on both GRE-T2* and QSM images (pattern B), suggesting more acute and extensive demyelination (loss of diamagnetism, but less magnetic susceptibility effect than iron deposition) and inflammation compared with pattern A lesions. Because no tissue specimens were available to perform histopathologic/histochemical analysis from our patients, our interpretation of the imaging features was based on the prior correlative imaging and histopathologic studies. More work is needed to ascertain the pathologic significance of susceptibility changes.
铁富集的巨噬细胞或巨噬细胞在铁富集的病变中或更多活动与这些病变相关。

**Fig 5.** A–C：显示大但模糊的异常高信号病变（黑色箭头）。

这些病变在SWI（黑色箭头）和QSM上呈高信号。

**Fig 5.** QSM值来自铁富集的和非铁富集的病变。箱图显示来自铁富集的和非铁富集的病变的平均QSM值（每百万）。

**铁富集的病变**（模式C和D）有显著高于非铁富集的QSM值。模式B的病变中大致圆形的微小病灶周围中央血管可能在这一阶段被阻塞。在另一项研究中，铁富集的病变的QSM值在0.30～0.44 ppb。

另一个有趣的现象是，只有70%的铁富集的病变在GRE-T2*加权像上显示高信号。

对于下述观点，有些限制。

我们假设铁富集的和广泛脱髓鞘的病变更早，因此更可能表明病变的存在。

中央静脉在这一阶段可能被阻塞。模式A的病变更急性。

在我们的研究中，大约100%的非铁富集的模式A病变有中央血管。

模式B的病变被中央静脉所通过。

模式C和D的病变显示了铁富集的QSM值。

铁富集的QSM值在铁富集的QSM值基础上。

QSM值的分布使用箱图显示。

**QSM值**（每百万）显示铁富集的和非铁富集的病变。

模式C和D的铁富集的病变有显著更高的QSM值。

模式B的病变有微小的QSM值。

模式C和D的QSM值进一步支持我们假设。

由于QSM值在铁富集的病变上。

模式C和D的QSM值进一步支持我们假设。

模式C和D的QSM值进一步支持我们假设。
obtain a more comprehensive understanding of the evolution of MS lesions by using multicontrast imaging, future studies would need to include patients with different types of MS (clinically isolated syndrome, secondary- and primary-progressive MS). Our patients with NMO had similar kinds of “nonspecific” subcortical lesions. A number of other kinds of NMO-specific lesions have been described but were not seen in our series. Another limitation of the current study was that R2* or T2* mapping was not performed; these sequences may provide additional quantitative information for the characterization of NMO and MS lesions.

CONCLUSIONS

Four morphologically different patterns were observed for MS lesions, while NMO lesions exhibited only 1 pattern. Approximately half of patients with MS (52.4%) had at least 1 iron-laden lesion, but none of the patients with NMO had iron-enriched lesions. Our study suggests that QSM, combined with other imaging sequences at 7T, helps further differentiate MS from NMO and provides insight into lesional pathogenesis and iron metabolism in these 2 autoimmune disorders of the central nervous system.

ACKNOWLEDGMENTS

We thank Dr James Babb for his help with data analysis.

Disclosures: Illya Kister—RELATED: Grant: Guthy-Jackson Charitable Foundation*. UNRELATED: Consultancy: Biogen-Idec; Grants/Grants Pending: National Multiple Sclerosis Society*, Biogen-Idec*, Serono*, Novartis*. Jens Wuerfel—UNRELATED: Board Membership: Novartis Advisory Board; Employment: CEO, MIAC AG; Payment for Lectures (including service on Speakers Bureau): Novartis, Biogen-Idec, Bayer, Teva; Payment for Development of Educational Presentations: Novartis. Salfeng Liu—RELATED: Grant: Canadian Institutes of Health Research; Heart and Stroke Foundation of Canada.* Synchrotron Medical Imaging Team grant CIF 99472.* Tim Sinnecker—RELATED: Grant: German Research Foundation;* German Competence Network Multiple Sclerosis*, Guthy-Jackson Charitable Foundation*; UNRELATED: Employment: Charité University Berlin; Asklepios Fachklinikum Teupitz; Travel/Accommodations/Meeting Expenses Unrelated to Activities Listed: Bayer, Novartis, Genzyme, Teva. E. Mark Haake—UNRELATED: Patents (planned, pending or issued) and Royalties: MR Innovations, Comments: patents on SWI and susceptibility-weighted imaging and mapping, Friedemann Paul—RELATED: Grant: Guthy-Jackson Charitable Foundation*; UNRELATED: Board Membership: Novartis, Chugai Pharmaceutical, Genzyme, Alexion Pharmaceuticals, MedImmune; Comments: various steering committees and advisory boards; Consultancy: Novartis, Biogen-Idec, Roche, Teva, Alexion Pharmaceuticals, MedImmune; Grants/Grants Pending: Guthy-Jackson Charitable Foundation*, National Multiple Sclerosis Society*; Payment for Manuscript Preparation: Bayer, Genzyme. Yulin Ge—RELATED: Grant: National Institutes of Health,* National Multiple Sclerosis Society.* Comments: This work was also partly supported by grant numbers: 5R01 NS029029, 3NS-029029–20S1, and 398259 of the National Institutes of Health and a Research Grant (RG4707A) of the National Multiple Sclerosis Society.* Money paid to the institution.

REFERENCES


